CHAPTER 5. MITIGATION AND DECARBONISATION

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Executive Summary

This chapter examines mitigation and decarbonisation pathways for Mediterranean countries at a moment when international climate policy is shifting from pledges to delivery. It treats mitigation as an implementation problem: translating targets into measurable emissions trajectories, investable programmes, and verifiable outcomes—a task made urgent by the second Global Stocktake, due in 2028. National mitigation frameworks across the region are highly diverse, which affects comparability, accountability, and instrument choice. Targets differ in form, ranging from the EU's absolute economy-wide commitment to a 55% net emission reduction by 2030 (with an indicative 66.25–72.5% by 2035 on the pathway to neutrality by 2050) to business-as-usual deviations and emissions-intensity targets elsewhere in the basin. Absolute economy-wide targets place a premium on inventory quality, sectoral coverage, and clarity regarding how removals and land sinks enter the net balance.

The chapter's sectoral analysis identifies the practical conditions for deploying mitigation options at scale. Energy-system transformation is the core near-term driver: the energy sector accounted for roughly 2.3 Gt, or about 75% of total Mediterranean GHG emissions in 2022 (excluding LUCF), far ahead of agriculture (~10%), industrial processes (~8%), waste (~6%), and LULUCF (~1%). Because electrification and efficiency propagate mitigation gains into end-use sectors, decarbonisation is a sequencing problem: early gains come from immediately deployable measures, while deeper reductions depend on enabling infrastructure and institutional reforms with longer lead times. This aligns with the COP28 global goals of tripling renewable capacity and doubling the rate of energy-efficiency improvement by 2030.

For industry, decarbonisation must address both energy-related and process emissions, with emissions concentrated in a few value chains (cement and non-metallic minerals, metals, chemicals and fertilisers, refining and petrochemicals). The chapter sets out a portfolio approach that combines efficiency, electrification, fuel and feedstock changes, circular-economy measures, and targeted capture and storage where emissions are structurally hard to eliminate. Industrial clusters and coastal zones are strategically important because shared infrastructure (power upgrades, hydrogen supply, and, in some contexts, CO_2 transport and storage) is more feasible through coordinated development. Decarbonisation is increasingly tied to competitiveness in trade-exposed sectors, creating incentives to build robust monitoring and verification capacity.

For agriculture, forestry, and land use, mitigation means reducing non-CO_2 emissions while protecting and enhancing sinks under climatic constraints. Key levers include nutrient and irrigation management, livestock methane, and land management affecting soil carbon. Mediterranean conditions raise reversal risks through drought and wildfire and may limit sequestration potential, making credible long-term monitoring and stewardship essential.

For transport, decarbonisation is a dual transition: vehicle and fuel technology change alongside demand management and infrastructure planning. Oil-based mobility remains dominant, and a high average vehicle age slows fleet turnover in the absence of renewal policies. Maritime transport is a basin-specific domain, given the concentration of shipping and the proximity of ports to cities. The most effective strategies combine electrification of high-uptime fleets, public and active mobility in dense corridors, and port measures that cut emissions at berth—designed alongside resilience planning, since electrified systems depend on climate-sensitive assets.

For buildings, efficiency and electrification are core levers, though Mediterranean conditions shift demand toward cooling and expose households to heat and affordability risks. The region shows two patterns: declining emissions in many northern contexts under renovation policies, and rising emissions in several southern and eastern contexts amid urban growth and cooling demand. The chapter emphasises renovation, heat-pump deployment, performance standards, and demand-side measures, while addressing energy poverty as an implementation constraint. Building policies deliver health, productivity, and resilience co-benefits only where financing, targeting, and social safeguards avoid widening inequality.

The chapter assesses carbon removal and sequestration with the same discipline as emissions reductions, distinguishing land-based from marine and coastal systems. Credible monitoring, reporting and verification systems are necessary to quantify mitigation outcomes and reduce uncertainty associated with carbon removal strategies *(high confidence)*. Land-based carbon removal can contribute to net mitigation pathways in Mediterranean countries, but its long-term effectiveness is constrained by drought, wildfire, ecosystem degradation and monitoring challenges *(high confidence)*. The permanence of carbon stored in vegetation and soils is vulnerable to increasing climate stress, particularly in drought-prone and fire-prone regions of the Mediterranean *(high confidence)*. Coastal blue carbon ecosystems, particularly seagrass meadows and coastal wetlands, provide measurable carbon sequestration benefits and deliver additional ecosystem services *(high confidence)*. Still, their spatial extent limits their contribution to mitigation and depends on the success of ecosystem conservation and restoration *(high confidence)*. Climate change impacts may reduce future blue carbon sequestration capacity *(medium confidence)*. Marine Carbon Dioxide Removal (mCDR) techniques remain at an early stage of development, and their effectiveness and scalability in the Mediterranean Sea are still uncertain *(medium confidence)*. Ecological impacts and governance frameworks are still poorly assessed *(medium confidence)*.

Technological carbon removal and carbon capture technologies may complement emissions reductions in hard-to-abate sectors *(high confidence)*. However, their mitigation potential in the Mediterranean remains uncertain. It depends on technology maturity, costs, infrastructure availability, and governance frameworks *(medium confidence)*, with significant uncertainties regarding long-term sustainability (*medium confidence*).

The chapter also assesses carbon trading mechanisms. Carbon markets are increasingly relevant across the Mediterranean through compliance systems, voluntary markets and cooperative approaches. Still, their effectiveness depends on the quality of governance—monitoring and verification, cap design and coverage, allocation and auctioning, registries and oversight, and the integrity of crediting and cooperation rules. Transparency, market volatility and environmental integrity are recurring constraints that can undermine legitimacy if not addressed through strong institutional design. Carbon pricing also interacts with industrial competitiveness and investment, and equity considerations—revenue recycling and just-transition mechanisms—are decisive for political durability.

Finally, the chapter integrates co-benefits and trade-offs into pathway design, treating mitigation as an intervention in coupled systems. Mitigation delivers strong additional benefits, including improved air quality, reduced health burdens, stronger energy security, and greater urban and coastal resilience. It also entails trade-offs that require explicit management, including competition for land among sequestration, food production, and biodiversity, and the risk that some adaptation investments raise emissions if powered by fossil energy or implemented without integrated planning. Policy packages must therefore manage these tensions through spatial planning, ecological safeguards, and sequencing that prioritises high-impact actions while avoiding lock-in.

5.0 Introduction

Mitigation is entering a more operational phase in the Mediterranean. Ten years after the Paris Agreement was adopted in 2015, Parties are moving from framing ambition to demonstrating delivery through measurable emission trajectories, credible implementation instruments, and transparent reporting (UNFCCC 2015). The first Global Stocktake, concluded at COP28 in 2023, confirmed that the world is not yet on a pathway consistent with limiting warming to 1.5°C, and signalled a stronger expectation that national and regional policy packages accelerate emissions reductions in the near term (UNFCCC 2023a).

The Mediterranean context sharpens this challenge. The region is a recognised climate hotspot, warming faster than the global average, with impacts that directly affect the feasibility of mitigation through water stress, extreme heat, coastal risks, and pressure on ecosystems and livelihoods. Decarbonisation pathways must therefore be designed for a setting where energy demand is rising in several countries, urbanisation and mobility pressures are intensifying, and climate impacts are already degrading the performance and resilience of the very infrastructure that enables mitigation—grids, ports, transport corridors, and water supply systems.

This chapter examines how sectoral strategies, nature-based solutions, and market instruments can be combined into pathways that are ambitious yet socially just and institutionally implementable. The framing follows the Paris Agreement's five-year ambition cycle: the next Global Stocktake concludes in 2028, making the period to 2030 and 2035 particularly consequential for credibility and course correction. A defining feature of the current cycle is that many Parties are communicating targets beyond 2030, including indicative 2035 signals—the EU's updated NDC, submitted in November 2025, reiterates the legally binding 2030 objective and introduces an indicative 2035 range on the pathway to climate neutrality by 2050 (Danish Presidency of the Council of the European Union and European Commission 2025). Across Mediterranean countries, however, NDC architectures remain heterogeneous—absolute and economy-wide, deviations from business-as-usual, or emissions-intensity reductions—which affects comparability, accountability, and instrument choice, particularly as carbon markets and cross-border trade instruments increasingly require robust emissions accounting and verification (UNFCCC 2023).

The analytical approach rests on three linked propositions. First, near-term mitigation is primarily determined by the pace of change in energy systems, since energy-related emissions dominate regional totals and electrification, renewables, and efficiency improvements propagate gains into transport, buildings, and parts of industry—consistent with the COP28 emphasis on tripling renewable capacity and doubling the rate of energy-efficiency improvement by 2030 alongside a just transition away from fossil fuels (UNFCCC 2023a). Second, land, coastal, and marine systems are simultaneously mitigation assets and risk factors: sinks and nature-based solutions can deliver net reductions, but only where ecological integrity, permanence, monitoring capacity, and governance allow, so removals must be evaluated with the same discipline as emissions reductions, including additionality and leakage (UNFCCC 2023). Third, mitigation is inseparable from distributional impacts; carbon pricing, subsidy reform, electrification, renovation, and land-use transitions all redistribute costs and benefits, making inclusive decarbonisation a design requirement that turns on affordability, employment transitions, energy poverty, and access to enabling infrastructure (UNFCCC 2023).

5.1 Emission pathways, sectoral and country-wide mitigation options

Key messages

- NDCs across Mediterranean countries remain heterogeneous in metrics and baselines (absolute, BAU deviation, intensity), which complicates comparability and the selection of instruments *(high confidence).*
- Energy-system change is the primary near-term driver because it propagates mitigation gains into transport, buildings, and parts of industry through electrification and efficiency.
- A credible regional contribution to the 2028 Stocktake requires linking inventories, scenarios, and sector levers into coherent, measurable pathways.

Ten years after the Paris Agreement was signed, the international community is preparing for the second Global Stocktake (GST), scheduled for 2028. The GST will assess whether commitments and actions taken so far are sufficient to reduce GHG emissions in line with efforts to limit the global temperature rise to well below 2°C, while striving to keep it within 1.5°C. Achieving this goal requires rapid and deep emissions reductions in all regions of the world. The GST is a five-year review process introduced by the Agreement to monitor global progress in reducing greenhouse gas emissions and adapting to the impacts of climate change. It bases its assessments on the GHG reduction commitments that each Party is required to define by submitting its Nationally Determined Contributions (NDCs) to the UNFCCC Secretariat every five years. The first GST, which concluded at COP28 in Dubai in 2023, found that the world is not currently aligned with the Agreement's goals. However, the final decision defined operational guidelines to inform medium- and long-term climate policies and plans, introduced follow-up mechanisms, and required all Parties to update their NDCs in 2025 (NDC 3.0), setting out indicative targets for 2035. In this latest round of updates, the

European Union, for example, set a target to reduce net emissions by 55% by 2030, with an indicative target of between 66.25% and 72.5% by 2035, aiming to achieve climate neutrality by 2050. The following table summarises the GHG reduction targets of each Mediterranean country (Table 5.1).

The first Global Stocktake outlines the urgent actions required to put the world back on track with the goals of the Paris Agreement. These include tripling renewable energy capacity and doubling the global average annual rate of energy efficiency improvements by 2030; accelerating efforts globally towards net-zero-emission energy systems; transitioning away from fossil fuels in energy systems; and accelerating and substantially reducing non-carbon-dioxide emissions globally (UNFCCC 2023)

As shown in Figure 5.1, the energy sector, which encompasses buildings, electricity and heat, fugitive emissions, manufacturing and construction, other fuel combustion, and transportation, is the largest contributor to GHG emissions in the Mediterranean. In 2022, emissions from this compartment amounted to 2.3 Gt, accounting for 75% of total GHG emissions (excluding LULUCF (ClimateWatch 2026)). This is followed by agriculture (0.28 Gt; 10%), industrial processes (0.23 Gt; 8%), waste (0.18 Gt; 6%), and LULUCF (0.02 Gt; 1%).

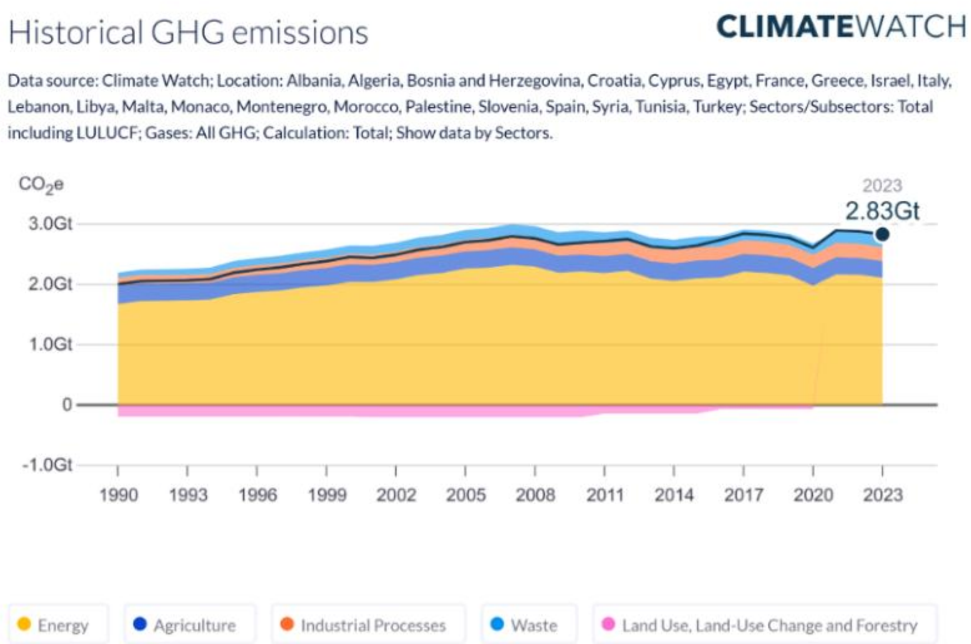

Figure 5.1 | Historical total GHG emissions in Mediterranean countries from 1990 to 2023, broken down by sector. Source: ClimateWatch, 2026. The energy sector includes buildings, electricity and heat, fugitive emissions, manufacturing and construction, other fuel combustion and transportation [13]..

[13] https://www.climatewatchdata.org/

Table 5.1 | GHG emission targets in the MED countries as submitted in their Nationally Determined Contributions (NDCs). Source: UNFCCC NDC Registry, 2026

Party (year of submission)	GHG targets
EU 27 countries (5 November2025) **EU countries included in the MED basin: Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, Spain**	2035; net economy-wide GHG emissions reduction; 66.25% to 72.5%; vs 1990. 2050; Climate neutrality
Albania (Revised NDC)	2030; economy-wide GHG emissions reduction; 20.9%; vs BAU; expressed as 3,170 kt CO_2e below BAU in 2030 (and 16,828 kt CO_2e cumulative avoided over 2021–2030 in the NDC scenario).
Algeria (First NDC submitted 20 October 2016)	2030; economy-wide GHG emissions reduction; 7% (domestic) to 22% (with support); vs BAU; higher end conditional on external finance, technology transfer, and capacity building.
Bosnia and Herzegovina (NDC for 2020–2030 (with 2050 targets included)	2030; economy-wide GHG emissions reduction; 12.8% (unconditional) and 17.5% (conditional); vs 2014 (equivalently 33.2% and 36.8% vs 1990); conditionality linked to international support. 2050; 50.0% (unconditional) and 55.0% (conditional) vs 2014.
Egypt (Updated First NDC 2030 (Second Update) submitted 26 June 2023)	2030; sector-specific BAU reductions (no single economy-wide headline target); power: 3% vs BAU (2030) with BAU 214,740 Gg CO_2e; oil and gas associated gases: 65% vs BAU (2030) with BAU 2,575 Gg CO_2e; transport: 7% vs BAU (2030) with BAU 124,360 Gg CO_2e.
Israel (Update of Israel's nationally determined contribution under the Paris Agreement). Submitted July 2021	2030; unconditional absolute GHG emissions reduction goal: 27% vs 2015 2050; unconditional absolute GHG emissions reduction goal: 85% vs 2015. Transport: 96% vs 2015; electricity generation: 85% vs 2015; industry 56% vs 2015; municipal waste 92% vs 2015
Lebanon (NDC 3.0 submitted 30 Sep 2025)	2035; economy-wide GHG emissions reduction; 22% (unconditional) and 33% (conditional); reference point stated in NDC-related communications as conditional on international support.
Libya (No NDC located in UNFCCC NDC Registry list (as of 29 December 2025))	No UNFCCC-registered NDC target available to report.
Monaco (NDC submitted July 2025)	2035; economy-wide GHG emissions reduction; 67.6%; vs 1990; no unconditional or conditional split stated 2050; Climate neutrality
Montenegro (Updated NDC submitted February 2025)	2030 and 2035; net economy-wide domestic GHG emissions reduction; at least 55% (2030) and 60% (2035); vs 1990; domestic only, without international credits.
Morocco (NDC 3.0 submitted 30 September 2025)	2035; economy-wide GHG emissions reduction; 53%; vs BAU (2035); reported split: 21.6% unconditional and 31.4% conditional on support.
Palestine (First NDC submitted 10 October 2021)	2040; GHG emissions reduction by 17.5% relative to the business-as-usual (BAU) levels under a scenario where the Israeli occupation continues (Status-quo Scenario), 2024; GHG emissions reduction by 26.6% by 2040 under a scenario where the Israeli occupation ends (Independence Scenario).
Tunisia (NDC 3.0 elements submitted 22 September 2025)	2035 (and 2030 intermediate); economy-wide carbon-intensity reduction (GHG per GDP); 62% by 2035 and 46.2% by 2030; vs 2010; split: 31% unconditional plus additional 31% conditional by 2035 (and unconditional 28% by 2030).
Türkiye (Second NDC (NDC 3.0) submitted 9 November 2025)	2035; economy-wide reduction vs BAU expressed in absolute terms; 466 Mt CO_2e reduction vs BAU (1,109 Mt CO_2e), limiting emissions to 643 Mt CO_2e in 2035; vs BAU (2035).
Syria (First NDC submitted 30 November 2018)	2020–2030; mitigation measures stated, but no quantified national GHG reduction target identified in the NDC text; reference point not specified as an economy-wide target.

Table 5.2 | Future projected total GHG emissions in Mt CO_2eq projections in some selected countries. Source: Climate Analytics, 2026 (https://1p5ndc-pathways.climateanalytics.org/countries/european-union).

	Base year (2019)	Based on 2018 IPCC SR1.5				
		2030	**2040**	**2050**	**2060**	**2070**
Algeria (1.5°C emissions range)	229	170	98	55	38	32
Bosnia and Herzegovina (middle of the 1.5°C compatible range)	30	13	6	3	2	1
Egypt (1.5°C emissions range)	373	355	243	165	124	96
France (1.5°C emissions range)	427 (2020)	206	85	61	42	13
Israel (middle of the 1.5°C compatible range)	90 (2020)	51	27	16	8	1
Italy (middle of the 1.5°C compatible range)	389 (2020)	158	55	33	16	1
Morocco (middle of the 1.5°C compatible range)	100 (2020)	64	46	34	26	22
Türkiye (1.5°C compatible pathway)	?	402	132	64	61	53

With the next Global Stocktake scheduled for 2028, this section focuses on preparing for it by presenting current GHG emissions in the Mediterranean region and analysing reduction pathways that align with the Paris Agreement's objectives. As an area particularly vulnerable to climate change, the Mediterranean region faces complex challenges, including growing energy demand, structural socio-economic disparities, and the increasing frequency and intensity of extreme weather events, such as heatwaves, droughts, and water stress (Chapter 2). Therefore, understanding how Mediterranean countries can effectively contribute to global mitigation efforts is crucial.

The following paragraphs analyse the emission pathways of the energy production, industry, agriculture, transport and buildings sectors. Multiple data sources were used to represent the historical GHG emission trend for the economic sectors described in the following sections:

- The EDGAR database[14] (Emissions Database for Global Atmospheric Research), developed by the European Commission's Joint Research Centre (JRC), provides a global, independent scientific dataset designed to support atmospheric modelling and climate policy analysis (Cripa et al. 2025). It provides detailed estimates of anthropogenic GHG emissions covering all countries and sectors from the 1970s to 2024.
- Climate Watch[15], an open data platform developed by the World Resources Institute, that collects, integrates and makes available data on GHG emissions at global and national levels. These datasets are derived from various authoritative sources and international inventories, such as the UNFCCC, IEA, FAO, and Global Carbon Project. They are harmonised using consistent methodologies to ensure comparability across countries and over time. The data covers all major GHG and economic sectors, including energy, industry, agriculture, waste, and land use, and enables detailed analysis by country, sector, and historical period to support climate policy monitoring.
- Regional statistics from international and regional organisations such as IRENA, OMEC and IEA are used for data on primary energy consumption, renewable electricity capacity and production and energy consumption in the transport sectors.

[14] https://edgar.jrc.ec.europa.eu/
[15] https://www.climatewatchdata.org/

5.1.1 Energy production

Key messages

- NDCs across Mediterranean countries remain heterogeneous in metrics and baselines (absolute, BAU deviation, intensity), which complicates comparability and the selection of instruments *(high confidence)*
- Energy-system change is the primary near-term driver because it propagates mitigation gains into transport, buildings, and parts of industry through electrification and efficiency
- A credible regional contribution to the 2028 Stocktake requires linking inventories, scenarios, and sector levers into coherent, measurable pathways.

Between 1990 and 2022, energy-related GHG emissions increased by 23%, slightly less than total GHG emissions (25%). After an 8% drop in 2020 due to the COVID-19 pandemic, energy-related emissions rose again to a level close to 2019. This means that despite policies and targets in place, the energy transition is still off-track. As already highlighted in MAR1 (2020) [16], regional strategies adopted to foster energy transition and climate mitigation are closely linked to the overall development model and may differ from country to country.

The share of north Mediterranean countries decreased over time, from nearly two-thirds of total energy-related GHG emissions in 1990 to about 46% in 2022. France, Italy, and Spain accounted for 78% of energy-related GHG emissions along the northern shore in 1990 (958 Mt CO_2eq). Their cumulative emissions peaked around 2005 (1185 Mt CO_2eq) and then progressively decreased to around 830 Mt CO_2eq in 2022 (Figure 5.2). The strongest reduction over time is observed in Albania (–36% between 1990 and 2022), followed by Greece (–28%). France achieved a 18% reduction over the same period, Italy 19%, whereas Spain recorded +6%. north Mediterranean countries reduced their emissions by 15% in 2022 compared with 1990. It is worth noting that, in several cases, the recovery from the Covid-19 pandemic resulted in increased emissions in 2021, which continued in 2022 (+11% in North Macedonia, +9% in Malta, +3% in Croatia, Montenegro, and Spain). Despite this rebound, overall energy-related GHG emissions in the north remain lower than in 2018-2019.

In the south and east Mediterranean countries, emissions nearly doubled since 1990, from 626 Mt CO_2eq to 1225 Mt CO_2eq in 2022 (calculated using ClimateWatch). In relative terms, the highest increase over the period is observed in Morocco, followed by Türkiye, Egypt and Jordan. In absolute terms, Türkiye alone is responsible for one-third of total energy-related emissions at the regional level. By adding Algeria and Egypt, more than 73% of the region's energy-related GHG emissions are covered.

Among all sectors, electricity generation is the one which has made the most relevant progress towards full decarbonisation (Figure 5.3). Renewable electricity in the Mediterranean is expanding, with more than 434 GW of cumulative capacity in place in 2025, according to IRENA statistics (International Renewable Energy Agency 2026). Notable progression is observed for non-hydro renewable technologies. Onshore wind capacity is now well over 106 GW and represents one quarter of total renewable electricity capacity at the regional level. Solar photovoltaic capacity is nearly 190 GW, accounting for 43% of total renewable capacity.

The evolution of renewable installed capacity by sub-region over the last decade is shown in Figure 5.4. Both the north and southeast regions show increasing trends, with a steeper acceleration in the south and east, where the compound annual growth rate of renewable energy technologies exceeded 10%, compared with 7% in the north. Still, the cumulative capacity of renewables in the southeast (110 GW) is about one-third of the capacity installed in the north.

[16] See, in particular, Section 3.3 'Energy transition', available at https://www.medecc.org/wp-content/uploads/2021/05/MedECC_MAR1_3.3_Energy-transition.pdf

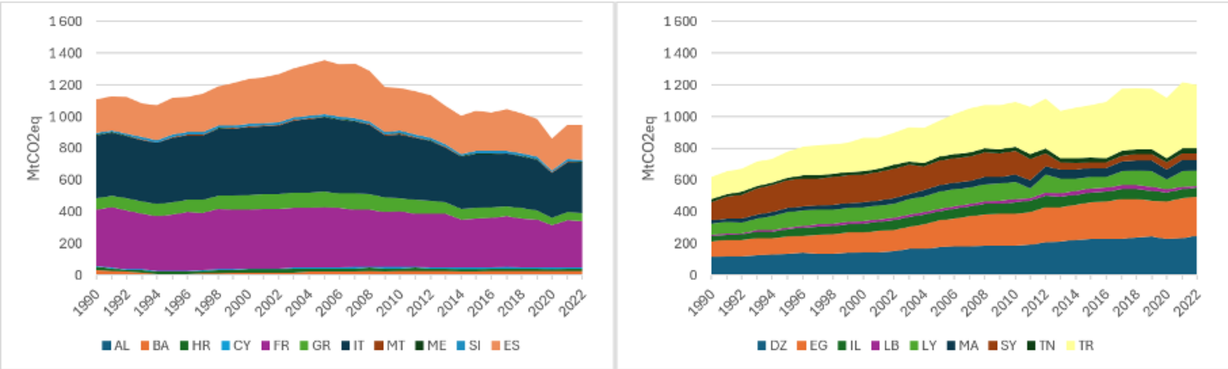

Figure 5.2 | Evolution of energy-related GHG emissions in the north and southeast Mediterranean. Source: own elaboration from ClimateWatch data, 2026

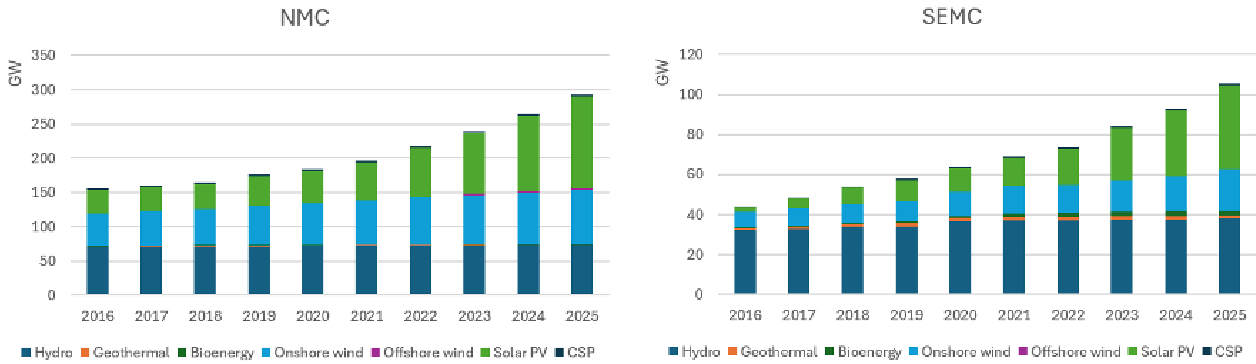

Figure 5.3 | Evolution of renewable power generation capacity between 2016 and 2025. Source: own elaboration from IRENA (International Renewable Energy Agency) 2026.

Italy, France and, Spain host about 80% of the total cumulative renewable electricity capacity in the northern region. In the south and east Mediterranean, the renewable electricity capacity is even more concentrated. Egypt, Israel and, Türkiye account for more than 86% of the total capacity in the southeastern area, with more than 70% in Türkiye alone. All southern and eastern Mediterranean countries have set targets for renewable energy for the 2030-2040 horizon. Reaching the targets would require adding an extra capacity of renewables about 3.5 times today's levels.

Governments are expanding renewable energy capacity coupled with energy storage and grid modernisation to improve system resilience. In addition, cross-border interconnections, such as the Elmed project [17], linking Tunisia to Italy, will improve stability and efficiency at the regional level. The growing role of renewable hydrogen and derivatives can provide additional mitigation opportunities.

IRENA (International Renewable Energy Agency 2025) developed a regional power system optimisation scenario – the MED-Optimised Scenario (MOS), which explores a pathway to decarbonise North Africa's power systems. Based on current and projected reductions in renewable energy technology costs and resource potential in North African countries, the model indicates significant expansion, particularly for solar technologies and green hydrogen, from 2023 to 2050. The scenario, which is aligned with the 1.5°C Paris Agreement target, indicates that GHG emissions can fall by 46% by 2050, compared to the existing policy trajectory in northern African countries.

In the Mediterranean Energy Perspectives publication (Organisation Méditerranéenne de l'Energie et du Climat 2025), OMEC has elaborated two different scenarios to 2050:

[17] https://elmedproject.com/it/

- The Reference Scenario (RS) is a business-as-usual scenario based on past trends, current policies and projects, and national targets. The scenario includes the unconditional targets of the Nationally Determined Contributions (NDCs) to the UNFCCC.
- The ProMED 'Net-Zero Carbon' Scenario (PM) assumes that the Mediterranean reaches carbon neutrality by 2050 through enhanced energy efficiency, technological innovation, and increased diversification of the energy mix. Overall, the combination of energy-efficiency measures and renewable-energy deployment would contribute the most to CO_2 reductions in the Mediterranean.

As illustrated in Figure 5.5, the PM Scenario projects a reduction in CO_2 emissions to 208 Mt CO_2 by 2050, corresponding to nearly a 90% decline relative to 1990 levels. This transition is primarily driven by renewable energy deployment and energy efficiency improvements, which together account for 88% of total emissions reductions. Greenhouse gases and carbon capture, utilisation and storage (CCUS) would complement the emission abatement. The feasibility of these mitigation pathways remains contingent on climate-related risks affecting energy systems, including heat stress, drought, and coastal exposure, as discussed in Chapter 3.

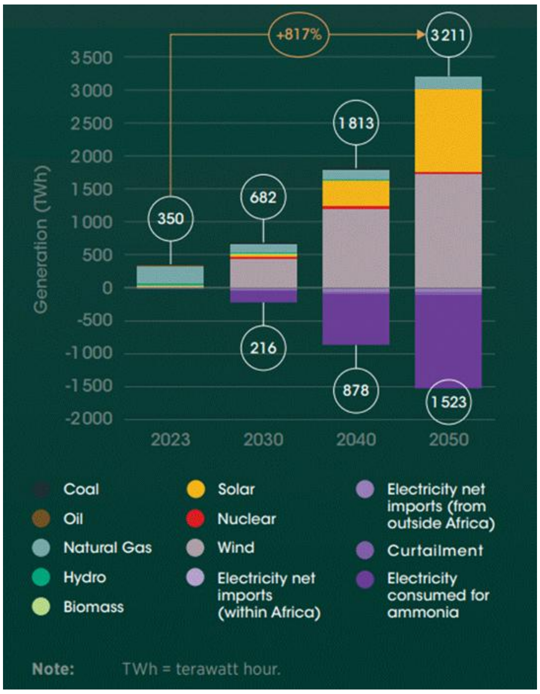

Figure 5.4 | Potential capacity expansion in Algeria, Egypt, Libya, Morocco and Tunisia between 2023 and 2050.
Source: International Renewable Energy Agency (2025).

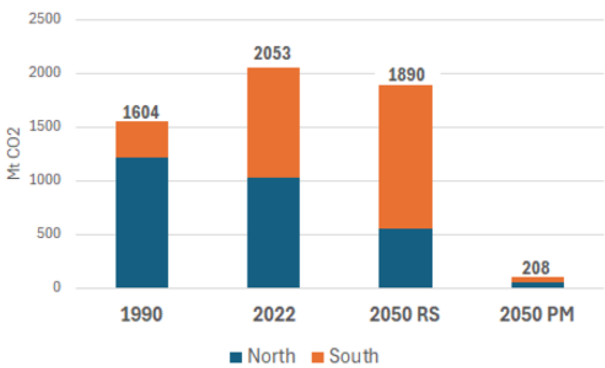

Figure 5.5 | CO_2 emissions reduction in the PM and RS compared to 2022 and 1990 levels. Source: Organisation Méditerranéenne de l'Energie et du Climat 2025.

5.1.2 Industry

Key messages

- Industry is dominated by a few hard-to-abate sectors (cement, steel, chemicals, fertilisers) *(high confidence).*
- Industry emitted about 9.0 Gt of CO_2 in 2022, roughly one-quarter of energy-sector CO_2 emissions.
- Cement has significant process emissions, around 60% from calcination in the EU evidence.
- EU CBAM and the revised EU ETS increase pressure for verified product emissions and decarbonisation *(high confidence).*
- EU cement and clinker imports in 2024 totalled 11.3 Mt, with a major share from Mediterranean suppliers.

Industrial decarbonisation in the Mediterranean is driven by the transformation of a limited number of emissions-intensive value chains, notably cement and other mineral products, iron and steel, refining and petrochemicals, and fertilisers. The mitigation challenge is structurally dual. A significant share of emissions is energy-related, arising from fossil fuels used for process heat and steam. At the same time, several subsectors generate substantial process emissions that persist even under fully decarbonised electricity because they are embedded in core chemical reactions, particularly in clinker production for cement and in parts of the chemicals sector (IPCC 2022).

The global benchmark highlights the problem of scale and pace. The International Energy Agency estimates that industry emitted 9.0 Gt CO_2 in 2022, about one quarter of global energy system CO_2 emissions (IEA 2023). This macro fact matters for the Mediterranean because several countries concentrate industrial activity around coastal corridors and port-industrial zones, where long-lived assets and export exposure can slow change unless policy, finance, and infrastructure are aligned.

A major Mediterranean-specific driver is the tightening interaction between industrial mitigation and trade-linked carbon constraints. The EU Emissions Trading System has been revised under Directive (EU) 2023/959, strengthening the framework for covered installations and updating the regulatory conditions that shape investment incentives in energy-intensive industry (European Parliament and Council of the European Union 2023). In parallel, the Carbon Border Adjustment Mechanism (CBAM), established by Regulation (EU) 2023/956, applies to embedded emissions in specified goods, including cement, iron and steel, aluminium, fertilisers, electricity, and hydrogen (European Parliament and Council of the European Union 2023). During the transition phase, reporting is required; from 2026, the mechanism shifts toward financial compliance via certificates, with operational details refined in subsequent EU acts and guidance (Reuters 2025). For Mediterranean exporters into EU markets, this means that credible emissions measurement and verified product-level carbon data increasingly affect market access and relative costs, not only environmental reporting.

Cement provides a clear illustration of why industrial decarbonisation cannot rely on power-sector decarbonisation alone. A Joint Research Centre technical report explains that, in the EU context, around 60% of cement emissions stem from calcination (process emissions), about 30% from fuel combustion for high-temperature thermal processes, and around 10% from electricity consumption (Marmier 2023). This decomposition implies a layered mitigation strategy: reducing the clinker-to-cement ratio and developing alternative binders target process emissions; fuel switching, thermal efficiency and alternative fuels target combustion emissions; and electrification and clean power procurement reduce electricity-related emissions (Marmier 2023). The trade dimension is directly relevant for the Mediterranean. Eurostat-based trade statistics compiled by CEMBUREAU for the full-year 2024 show EU cement and clinker imports of 11.3 Mt, with Türkiye (38.9%), Algeria (14.1%), Ukraine (14.5%), Egypt (8.9%), and Tunisia (7.9%) among the largest sources (CEMBUREAU 2025). This pattern is analytically important because CBAM applies precisely to these product categories, raising the value of verified emissions intensities and accelerating incentives for low-carbon cement production pathways on both sides of the Mediterranean.

For steel and other primary metals, the mitigation frontier is shaped by high-temperature heat requirements and, for primary steel, the need for a reducing agent. IPCC AR6 WGIII emphasises that deep industrial mitigation relies on a portfolio that includes higher recycling and material efficiency to reduce primary production, electrification where feasible, hydrogen-based process routes for specific applications, and carbon capture and storage in residual hard-to-abate segments (IPCC 2022). In Mediterranean settings, these routes are constrained by the availability of infrastructure and by the pace at which low-carbon electricity can scale at a predictable cost. The practical implication is that industrial decarbonisation policy must be coordinated with power-sector investment, grid reinforcement, and system flexibility, since electrification and hydrogen production both increase dependence on robust electricity supply.

Chemicals and fertilisers require a distinct framing because emissions stem not only from energy use but also from feedstock use and process chemistry. IPCC highlights that mitigation options span efficiency, process innovation, circularity, and demand-side measures, as well as low-carbon energy and feedstocks, including hydrogen where relevant (IPCC 2022). For the Mediterranean, this connects directly to export-oriented fertiliser value chains and to emerging industrial strategies linked to low-carbon hydrogen. At the same time, because several southern and eastern Mediterranean countries are water-stressed, hydrogen-related industrial pathways introduce additional feasibility constraints linked to water supply, electricity needs, and system integration, which must be treated as implementation conditions rather than assumptions.

Across these subsectors, the evidence base points toward five cross-cutting mitigation levers that are consistently emphasised in authoritative assessments. First, energy efficiency remains a near-term mitigation option across essentially all industrial facilities, including through process integration and better use of waste heat. Second, electrification of low- and medium-temperature heat, combined with decarbonised electricity, reduces combustion emissions where technologies are commercially available. Third, material efficiency and circular economy strategies reduce demand for primary materials, thereby lowering both energy-related and process emissions, and the IPCC stresses that these options are often underrepresented in scenario modelling despite their mitigation potential. Fourth, low-carbon fuels and feedstocks, including hydrogen in selected applications, become relevant as the power system decarbonises and supporting infrastructure matures (IPCC 2022). Fifth, carbon capture and storage become a central residual option in sectors dominated by process emissions, such as cement, where a significant fraction of emissions cannot be eliminated by electrification alone (Marmier 2023; IPCC 2022).

Implementation in the Mediterranean is therefore less about identifying single ‘best’ technologies and more about aligning investment cycles, infrastructure build-out, and trade and regulatory signals. The EU policy environment already provides strong external incentives through the EU ETS revision and CBAM scope and compliance requirements (European Parliament and Council of the European Union 2023a 2023b). For non-EU Mediterranean countries with significant exports into EU markets, the near-term industrial priority becomes twofold: building credible monitoring, reporting and verification capacity for installations and products; and developing bankable transition pipelines in the most exposed subsectors, particularly cement, metals, and fertilisers, where low-carbon differentiation and verified emissions performance are increasingly linked to competitiveness (CEMBUREAU 2025).

5.1.3 Agriculture, forestry and other land uses

Key messages

- Net GHG emissions from the AFOLU sector account for 4-8% of total Mediterranean emissions in the period 2014-2023 (*medium confidence*).
- Net AFOLU emissions have almost tripled since 1990, driven by a reduced LULUCF carbon sink (*low confidence*).
- Main sources of agricultural emissions include CH_4 from enteric fermentation and N_2O from agricultural soils. CH_4 and N_2O emissions from enteric fermentation, manure management (i.e.

manure storage and application) and deposition on pasture make livestock the main source of agricultural emissions (*high confidence*).

- CH_4 emissions from ruminants can be mitigated through dietary manipulation, feed additives, herd size management and breeding (*high confidence*).
- Optimised nitrogen fertilisation (rate, timing, and fertiliser type), improved irrigation management, and the use of organic amendments and nitrification inhibitors can reduce soil N_2O emissions (*high confidence*).

According to the IPCC Guidelines for National Greenhouse Gas Inventories (2006), the AFOLU sector is both a source and a sink of greenhouse gases, comprising two sub-sectors: Agriculture, the primary driver of CH_4 and N_2O emissions, and Land Use, Land Use Change and Forestry (LULUCF), which is responsible for net CO_2 fluxes.
Greenhouse gas fluxes in AFOLU result from both direct and indirect effects of human activities (CO_2 fertilisation, N deposition, and other climate-change-related disturbances, such as fires and drought). These disturbances, inherently dynamic and complex (see Box 5.1), make AFOLU fluxes among the most uncertain to be quantified. The Mediterranean AFOLU sector is a significant source of emissions (Table 5.3), accounting for roughly 4-8% of total net Mediterranean emissions (average for 2014-2023, according to FAOSTAT and EDGAR databases) (Figure 5.1). From 1990 to 2023, Mediterranean AFOLU emissions have shown mixed trends across databases and sources. According to FAOSTAT, AFOLU emissions have almost tripled since 1990 (from 105.1 to 296.6 Mt CO_2eq), with a drastic rise since 2000 driven by a reduced LULUCF carbon sink rather than by changes in agricultural emissions (Table 5.3). According to the EDGAR database, Mediterranean AFOLU emissions instead dropped by 16% between 1990-99 and 2014-23, despite sharp variable trends between sub-regions. Both databases confirm rising emissions in the eastern Mediterranean between 1990-99 and 2014-23 (EDGAR: +158.0% and FAOSTAT: +81.9%), while contrasting trends emerge for the southern (EDGAR: +28.3 and FAOSTAT: -36.8%) and northern Mediterranean, with the latter nearing neutrality according to EDGAR.

In line with the IPCC (2006), agricultural emissions are CH_4 and N_2O emissions resulting from biological and biogeochemical processes associated with livestock and crop production, including enteric fermentation, manure management, agricultural soils, rice cultivation, and biomass burning. Hence, the figures below exclude on–farm energy use and all other components of the food system beyond the production phase. Using the FAOSTAT database, total agricultural emissions were estimated at over 280 Mt CO_2eq yr^{-1} during 2014–2023, accounting for almost 10% of total Mediterranean anthropogenic emissions and representing the dominant component of the AFOLU sector emissions. Emissions from agriculture have remained nearly stable over the 1990–2023 period, with minor variations by gas, but divergent trends among sub-regions. Agricultural emissions fell by almost 12% in the northern Mediterranean between 1990–1999 and 2014–2023 (Table 5.3), with 57% of total agricultural emissions occurring primarily in Italy, France and Spain. On the contrary, agricultural emissions in the eastern and southern Mediterranean increased by 21–25%, driven mainly by Türkiye and Egypt. One of the main reasons for the increase in agricultural emissions in these sub-regions is the increased animal activities and grazing, which are the main sources of agricultural emissions in the Mediterranean. Indeed, CH_4 produced through microbial methanogenesis in ruminants or enteric fermentation is consistently the largest source of agricultural emissions, followed by CH_4 and N_2O from manure storage and application, and deposition on pasture.

Agricultural soils are the second-largest source of agricultural emissions (Figure 5.1) and the main driver of N_2O emissions from synthetic fertilisers, crop residues, manure applied to soils and left on pasture, in line with global trends (Nabuurs et al. 2022). The use of synthetic fertilisers is emerging as a growing contributor to agricultural emissions in the southern and eastern Mediterranean. This is consistent with the long-term intensification of Mediterranean agricultural systems, as noted by Lassaletta et al. (2021). Between 1990 and 1999, and between 2014 and 2023, nitrogen fertiliser intensity (kg N ha^{-1}) rose by 42% and 36% in the southern and eastern Mediterranean, respectively, with Egypt and Türkiye as the primary contributors (FAOSTAT 2026). This contrasts with Northern Mediterranean and southern European countries, which had an 8% decline in N intensity use and a 16% decline in total N use (FAOSTAT 2026), probably reflecting the enforcement of EU policies such as the Nitrates Directive and the Common Agricultural Policy (CAP) reforms, and the contraction of cropland area over the same period. In southern and eastern Mediterranean countries, the concurrent expansion of irrigated cropland (Zeng et al. 2024) may compound the rising trend in N_2O emissions from fertiliser use, by creating suitable conditions for nitrification and denitrification (Trost et al. 2013; Cayuela et al. 2017). The rise in animal production and the intensification of crop production could be responses to rising food demand and the need to increase yields to accommodate changes in dietary habits and population growth (see Chapter 2).

Table 5.3 I Changes in agriculture and LULUCF emissions (Mt CO_2eq yr^{-1}) in Mediterranean countries. Source: Climate Watch (2026) based on FAOSTAT (2026). * See Box 5.1 on methodology. The North Mediterranean sub-region includes all countries on the Northern shore of the Mediterranean – Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Slovenia and Spain; The East Mediterranean includes Lebanon, Israel, Palestine, Syria, Türkiye; the South Mediterranean includes Algeria, Egypt, Libya, Morocco and Tunisia.

	Agriculture (CH_4+N_2O)			LULUCF (CO_2)		
	Total GHG emissions		Change	Total GHG emissions*		Change
Country	1990–1999	2014–2023	%	1990–1999	2011–2020	%
Albania	3.9	2.9	–26	0.0	0.9	1859
Algeria	8.0	13.1	63	0.2	0.2	0
Bosnia and Herzegovina	2.4	2.5	5	–11.0	–2.0	–82
Croatia	3.5	2.6	–26	–0.8	–3.1	278
Cyprus	0.4	0.4	–6	–0.1	–0.3	300
Egypt	24.4	26.7	9	n.a	n.a	n.a.
France	85.1	73.9	–13	–24.7	–43.3	75
Greece	9.6	7.4	–22	1.3	–6.3	–570
Israel	1.2	1.5	24	0.1	–0.1	–186
Italy	40.5	32.7	–19	–34.6	–18.6	–46
Lebanon	0.5	0.8	45	–0.1	0.1	–219
Libya	2.2	3.0	38	0.0	0.0	0
Malta	0.1	0.1	–37	n.a	n.a	n.a.
Monaco	n.a	n.a	n.a.	n.a	n.a	n.a.
Montenegro	0.8	0.4	–46	–2.6	0.0	–101
Morocco	11.2	14.8	33	–8.2	–3.0	–63
Palestine	0.2	0.4	140	0.0	0.0	0
Slovenia	2.1	1.7	–22	–9.4	2.5	–127
Spain	39.5	41.2	4	–83.1	–10.7	–87
Syria	6.3	6.2	–1	–1.5	–1.5	–2
Tunisia	4.0	4.5	12	–0.9	2.9	–435
Türkiye	41.5	51.4	24	–16.9	–24.7	46
Total	**287.4**	**288.2**	**0.3**	**–192.3**	**–107.0**	**44.4**
North Mediterranean	187.9	165.8	–11.8	–164.9	–80.8	51.0
South Mediterranean	49.8	62.2	24.8	–8.9	0.1	101.7
East Mediterranean	49.6	62.2	21.3	–18.5	–26.2	41.8

LULUCF emissions vary substantially across years and data sources, primarily due to forest CO_2 emissions and removals. Globally, the LULUCF sector is a net source of GHGs, with deforestation as the main driver of emissions (Nabuurs et al. 2022). In the Mediterranean region, the LULUCF acts as a net sink, with no clear trend from 1990 to 2023, as conflicting results emerge among data sources. Unlike the EDGAR database, which shows an almost 50% increase in the LULUCF sink due mostly to the north Mediterranean increase in C sinks, FAOSTAT (Figure 5.1) and bookkeeping models of the Global Carbon Budget (Friedlingstein et al. 2025) indicate that Mediterranean LULUCF emissions have been increasing since 2012, especially in the north Mediterranean (Table 5.3). While no agreement is found regarding north and east Mediterranean trends, both sources confirm rising emissions in the south Mediterranean (+24% in EDGAR and a shift from sink to source in FAOSTAT between 1990–1999 and 2014–2023).

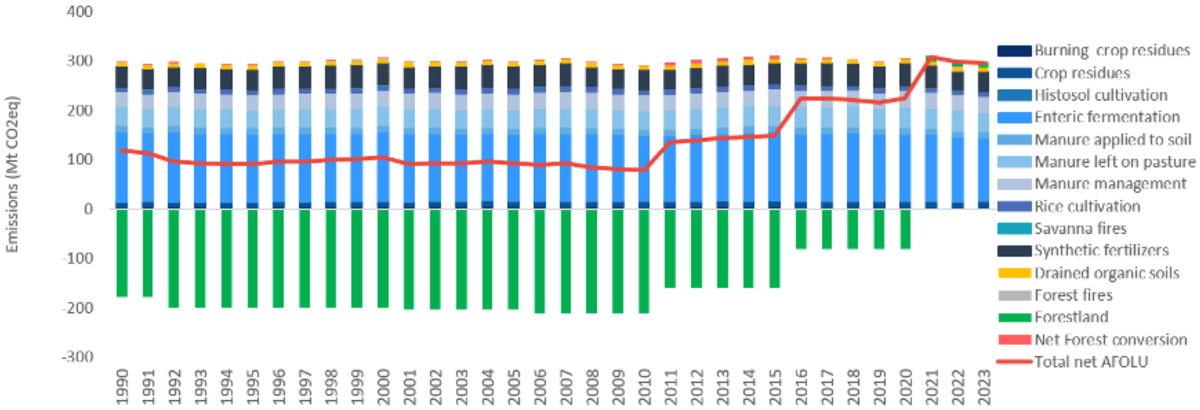

Figure 5.6 | Emissions (Mt CO_2eq) from AFOLU sources from 1990 until 2023. Source: FAOSTAT 2026.

Regardless of the conflicting trends and variable magnitudes of total net LULUCF emissions - and their sources - across the different databases (see methodological Box 5.1 thereafter), deforestation is a confirmed and growing source of emissions across the Mediterranean basin (+143% in EDGAR; +85% in FAOSTAT between 1990–1999 and 2014–2023). The increase is highest in the east and the north Mediterranean. Despite this increase, forest area in the Mediterranean has steadily increased over the past three decades (Figure 5.6). France, Italy, Spain, and Türkiye account for more than 75% of the forest land in the Mediterranean region and have seen increases in forest area of 14-37% between 1990 and 2023 (FAOSTAT 2026). Despite the expansion of forest cover (Figure 5.7), forests have become increasingly vulnerable to degradation, a trend that will be exacerbated as climate change intensifies (Cramer 2020; FAO 2025). Forest degradation could be a driver of the weakening of LULUCF carbon sinks noted in FAOSTAT, alongside deforestation (*low confidence*). This is in line with what was reported at the EU level, where the average net annual land carbon sink was 30% smaller in 2014-2023 compared to the decade before (EEA 2025). As discussed by the EEA (2025), a decline in forest carbon sink in southern Europe could be attributed to forest harvesting and logging, mature stands and natural disturbances. FAO (2025) also points to recurrent drought stress, pest and disease outbreaks and increasing fire disturbances as key drivers of Mediterranean forest degradation and the loss of their overall sink capacity.

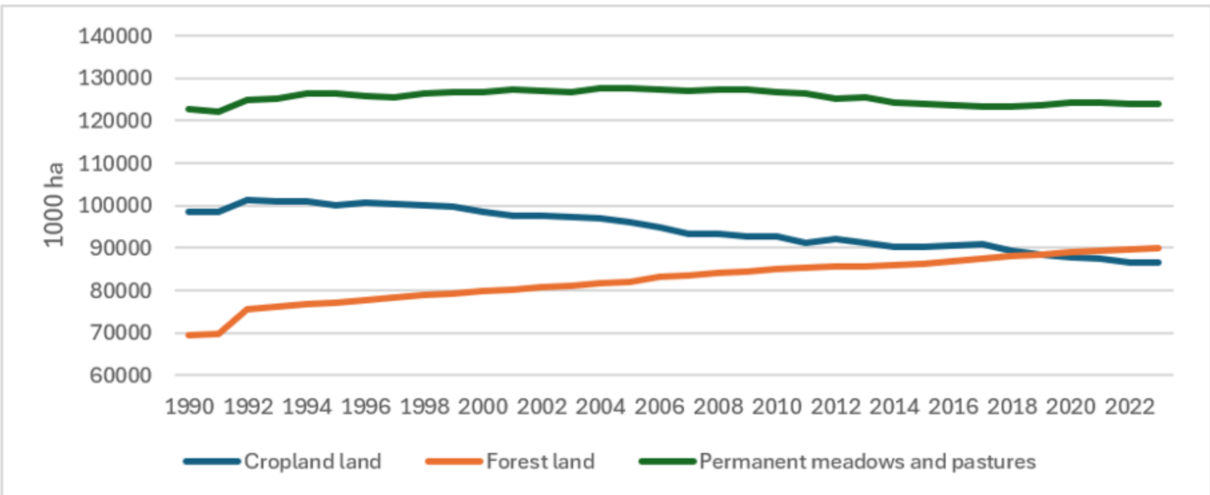

Figure 5.7| Trends in land area under specific land uses. Cropland represents the FAOSTAT category ‘arable land’, which includes land under temporary crops, meadows, pastures, and fallow. ‘Forest’ and ‘permanent meadow and pasture’ follow FAOSTAT categories. Source: FAOSTAT 2026.

Reducing emissions from the AFOLU sector in the Mediterranean region requires implementing measures that lower CH_4 and N_2O from livestock and agricultural soils (Table 5.3). Methane emissions from enteric fermentation represent the largest share (Fig. 5.8). As reported in the IPCC AR6, mitigation measures include feed management strategies (Kumari et al. 2020; Arndt et al. 2022; Roques et al. 2024), with *high confidence* that dietary manipulation (e.g. use of concentrates) and use of additives can reduce CH_4 emissions in intensive livestock systems. There is *high confidence* that managing herd size, improving grassland and pasture management, increasing animal productivity, and breeding low-emitting animals are mitigation strategies that can be effective across different livestock farming systems, including pastoral systems (Kumari et al. 2020; Zubieta et al. 2021).

Agricultural soil emissions are mostly associated with manure management (CH_4 and N_2O) and input of synthetic fertilisers (N_2O). As also reported in MAR1 (Cramer 2020), GHG soil emissions in Mediterranean agro-ecosystems can be mitigated through adjusted fertilisation and irrigation (*medium confidence*) (Aguilera et al. 2013). In particular, N_2O emissions from cropping systems differ markedly between rainfed and irrigated agriculture, reflecting strong contrasts in soil moisture regimes, fertiliser inputs, and microbial activity (Mrabet et al. 2020). Rainfed systems, typically characterised by low soil moisture and cooler conditions, exhibit substantially lower emission factors (≈ 0.27%), well below the IPCC default value of 1%. In contrast, irrigated systems receiving high water and nitrogen inputs show higher and more variable emission factors (≈ 0.63%), with sprinkler irrigation reaching 0.91% and drip irrigation reducing emissions to around 0.51% (Cayuela et al. 2017). Mitigation options include optimised nitrogen fertilisation (rate, timing, and fertiliser type), improved irrigation management, and the use of organic amendments and nitrification inhibitors. Adjusted fertilisation alone was estimated to reduce N_2O emissions by 30–50% in Mediterranean agro-ecosystems, while drip irrigation technologies could reduce emissions by more than 50% relative to sprinkler systems (Sanz-Cobena et al. 2017). The use of nitrification inhibitors was also assessed as a high-potential strategy to reduce N_2O emissions (Ruser and Schulz 2015; Gilsanz et al. 2016; Bozal-Leorri et al. 2021).

Retaining crop residues in the field can contribute to soil carbon sequestration (Section 5.2), but increased N_2O emissions can offset mitigation benefits (Lugato et al. 2018; Xia et al. 2018), which can be mitigated by avoiding the incorporation of crop residues when the soil is wet and in combination with N fertilisation (Abalos et al. 2019).

Box 5.1 Methodological differences and uncertainties in LULUCF estimates

GHG fluxes from the land use, land-use change, and forestry (LULUCF) sector remain the largest source of uncertainty in anthropogenic GHG assessments (McGlynn et al. 2022; Nabuurs et al. 2022). LULUCF uncertainty is driven by the high spatio-temporal variability of fluxes, including their natural variability due to the complex biogeochemical and physical processes underlying them; observational limitations at regional and global scales; and methodological inconsistencies, including conflicting definitions, accounting boundaries, and methods (McGlynn et al. 2022). Consequently, UNFCCC national GHG inventories and several third-party datasets used to estimate LULUCF fluxes may yield variable estimates and disagree on the magnitude and trends of emissions (FAOSTAT: 20.7 Mt CO_2eq, EDGAR: -139.7 Mt CO_2eq, Global Carbon Budget (GCB) [18]: -33.2 Mt CO_2eq for 2023). The methodological differences are well documented and increasing efforts have been made in recent years to reconcile discrepancies in LULUCF estimates, particularly between global models and national inventories, to better track policy targets (Grassi et al. 2022 2023).

This assessment has relied principally on FAOSTAT data as a harmonised and complete source of AFOLU emissions for all Mediterranean countries to describe historical trends, rather than to provide accurate estimates of year-to-year variability or to track progress toward climate targets. Comparisons with EDGAR and GCB data are mentioned whenever appropriate.

[18] average of three bookkeeping models: OSCAR (Gasser et al. 2020), BLUE (Hansis et al. 2015) and LUCE (Qin et al. 2024)

5.1.4 Transport

Key messages

- Transportation is the second largest contributor to GHG emissions from energy in the Mediterranean region, with a steady growth since 1990 *(high confidence).*
- Although the northern region is responsible for the largest share of transport-related emissions, the highest increase occurred in the south, whose share grew from 23% in 1990 to 41% in 2022
- More than 60% of transport-related GHG emissions (419 Mt CO_2eq in 2022) come from only four countries: France, Italy, Spain and Türkiye.
- The main reason for this trend is the heavy dependence on fossil fuels, which still account for 94% of energy use in transport. Also, the average age of vehicles around the region is high, so in the absence of dedicated policies to renew the fleet, emissions will continue to be high due to inefficient vehicle stock *(medium confidence).*
- Emissions are also increasing in the maritime sector. The Mediterranean is Europe's highest-emitting sea basin *(high confidence).*

The transport sector is the second-largest contributor to energy-related GHG emissions in the Mediterranean, after the electricity and heat sector. In 2022, GHG emissions from transport were 674 million tonnes, accounting for 30% of energy-related emissions and 22% of total GHG emissions excluding LUCF, broadly in line with global trends.

Emissions have risen sharply. As shown in Table 5.4, between 1990 and 2022, regional growth was 62%. Although the northern region accounts for 59% of total transport emissions, emissions in the south grew almost threefold, from less than 100 Mt CO_2eq in 1990 to nearly 280 Mt CO_2eq in 2022. The southern share of total transport emissions was 23% in 1990 and has grown to 41% in 2022.

5.1.4.1 Baseline pressures: road dominance, aviation rebound, and the role of shipping.

Across Mediterranean economies, road transport is typically the dominant mode for daily mobility and local logistics, and it is therefore a central source of transport emissions and air pollutant exposure. Where detailed national datasets are incomplete, EU reporting offers a robust benchmark for understanding the structure of the transport problem in the northern Mediterranean. The EEA's EU-27 dataset for 2022 (including international bunkers in the transport total) shows that road transport accounts for the largest share of transport GHG emissions. (EEA 2025). On the demand side, Eurostat reports that cars accounted for 72.2% of EU passenger-kilometres in 2022, decreasing to 70.6% in 2023, while aviation increased from 13.1% (2022) to 14.7% (2023). (Eurostat 2024 2025). This pattern is analytically important for the Mediterranean because it signals that road measures remain necessary even as rail investment expands, and that tourism-sensitive aviation can rapidly increase its share of transport work during recovery phases. Maritime transport adds a basin-specific dimension. UNEP/MAP reports that 25% of global maritime traffic and 30% of the world's oil traffic are concentrated in the Mediterranean (UNEP/MAP 2021). This places ports at the centre of decarbonisation and air-quality policy, and it creates a strong rationale for interventions that reduce emissions at berth and within port-city interfaces.

5.1.4.2 Road

Many countries around the Mediterranean experienced rapid urbanisation and a growing middle class, leading to increased adoption of private passenger vehicles and severe congestion and air pollution in urban environments. A look at passenger car stock in EU Mediterranean countries for 2023 reveals that hydrocarbons still represent the dominant power source for cars, as shown in Table 5.5. Although comparable statistics are not available for the entire region, it is expected that the share of fossil fuels is even higher in the south and east Mediterranean countries.

Table 5.4 | GHG emissions from the transport sector. Source: ClimateWatch 2026. [PLACEHOLDER: The table will be updated with 2023 data from ClimateWatch]

Country	GHG emissions from transport Mt CO_2 eq yr^{-1}		GHG from transport 2022 vs 1990
	(1990–1999)	(2014–2022)	
Albania	0.69	2.15	+140%
Algeria	16.25	34.47	+185%
Bosnia and Herzegovina	1.30	3.18	+83%
Croatia	3.47	5.86	+85%
Cyprus	1.46	2.01	+62%
Egypt	21.61	45.48	+250%
France	124.75	129.76	+9%
Greece	17.50	19. 60	+17%
Italy	108.81	111.93	+8%
Lebanon	3.73	6.08	+243%
Libya	8.81	15.48	+185%
Malta	0.61	0.56	+63%
Morocco	5.92	14.01	+349%
Serbia	3.72	6.10	+79%
Montenegro	0.48	0. 66	+94%[19]
Slovenia	3.53	5.09	+116%
Spain	75.24	96.78	+47%
Syria	8.15	9.24	–31%
Tunisia	3.19	6.08	+225%
Türkiye	32.42	57.88	+222%

Table 5.5 | Passenger cars by fuel type (%), year 2023. N.B.: Malta is not included in the study. Source: ACEA 2025.

Country	Petrol	Diesel	Battery electric	Plug-in hybrid	Hybrid electric	Natural gas	LPG	Other
Croatia	38.1%	56.0%	0.4%	0.2%	2.1%	0.0%	3.1%	0.0%
Cyprus	73.6%	21.1%	0.3%	0.0%	4.9%	0.0%	0.0%	0.1%
France	40.6%	50.7%	2.2%	1.5%	4.4%	0.7%	0.0%	0.0%
Greece	88.4%	8.9%	0.2%	0.3%	1.9%	0.1%	0.1%	0.0%
Italy	43.3%	41.0%	0.5%	5.4%		2.3%	7.4%	0.0%
Portugal	36.0%	57.1%	1.8%	1.7%	2.3%	0.0%	0.0%	1.2%
Slovenia	45.7%	50.0%	1.0%	0.3%	2.2%	0.0%	0.7%	0.0%
Spain	39.4%	54.2%	0.6%	0.8%	4.7%	0.1%	0.4%	0.0%
EU	50.0%	39.5%	1.8%	2.1%	3.2%	0.6%	2.6%	0.2%

[19] Relative to 2005

The other important element is the age of vehicles, which is strictly related to energy consumption and emissions levels. The average age of cars in the EU is 12.5 years, up from previous years. France and Slovenia have the 'youngest' stock, with 11.2 and 11.5 years, respectively, whereas the average age of cars in Greece is 17.5 years.

This underscores an important fact: it can take years for older vehicles to be replaced by newer models equipped with cleaner, greener technologies. This emphasises the need for sectoral policies to foster a swift transition to greener models.

Making progress in electric mobility is a clear priority for enabling a sustainable energy transition. The market for electric vehicles witnessed unprecedented growth over the last few years, reaching around 28 million units in 2022 (about 2% of the total vehicle stock), up from fewer than 30,000 in 2010. More than 70% of the global electric vehicle stock consists of battery electric vehicles. In the EU and all EU Mediterranean countries, the largest share is held by hybrid electric vehicles (see Table 5.5). Although the number of electric cars remains small, the upward trend is evident, with a clear acceleration since 2021. This is the result of several policies and measures implemented by countries, as well as behavioural change among the Mediterranean population, who are adopting more environmentally conscious lifestyles.

A study conducted by the World Bank (WB 2023) analysed current and projected trends for electric vehicles in three south Mediterranean countries: Egypt, Jordan and Morocco. In-depth analysis of transport electrification in these three countries revealed some common patterns. For instance, all three countries have established GHG emissions-reduction targets for their rapidly growing transport sectors through their Nationally Determined Contributions (NDCs), national climate change strategies, and transport-sector strategies and commitments. At the same time, all three countries are making progress in scaling up the share of renewable energy. Egypt, Jordan, and Morocco all have ambitious targets to increase Battery Electric Vehicles (BEV) adoptions, including in the public transport segment. By 2030, Morocco seeks to achieve a 10% market share for passenger BEVs and a 100% market share for e-buses and e-taxis. Jordan aims to have a 50% share of BEVs in its public fleet by 2030. Egypt is aiming for a 13% share of new private LDV11 sales to be electric by 2025, 36% by 2030, and 50% by 2040. To serve these BEVs, Egypt aims to install 1250 and 3100 public charging points by 2030 and 2040, respectively, as well as 34,000 and 400,000 private charging points by 2030 and 2040, respectively.

The EU Mediterranean countries are formally adopting measures in their revised National Energy and Climate Plans to translate this goal into concrete measures, therefore creating favourable market conditions for the development of electric vehicles. Outside the EU, other Mediterranean countries are also adopting new policies to reduce transport emissions and increase the share of electric or hybrid vehicles. Some of these dedicated measures are briefly presented in Table 5.6.

Table 5.6 | Main policies and measures for Electric Vehicles (EV) adopted by south and east Mediterranean countries Source: IEA, Global EV Policy Explorer 2026.

Country	Main sectoral measures
Algeria	Ban on imports of cars more than 3 years old (2021) Customs exemptions of up to 80% on EV imports
Egypt	Custom duties exemption (2018) on imported used EVs that are no more than 3 years old A decree (#549/2020) to encourage local assembly of EVs reduced local content to 10%, custom duties of 30% on EVs carrying 10 persons or more)
Morocco	Electric Mobility Roadmap is under preparation
Tunisia	A pilot project of 5000 EVs to be deployed during the 2023–2025 period, with a subsidy scheme (10 000 dinars per vehicle)
Türkiye	30% ZEV sales in M/HDVs by 2030, 100% by 2040

5.1.4.3 Maritime

The Mediterranean is both a global hub and a vulnerable bottleneck. About 10% of world trade and 22% of global container traffic pass through the Suez Canal alone. Intra-Mediterranean shipping is growing, accounting for nearly 60% of regional traffic. At the same time, the region's chokepoints are exposed to congestion, political instability, and regulatory changes—making the resilience of maritime corridors a pressing strategic priority. The regional fleet is expanding but also ageing. The fleet remains older than the global average, with many vessels exceeding 25–30 years. Container ships are the fastest-growing segment, while general cargo vessels are in structural decline. Without accelerated renewal, compliance with upcoming decarbonisation requirements will remain challenging. Emissions are rising, making the Mediterranean area Europe's highest-emitting sea basin (Figure 5.8). Between 2015 and 2023, maritime CO_2 emissions in the region increased by 15%, reaching an annual average of 64 million tonnes. Methane emissions surged by more than 200% due to the growing LNG fleet. While efficiency improvements have reduced emissions per tonne-kilometre, overall emissions continue to rise as rerouted voyages lengthen and demand expands. Five countries—Cyprus, France, Greece, Italy, Türkiye—are responsible for the majority of regional emissions (Figure 5.9).

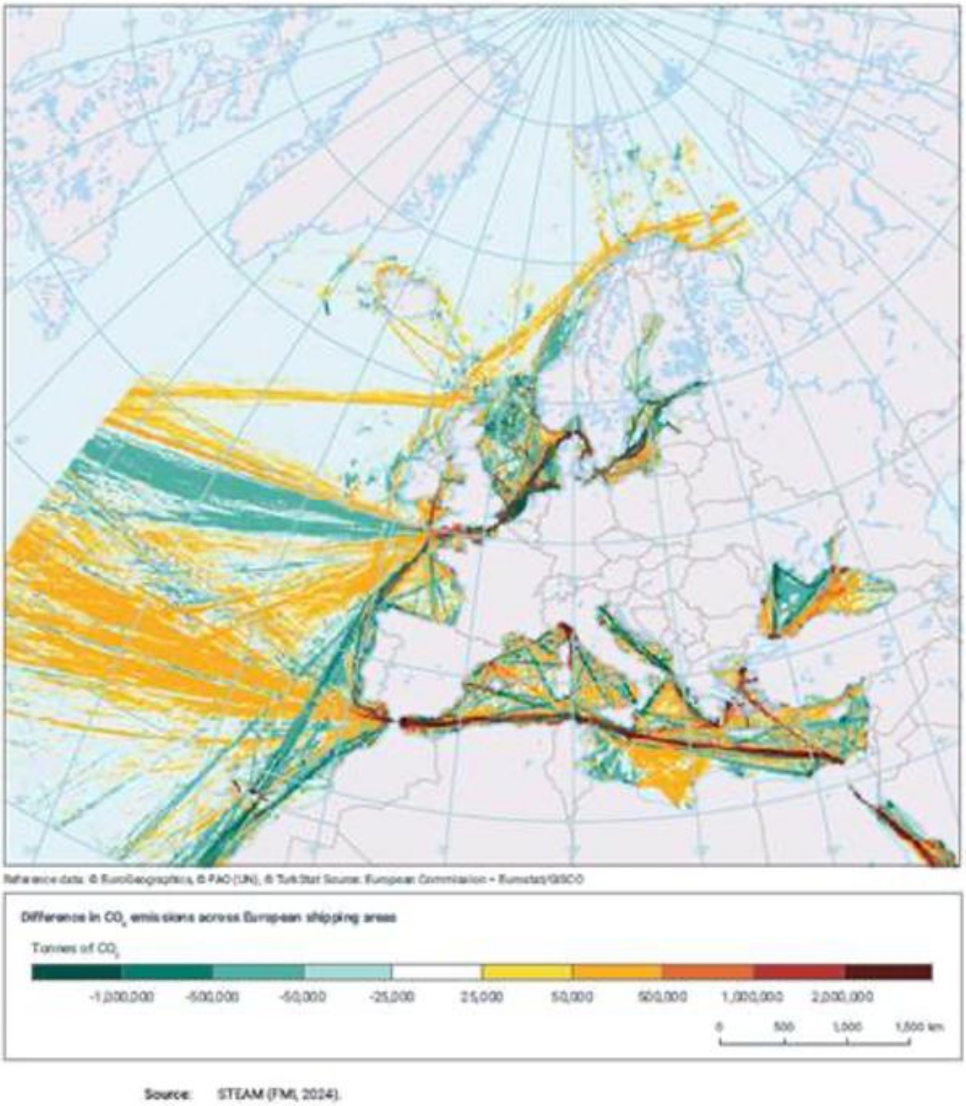

Figure 5.8 | CO_2 emissions across European shipping areas. Source: EEA 2025.

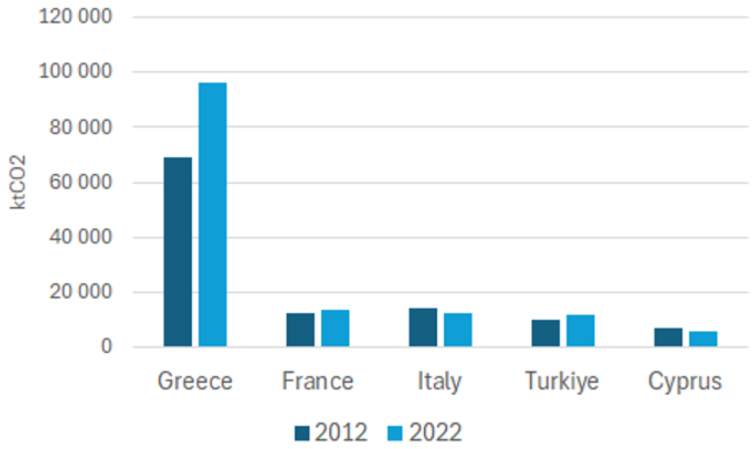

Figure 5.9 | CO_2 emissions from maritime transport in selected Mediterranean countries. Source: UNCTAD 2023.

A new regulatory framework is reshaping the Mediterranean maritime sector. The 2023 IMO GHG Strategy, the forthcoming IMO Net-Zero Framework, the Mediterranean SECA, and the EU Fit for 55 package are introducing increasingly stringent environmental requirements, driving investments in alternative fuels, energy efficiency, shore-side electricity, and port infrastructure. These measures also increase the economic significance of carbon pricing, particularly through the EU ETS.

The sector's energy transition is progressing, albeit unevenly. While most vessels continue to rely on conventional fuels, a growing share of newbuilds is designed to operate on alternative fuels. LNG remains the predominant transitional option, supported by expanding bunkering infrastructure, although concerns regarding methane emissions remain. Biofuels provide near-term decarbonisation opportunities, whereas ammonia, methanol, hydrogen, electrification, and hybrid propulsion systems offer longer-term potential but require substantial investments, robust safety standards, and stable policy frameworks.

Several Mediterranean initiatives illustrate this transition. Ports across the region are implementing decarbonisation strategies focused on renewable energy integration, operational efficiency, and sustainable infrastructure, supported by regional cooperation platforms and green shipping programmes such as the Mediterranean Green Shipping Network, the GreenMED project, the Green Ports Cluster, the MENA Maritime Development Programme, and the Mediterranean Sustainable Shipping Observatory. At the same time, major shipping companies are investing in low-carbon fuels and cleaner propulsion technologies through strategic partnerships and innovation initiatives to advance maritime decarbonisation.

5.1.5 Buildings

Key messages

- In 2023, the building sector accounted for 9% of GHG emissions in the Mediterranean region.
- Energy demand in buildings is shifting from winter heating to summer cooling *(high confidence*).

Significant reductions in greenhouse gas emissions can be achieved by implementing a combination of strategies, including: (1) improving the energy performance of buildings *(high confidence)*, (2) increasing energy efficiency through the use of energy-efficient appliances *(high confidence)*, (3) installing renewable energy systems *(high confidence)*, (4) electrifying buildings using clean energy sources *(high confidence)*, and (5) adopting 'soft measures' to encourage more conscious energy use *(medium confidence)*.

The Mediterranean building stock is generally old and characterised by low energy efficiency (Manso-Burgos et al. 2023; Katsaprakakis et al. 2020). Many buildings were constructed before modern insulation and energy efficiency standards were introduced, resulting in high energy demand. Climatic conditions further influence energy demand patterns in the region (Chapter 1) (Urdiales-Flores et al. 2024), moreover several studies have demonstrated that the energy demand in Mediterranean countries is shifting from winter heating to summer cooling (Section 3.1.2 on energy) (Rodrigues and Fernandes 2020; Giannakopoulos et al. 2009; Zhao et al. 2025; Spinoni et al. 2018; Ferrari et al. 2023; Salvati et al. 2017; Salata et al. 2023; Zhao et al. 2025; Alafya and Maka 2025) *(high confidence)*. Given its strong potential for efficiency improvements and energy savings, with estimates reaching up to 65% in some contexts (e.g. Crete, Greece (Katsaprakakis et al. 2020) or a 25% reduction in CO_2 emissions in the case of Córdoba (Blázquez et al. 2021). The building sector plays a crucial role in achieving substantial energy savings and reducing GHG emissions, thereby contributing to climate neutrality (López-Ochoa et al. 2023; Salvia et al. 2021) *(high confidence)*. In 2023, the building sector in Mediterranean countries, including municipal, residential, and commercial buildings, accounted for around 9% of total GHG emissions (261 Mt CO_2eq, compared to 2870 Mt CO_2eq; own calculation based on ClimateWatch data). ClimateWatch (1990-2023) and EDGAR (1990-2024) datasets reveal a persistent geographical divide in building-sector GHG emissions across Mediterranean countries (Tables 5.7 and 5.8). Northern Mediterranean countries, considerably within the EU, show a long-term decline in emissions since 1990, reflecting improvements in energy efficiency, building retrofits, and climate policies. In contrast, southern and eastern Mediterranean countries exhibit increasing emissions, driven by rapid urbanisation, population growth, and rising demand for cooling and electricity services (IEA 2023; UNEP 2024). Although Climate Watch generally reports lower absolute emission levels than EDGAR, both datasets identify consistent temporal patterns, including substantial reductions in European countries and sustained growth in North African and eastern Mediterranean regions. Differences between the datasets attributable to variations in sectoral definitions and emission accounting methodologies (Banja et al. 2025; Climate Watch 2025). These findings highlight the need for mitigation strategies that combine efficiency improvements with targeted policies to address the expansion of building stock in emerging economies.

The EDGAR dataset highlights a pronounced and persistent spatial divergence in building-sector GHG emission trajectories across Mediterranean countries over the period 1990–2024. On the one hand, most European countries exhibit substantial reductions, consistent with long-term improvements in energy efficiency, building regulations, and structural changes in energy systems (Maduta et al 2023). On the other hand, North Africa and several eastern Mediterranean countries display strong and sustained growth, reflecting rapid urbanisation, population growth, and increasing energy demand for space cooling and residential services (Haouraji et al. 2021; Carlucci et al. 2024). Overall, the EDGAR data reveal a clear north–south and west–east gradient: the Mediterranean region is characterised not by uniform decarbonisation, but by simultaneous mitigation in the north and expansion in the south, with growing implications for future climate policy coordination at the Mediterranean scale.

Table 5.7 | Building GHG emissions in Mediterranean countries. Source: Edgar database 2025 [20]. Data are averaged over the periods between 1990 and 1999, between 2000 and 2009, between 2010 and 2019, and between 2020 and 2024, and changes in GHG emissions (between 1990 and 2024) are reported.

Countries	Average GHG emissions for the building sector [Mt CO2eq yr^{-1}]				GHG emissions [Mt CO_2eq yr^{-1}] in 1990 and 2024 and the change in 2024 compared with 1990 (%)		
	1990–1999	2000–2009	2010–2019	2020–2024	1990	2024	%
Albania	0.85	0.93	0.73	0.83	2.39	0.82	−66%
Algeria	8.07	12.07	23.72	31.14	6.61	29.70	+349%
Bosnia and Herzegovina	2.56	1.68	1.48	1.19	5.63	1.20	−79%
Croatia	3.49	4.11	3.38	3.17	4.04	3.05	−25%
Cyprus	0.21	0.45	0.57	0.51	0.19	0.50	+166%
Egypt	10.36	16.65	21.08	17.94	10.15	18.47	+82%
France and Monaco	106.27	104.63	86.36	68.56	101.45	60.00	−41%
Greece	9.47	13.19	7.53	6.31	8.64	5.79	−33%
Israel and Palestine	2.88	4.37	2.51	2.16	1.85	2.52	+36%
Italy	78.10	84.04	76.58	65.43	77.03	60.06	−22%
Lebanon	2.19	1.72	0.85	0.60	0.56	0.50	−11%
Libya	1.90	2.29	1.57	1.19	1.37	1.30	−5%
Malta	0.11	0.11	0.14	0.14	0.09	0.14	+51%
Morocco	4.09	6.44	9.71	11.89	2.91	12.81	+340%
Serbia and Montenegro	4.81	4.60	3.93	3.81	7.92	3.61	−54%
Slovenia	2.70	2.69	1.69	1.29	2.09	1.26	−40%
Spain	25.67	35.49	33.56	31.68	21.79	30.09	+38%
Syria	8.06	8.77	4.72	3.03	9.19	3.03	−67%
Tunisia	3.33	4.31	4.25	4.85	2.58	5.19	+101%
Türkiye	36.11	47.88	66.86	73.49	33.33	75.02	+125%
Total					**299.8**	**315.1**	**+5%**

[20] https://edgar.jrc.ec.europa.eu/report_2025

Table 5.8 | Building GHG emissions in Mediterranean countries. Data are averaged over the periods between 1990 and 1999, between 2000 and 2009, between 2010 and 2019, and between 2020 and 2023, and changes in GHG emissions (between 1990 and 2023) are reported. Source: Climatewatch 2025. [21]

Country	Average GHG emissions for the building sector [Mt CO_2eq yr^{-1}]				GHG emissions [Mt CO_2eq yr^{-1}] in 1990 and 2023 and the change in 2023 compared with 1990 (%)		
	1990–1999	2000–2009	2010–2019	2020–2023	1990	2023	%
Albania	0.39	0.45	0.45	0.54	0.45	0.54	+20%
Algeria	8.35	11.98	20.26	27.63	6.89	27.4	+298%
Bosnia and Herzegovina	0.21	0.21	1.03	1.16	0.36	1.05	+192%
Croatia	2.58	3.30	2.66	2.44	2.65	2.28	-14%
Cyprus	0.21	0.39	0.46	0.41	0.18	0.38	+111%
Egypt	10.50	13.44	17.15	16.28	10.49	16.82	+60%
France	93.53	89.64	73.10	57.98	89.55	49.52	-45%
Greece	6.49	10.31	6.42	5.48	5.47	4.55	-17%
Israel	1.65	2.40	1.17	0.77	1.42	0.87	-39%
Italy	68.16	74.80	68.57	58.61	67.52	51.78	-23%
Lebanon	2.26	1.81	0.87	0.82	0.62	1.01	+63%
Libya	3.43	3.93	3.89	3.48	2.91	3.54	+22%
Malta	0.10	0.09	0.12	0.09	0.09	0.09	0
Morocco	3.34	5.32	7.41	8.91	2.47	9.21	+273%
Serbia	2.79	3.08	2.90	3.00	2.72	2.84	+4%
Slovenia	2.64	2.36	1.40	1.03	2.07	1.00	-52%
Spain	20.13	27.09	25..55	23.60	17.18	21.87	+27%
Syria	3.66	5.85	3.39	2.25	2.94	2.38	-19%
Tunisia	2.76	3.68	3.42	3.76	2.15	3.75	+74%
Türkiye	28.12	36.88	54.95	62.05	26.81	60.17	+124%
Total					**244.9**	**261.1**	**+7%**

<u>Legislative framework on buildings and GHG targets.</u> The regulatory framework and the analysis of GHG emissions targets from buildings can be substantially classified for different geographical areas. The Mediterranean countries of the European Union have a common policy to reduce GHG emissions from Buildings. In Europe, the Energy Efficiency Directive (EED) 2012/27/EU and the Energy Performance of Buildings Directive (EPBD) 2010/31/EU are the main legal frameworks for improving the energy performance of buildings (Maduta et al. 2023). Approved in May 2024, the European Energy Performance

[21] https://www.climatewatchdata.org/ghg-emissions

of Buildings Directive (EPBD 2024) sets out binding targets to improve the energy efficiency of buildings and achieve zero emissions by 2050. The directive calls for the progressive renovation of the least efficient buildings, climate neutrality for new constructions from 2030 (2028 for public buildings) and the phasing out of fossil fuels for heating by 2040. It represents the most advanced and binding commitment to reducing GHG emissions from buildings in Europe. Moreover, to support the transition to low-carbon buildings and construction in the Mediterranean region, the European Commission launched the Energy Efficiency of Buildings in the Mediterranean Region [22] (PEEB Med) initiative [23] at COP27 in 2022, under the umbrella of the Partnership for Energy Efficiency in Buildings (PEEB). The initiative provides technical assistance and project financing to seven Mediterranean countries. The seven southern Mediterranean countries are: Algeria, Egypt, Jordan, Lebanon, Morocco, Palestine, and Tunisia. The initiative aims to facilitate the transition to low-carbon, energy-efficient and climate-resilient buildings and construction methods by providing technical assistance and concessional loans for construction projects, such as social housing, schools and healthcare facilities. The European Environment Agency (EEA 2025) reports the reduction of GHG emissions from energy use in buildings both for the whole European Union and for each country in the period 2005–2023 and the changes in emissions in the period 2005–2030 with current measures and with additional measures (Table 5.9)

Table 5.9 | Variations for GHG emissions for energy use in buildings for the European Union countries of the Mediterranean area. Source: EEA 2025.

	Percentage change 2005–2023	Percentage change 2005–2030 with existing measures	Percentage change 2005–2030 with additional measures
EU-27	–31%	–47%	–53%
Croatia	–37%	–35%	–60%
Cyprus	–26%	+6%	–8%
France	–50%	–61%	–70%
Greece	–62%	–76%	–76%
Italy	–29%	–29%	–39%
Malta	–10%	+13%	+13%
Slovenia	–58%	–73%	–77%
Spain	–26%	–44%	–53%

GHG emission reduction policies in the building sector in the African Mediterranean countries are still under development and consolidation. There are international cooperation initiatives, such as the PEEB Med program, funded primarily by the European Commission, that promotes energy efficiency in buildings in the southern Mediterranean, helping countries such as Algeria, Egypt, Jordan, Lebanon, Morocco, Palestine, and Tunisia achieve their climate goals. The Climate Analytics project uses IPCC-assessed 1.5°C-compatible pathways, combined with the latest scientific evidence, to show how a selection of 64 countries, across all regions and levels of development, can align their decarbonisation pathways with the Paris Agreement and deliver on their promises to prevent the worst impacts of climate change [24]. Among the North African countries bordering the Mediterranean Sea, development scenarios are available for Algeria, Egypt, and Morocco.

In Morocco, energy demand in the building sector is expected to grow due to population increase, urban expansion, and wider use of air conditioning and heating (UNFCCC 2022). To align with 1.5°C pathways, the sector should be decarbonised by 2056, primarily through rapid electrification, with the share increasing from 27% in 2019 to 82–85% by 2050. Morocco plans to mitigate 3,782 Mt CO_2e by 2030 via measures such

[22] https://international-partnerships.ec.europa.eu/policies/global-gateway/energy-efficiency-buildings-mediterranean-region_en#key-information
[23] https://peeb.build/peeb-med/
[24] https://1p5ndc-pathways.climateanalytics.org/about

as solar water heaters, LED lighting in homes, energy performance standards for appliances and buildings, 1,000 MWp of self-consumption solar capacity, and improved public lighting efficiency. Tunisia has developed a relatively structured regulatory framework for building energy efficiency. This includes the introduction of energy performance classes for buildings and mandatory consideration of both heating and cooling demand during building design and permitting processes (Zagarella et al. 2024). This reflects a more systematic approach compared to several other countries in the region. The Western Balkan and Middle Eastern countries have a heterogeneous picture. Albania is gradually aligning itself with European policies for building efficiency and emissions reduction, with standards that include minimum energy performance requirements, retrofits, and the introduction of renewable energy. Bosnia and Herzegovina should increase electrification in the building sector to 57–58% by 2030 and 69–78% by 2050 to align with 1.5°C pathways. Fossil and synthetic fuels are projected to decline significantly, with coal almost completely phased out by 2050, while biomass remains an important component (over 10%) in most scenarios except the low-energy-demand case. However, current policies focus mainly on the renovation of public and government buildings, with no targeted support programmes or incentives for residential and private buildings (Climate Analytics Bosnia and Herzegovina 2025). Future scenarios indicate that the share of electricity in the Serbian building sector's energy mix will increase from 43% in 2019 to 56%-61% in 2030 and 69%-80% in 2050. In April 2021, the Serbian government passed the Law on Energy Efficiency and Rational Use of Energy, which established a government agency responsible for managing financing for energy-efficiency improvements. The law provides subsidies for energy-efficiency renovations in public buildings and grants VAT and customs duty exemptions for the purchase and installation of energy-efficient equipment (Climate analytics Serbia 2025). The Israeli building sector already has a high level of electrification: approximately 84% in 2019. To achieve 1.5°C compatibility, however, this contribution should increase to 88%–96% by 2030 and to 96%–99% by 2050. Therefore, emission reductions in the sector will be achieved through decarbonising the country's electricity generation. The Israeli government has introduced a green building standard that requires new buildings to meet specific environmental criteria (Climate Analytics Israel 2025).

Tables 5.10a and 5.10b show the results for GHG emissions from buildings in some Mediterranean countries, obtained from variants of the SSP1 scenario used in the climate modelling runs, combined with different assumptions about energy demand and the use of CO_2 removal technologies.

Algeria relies primarily on electricity to gradually phase out fossil fuels in buildings. By 2050, electricity's share is expected to rise to 93%. The remaining energy demand in buildings could be met through heat (Climate analytics Algeria 2025). Algeria, with over 240 hot springs, has significant geothermal energy potential (CDER 2019). In 2022, 60% of the building sector's energy needs in Egypt were met by electricity, 9% by biomass, and the remainder by fossil fuels. Pathways compatible with a 1.5°C increase in temperature place greater emphasis on managing the projected sharp rise in cooling demand than on rapidly shifting the fuel mix. Egypt's national smart city strategy is expected to improve the building sector's energy demand by introducing smart grids and metres (Climate analytics Egypt 2025). The highest ambition scenario for Türkiye's building sector foresees increased electrification of buildings alongside energy-efficiency measures. The share of electricity in building energy demand is projected to reach 43% by 2030 and 72% by 2040. Türkiye also has significant rooftop solar potential (over 120 GW). Renovating poorly insulated buildings and deploying heat pumps could further reduce emissions and household energy costs (Climate Analytics Türkiye 2025). In the context of the meetMED II regional project, an Energy Efficiency Building Code (LEEB 2025) was drafted to promote building efficiency in Lebanon. However, actual implementation remains limited, and many standards are currently voluntary or under development (Lebanon Energy Efficiency Buildings Code (LEEB 2025)). Libya has not submitted updated NDCs or national climate policy plans consistent with the Paris Agreement, resulting in no official emissions reduction targets or explicit references to the buildings sector. The long conflict in Syria has degraded institutional and infrastructural capacities, hindering the development and implementation of structured climate and energy policies (Kinder et al 2025).

In summary, the building sector can contribute significantly to climate change mitigation by implementing various strategies, preferably combined to enhance their effectiveness (Rahmani et al. 2022, De Oliveira et al. 2024). These include: (1) improving the energy performance of buildings through envelope retrofits, such as insulating the building envelope and replacing windows (Panagiotidou et al 2021, Villano et al 2026), (2) increasing end-use efficiency by replacing appliances with high-efficiency alternatives, (3) installing renewable energy systems at building level (Elaouzy et al 2023), (4) building electrification with clean energy supply (Borge-Diez et al 2022, Costanzo et al 2024, Abd Alla et al 2022), (5) adopting 'soft measures', which encompass strategies to raise users' awareness of their energy consumption, thereby encouraging more sustainable behaviours and efficient energy use (Iweka et al. 2019; Pietrapertosa et al. 2021). Furthermore, incentivising nearly zero-energy buildings (NZEBs) is key to achieving the highest possible level of energy performance, thereby drastically reducing energy consumption and greenhouse gas emissions throughout a building's entire life cycle (Causone et al. 2019).

Table 5.10a | GHG emissions projections in Mt CO_2eq from the buildings sector to 2050 under the scenarios. Source: Climate Analytics 2026

	Base year (2019)	Scenarios			
		SSP1 Low CDR Reliance	**Low Energy Demand**	**High Energy Demand - Low CDR Reliance**	**SSP1 High CDR Reliance**
Bosnia and Herzegovina	0.6	0.1	0.2	0.1	0.7
France	62	23	3	1	25
Israel	3	0.4	0	0.2	1
Italy	62	27	1	0	21
Morocco	8	4	0	9	9
Serbia	2.2	0.2	0.3	0.1	1.9
Spain	23	7	1	1	10

Table 5.10b | GHG emissions projections in Mt CO_2eq from the buildings sector to 2050 under the scenarios. Source: Climate Analytics 2026

	Base year (2020)	Scenarios			
		Minimal CDR Reliance	**Net-zero Commitments**	**Deep Electrification**	**Highest possible Ambition**
Algeria	27	3	3	2	
Egypt	15	4	4	3	
Türkiye	61				5

5.1.6 Country-wide mitigation portfolio

Key messages

- National pathways must translate heterogeneous NDC architectures into implementable policy packages with measurable sector milestones and credible investment plans *(high confidence).*
- Priority is coherence across instruments: standards, pricing, public investment, and sector strategies aligned to infrastructure constraints and administrative capacity *(medium confidence).*
- Case-based learning across countries improves feasibility by documenting what is deliverable under different fiscal, institutional, and energy-system conditions *(medium confidence).*
- The Mediterranean can accelerate deep decarbonisation by scaling its solar and wind resources (PV, CSP, floating offshore wind and floating PV) complementing them with green hydrogen, energy-efficient buildings and sustainable mobility solutions, supported by good planning and infrastructure upgrades *(high confidence).*

Section 5.1.6 synthesises country-wide mitigation portfolios across Mediterranean Parties (Table 5.1), using the NDC target statements summarised in Table 5.11 as the entry point. Those targets already show the basin's dispersion in mitigation framing: the European Union communicates an absolute, net economy-wide pathway anchored to 1990 with an indicative 2035 range (Danish Presidency of the Council of the European Union and European Commission 2025), Morocco frames its 2035 ambition as a deviation from BAU with a quantified unconditional and conditional split, Tunisia communicates a carbon-intensity reduction against 2010 with intermediate milestones, and Egypt reports quantified BAU reductions for specific sectors rather than a single economy-wide headline. In parallel, several Parties combine unconditional and conditional tracks (for example, Bosnia and Herzegovina) or define domestic-only targets (for example, Montenegro). At the same time, some have no current registry entry to translate into a national pathway (for example, Libya).

A mitigation portfolio, in this context, is the set of policy instruments, investment programmes, and institutional arrangements through which a country converts its NDC framing into a measurable emissions trajectory. Portfolios differ not only because national circumstances vary, but also because the target architecture changes the logic of implementation and verification. Absolute targets require clarity on sector coverage, treatment of removals, and the domestic measures expected to deliver reductions. BAU-deviation targets rely on the credibility of baseline assumptions and on whether the sector measures can plausibly generate the stated gap relative to the counterfactual. Intensity targets depend on the interaction between structural change, growth dynamics, and mitigation policy, which means the portfolio needs to identify where emissions reductions come from in physical terms rather than only in ratio terms. Across these variants, conditional components signal which measures are treated as finance- or technology-dependent and how much of the pathway is presented as deliverable with domestic resources.

The country cases that follow focus on how these portfolios are assembled in practice, with attention to three concrete elements that condition delivery. First, each target is translated into an operational pathway by identifying the main sector sources, the implied timing of reductions to 2030 and, where relevant 2035, and the stated role of removals upon their entry into the accounting. Second, the profiles document the instrument mix underpinning delivery, including regulatory measures, public investment pipelines, incentives, and institutional reforms, with an emphasis on what is already in force versus what remains planned. Third, they record the enabling conditions explicitly referenced in national submissions, notably the scale and structure of financing needs, the extent of conditionality, and the maturity of monitoring, reporting, and verification arrangements that make progress measurable and comparable within the Paris transparency framework.

Albania. Albania's revised NDC sets an economy-wide target of a 20.9% reduction in GHG emissions by 2030 against a business-as-usual (BAU) baseline—about 3.17 Mt CO_2eq avoided in 2030 and roughly 16.8 Mt CO_2eq cumulatively over 2021–2030 (Republic of Albania, Revised NDC 2021). Because the target is defined relative to projected rather than historical emissions, its environmental significance and measurability are conditional: realised abatement depends on the BAU assumptions and on whether the policy package is delivered at the pace assumed in the modelling. On current evidence, the commitment is therefore best assessed as contingent on implementation rather than as a secured reduction *(medium confidence)*. Albania's mitigation profile is comparatively favourable in the power sector, where hydropower dominance keeps generation emissions low relative to regional peers; the same dependence, however, transfers risk to hydrological variability and raises the assessed weight of diversification and demand-side measures *(high confidence)*. The principal levers—energy efficiency, complementary solar and wind, and end-use electrification—are well identified, with transport a persistent structural constraint owing to oil dependence. The pathway rests on LEAP scenario modelling and an existing strategy architecture, but these remain considerably planning instruments, with their contribution to realised abatement not yet demonstrable *(medium confidence)*. Relative to regional peers, a notable feature is the stated intent to embed GHG accounting, shadow carbon pricing, and climate screening into public investment appraisal—a potential shift from project lists toward systemic mainstreaming—though this is assessed as a prospective rather than an operational strength *(low confidence)*. Overall, feasibility is strongly support-dependent: delivery hinges on international finance and technical assistance for renewables scale-up, grid modernisation and efficiency, and is constrained by BAU uncertainty, limited administrative capacity, and the absence of an economy-wide carbon-pricing instrument *(medium confidence)*.

Algeria. Algeria's currently registered NDC is its first NDC, submitted on 20 October 2016, and it sets its mitigation ambition as a deviation from business-as-usual (BAU), with an explicit domestic-versus-conditional split. The headline mitigation commitment is 7% reduction vs BAU by 2030, presented as achievable with national means, increasing to up to 22% vs BAU by 2030, conditional on international support (finance, technology transfer, and capacity building), over the implementation horizon 2021–2030. The NDC frames mitigation measures as spanning energy, industrial processes, agriculture, land use, and waste, with coverage of key gases including CO_2, CH_4 and N_2O.

The mitigation story is then operationalised through a package of sector levers with several quantified signals. Algeria highlights renewables and energy efficiency as core pillars, including an objective to generate 27% of electricity from renewable sources by 2030, alongside demand-side measures such as improved building insulation and expanded LPG use in parts of the vehicle fleet. Upstream emissions are also targeted, with the NDC citing a goal to reduce gas flaring to below 1% by 2030, complemented by methane-related actions in waste management, and a sink-side contribution via large-scale reforestation objectives. The same conditionality that defines the 7% to 22% range is used to position these measures: deeper mitigation is explicitly linked to scaled external support.

Bosnia and Herzegovina. Bosnia and Herzegovina's NDC sets a dual mitigation pathway for 2030, expressed primarily against the latest full inventory baseline (2014) and restated against 1990 for comparability. The unconditional target is −12.8% vs 2014 by 2030, equivalent to −33.2% vs 1990, while the conditional target strengthens this to −17.5% vs 2014 by 2030, equivalent to −36.8% vs 1990, with the higher ambition explicitly dependent on enhanced international support, particularly to accelerate decarbonisation and manage a fair transition in mining areas. The NDC also extends the trajectory to 2050, targeting −50% (unconditional) and −55% (conditional) vs 2014, signalling that the 2030 reductions are intended as a stepping stone toward a deeper mid-century transformation. Coverage is economy-wide, spanning power and heat, buildings, transport, industry, agriculture, forestry, and waste, and includes the main greenhouse gases (CO_2, CH_4, N_2O, and HFCs), with sinks addressed through forestry measures.

The mitigation profile is structurally dominated by the energy system, particularly coal and lignite-based electricity and heat, which drives high emissions intensity and concentrates both opportunities and risks. This concentration means that the largest marginal abatement potential lies in power-sector restructuring, but it also raises lock-in concerns related to asset lifetimes, employment, and security of supply. The NDC frames implementation through inventory-based projections and LEAP modelling out to 2050, with near-term measures focused on stopping emissions growth and deeper reductions tied to the scale-up of renewables, efficiency improvements, and the managed retirement or transformation of high-emitting units. Forestry is positioned as a complementary sink, with planned measures intended to increase removals by about 93 Gg CO_2eq by 2030, but not as a substitute for core energy decarbonisation. On feasibility, the NDC quantifies the investment scale at about BAM 17 billion by 2030 (noted as above 5% of GDP), and it makes clear that the conditional pathway hinges on concessional finance and de-risking for clean power and grids, plus structured just-transition programmes for coal regions and stronger MRV and policy coordination.

Croatia. As an EU Member State, Croatia does not submit an individual NDC; its mitigation commitments are embedded in the European Union's collective NDC and implemented through the EU Emissions Trading System (power and industry) and the Effort Sharing Regulation (ESR) for non-ETS sectors (transport, buildings, agriculture, waste and small industry). Under the revised ESR, Croatia's 2030 target is a 16.7% reduction relative to 2005, which it is projected to meet or overachieve with current and planned measures (European Commission 2024; Regulation (EU) 2023/857).

Croatia's emissions profile benefits from a high share of hydropower in electricity generation and from shared nuclear capacity at the Krško plant (with Slovenia), which moderates power-sector emissions relative to regional peers. The main mitigation levers are further deployment of renewables (solar and wind), energy efficiency and building renovation, and decarbonisation of a tourism-intensive transport and services economy, as set out in its National Energy and Climate Plan. Structural challenges include seasonal demand peaks linked to tourism and the need for grid modernisation to integrate variable renewables. Assessed against its ESR pathway, Croatia is among the lower-risk EU Mediterranean cases: the hydropower and shared-nuclear base limits power-sector exposure, leaving tourism-driven seasonal demand peaks and transport as the main residual pressures on the 2030 target *(medium confidence)*.

Egypt. Egypt's most recent UNFCCC registry filing is the Updated First NDC 2030 (Second Update) submitted on 26 June 2023, and its mitigation approach is presented through quantified, sector-based targets rather than a single economy-wide percentage reduction. For electricity generation, transmission and distribution, the NDC reports 2015 emissions of 87,694 Gg CO_2e and 2030 BAU emissions of 214,740 Gg CO_2e, with a stated 3% reduction vs BAU by 2030; it pairs this with a structural target of 42% renewables in the electricity generation mix by 2030, supported by grid upgrades and smart-grid measures. This framing places the power sector at the centre of mitigation while keeping the quantified metric explicitly anchored to BAU projections for 2030.

Two additional mitigation pillars are quantified in the same way. For oil and gas associated gases, Egypt reports 2030 BAU emissions of 2575 Gg CO_2eq and a 65% reduction vs BAU, quantified as 1682 Gg CO_2eq, linked mainly to reducing flaring through the recovery and utilisation of associated gas. For transport, it reports 2030 BAU emissions of 124,360 Gg CO_2eq and a 7% reduction vs BAU, quantified as 8960 Gg CO_2eq, linked to modal shift and mass transit investments, such as metro expansion. The financing section then reinforces how central mitigation is to the conditionality logic: Egypt estimates USD 196 billion for mitigation and USD 50 billion for adaptation, for a total of USD 246 billion, and frames implementation as contingent on adequate international support, including concessional finance and, where appropriate, grants.

Lebanon. Lebanon's latest filing is the Lebanon NDC 3.0, submitted on 30 September 2025, and public documentation referencing the NDC text provides a clear mitigation headline for 2035 with an unconditional and conditional split. Lebanon commits to a 22% reduction in national GHG emissions by 2035 as an unconditional contribution, rising to 33% by 2035 conditional on international support. The mitigation package is also linked to an energy transition objective to raise renewables to 25%-30% of the national energy mix, signalling that power-sector restructuring is a primary mitigation lever.

A second mitigation signal is Lebanon's framing of 2035 as a waypoint on a longer trajectory rather than a standalone target year. UNDP communications around NDC 3.0 describe the NDC as setting targets through 2035 while 'setting a trajectory' toward net-zero emissions by 2050, clarifying the intended direction of travel beyond the NDC horizon. The same public framing links mitigation to system resilience and reduced exposure to imported fuels, while keeping the higher-ambition tier explicitly conditional on external support, which is central to interpreting the difference between the 22% and 33% levels in implementation terms.

Montenegro. Montenegro's updated NDC sets strictly domestic net targets of at least −55% by 2030 and −60% by 2035, economy-wide and including LULUCF, with no recourse to international credits (Government of Montenegro 2025). The decisive feature for assessment is that net emissions were already around 72% below 1990 in 2022, which reframes the challenge: compliance depends less on cutting gross emissions further than on safeguarding the land sink that keeps the net balance low, making the target unusually sensitive to LULUCF accounting and to forest disturbance risk *(medium confidence)*.

Delivery risk is highly concentrated. Energy dominates gross emissions, and within it, a single asset—the TPP Pljevlja coal plant—accounts for a disproportionate share, so the trajectory hinges on a single high-leverage but high-exposure decision rather than on a diversified portfolio *(medium confidence)*. The NDC frames its additional measures explicitly as convergence with the EU climate acquis (EU ETS, efficiency and renewable directives, transport and industrial standards), positioning a national ETS and MRV framework as the enabling channel toward eventual participation in the EU ETS. Feasibility is therefore tightly bound to EU-accession financing: the NDC quantifies needs at roughly €1.57 billion for the 2030–2035 targets plus a further €1.26 billion for accession-driven measures, which is substantial relative to the size of the economy and makes the higher-ambition pathway contingent on external support *(medium confidence)*.

Morocco. Morocco's UNFCCC registry entry records NDC 3.0 with a submission date of 30 September 2025, and the mitigation pledge is framed as a BAU deviation with a clearly quantified unconditional and conditional split. According to the NDC content, Morocco commits to a 53% reduction in GHG emissions by 2035 vs BAU, comprising 21.6% unconditional measures and 31.4% conditional measures that depend on international support. This structure is important analytically because it makes the mitigation ceiling directly contingent on the availability of finance and implementation partnerships, rather than presenting a single undifferentiated headline. Mitigation delivery is presented as power-sector-led, with Morocco aiming to scale renewables rapidly and citing an objective to raise renewable capacity to more than 15 GW by 2030, supported by enabling infrastructure such as grid reinforcement and storage. The same NDC framing introduces an explicit coal trajectory, including a 2040 coal phase-out date, conditional on international support, alongside an unconditional phase-out intention in the 2040s, positioning coal retirement as one of the major levers for meeting post-2030 mitigation ambition. Public summaries linked to the NDC also quantify investment magnitudes, including more than USD 21 billion for green electricity investment and an aggregate envelope reported around USD 96 billion for mitigation and adaptation combined (as stated in NDC-related documentation).

Jordan. Jordan's latest registry entry, Jordan NDC 3.0, submitted on 22 September 2025, is a forward-looking framework that builds on Jordan's previously quantified mitigation pledge rather than presenting a single new headline number for 2035. The mitigation baseline is Jordan's earlier macro target of 31% below BAU by 2030 (raised from 14% in the prior cycle), which remains the reference point for discussing ambition and progress. Within the NDC 3.0 narrative, Jordan reports that by 2024 it had already achieved 24.8% of its pledged 31% reduction, using this as evidence of delivery capacity and as a platform for scaling ambition. The mitigation emphasis in NDC 3.0 is therefore focused on how Jordan plans to move beyond its current pledge through conditional pathways. The document indicates that conditional targets may aim to exceed the 31% threshold if international partnerships materialise, pointing to higher-cost levers such as green hydrogen, advanced storage, high-performance building standards, and industrial efficiency. It also signals that the unconditional contribution may exceed 5%, associating that domestic share with accelerated electric mobility, distributed solar, storage, and related urban measures, and frames the NDC process as a basis for embedding a 2050 net-zero trajectory in sector strategies.

European Union. The EU's NDC is filed as a single joint submission, dated 5 November 2025, made 'by the Danish Presidency of the Council of the European Union and the European Commission on behalf of the European Union and its Member States'. The same joint NDC is catalogued under individual Member State entries in the UNFCCC registry, but the underlying instrument is the single EU text. The submission itself is structured into four parts: background, the NDC, a short update on progress, and a transparency annex (‘Information to facilitate Clarity, Transparency and Understanding’, ICTU), where many of the technical definitions and scope details are spelt out. The 2030 element is the familiar anchor: a net domestic reduction of at least 55% in greenhouse gas emissions by 2030 compared with 1990. The wording carries several signals. First, it is anchored to an absolute historical baseline (1990), which is the standard reference point for EU climate targets. Second, it is explicitly ‘net’ and ‘domestic’. In the NDC’s own background section, the EU links this 2030 target to the European Climate Law adopted in 2021, noting that the law confirmed the domestic reduction of net emissions by at least 55% by 2030 as legally binding. In plain terms, the EU is presenting 2030 as a fixed waypoint that EU legislation has already operationalised, rather than as a political aspiration that still needs to be converted into rules.

‘Net’ is important because the EU is not talking only about gross emissions from energy, transport, buildings, industry, agriculture, and waste. It also accounts for removals that reduce the net balance. This is exactly how the EU defines its mid-century endpoint in law: emissions and removals regulated in EU law must be balanced within the Union by 2050, which is what ‘net zero’ means in this context, and the EU should aim to achieve negative emissions thereafter. The ICTU section of the NDC also makes clear that the contribution is economy-wide and includes the land-use and forestry sector (LULUCF) alongside the standard inventory sectors, which is one of the concrete ways in which ‘net’ is implemented in practice. The NDC also provides a clear statement of scope and coverage, which helps when comparing it with non-EU Mediterranean NDCs, which are often framed as BAU deviations or conditional pledges. In the ICTU annex, the EU lists the gases covered (CO_2, CH_4, N_2O, and the main fluorinated gases, including NF_3) and explicitly references the inclusion of LULUCF. It also states that the EU NDC is an absolute, economy-wide greenhouse gas emissions reduction target, which is a meaningful methodological signal: the headline is not a sectoral pledge, not an intensity target, and not a BAU reduction claim.

The 2035 figure (an indicative range of 66.25% to 72.5% net reduction vs 1990) is best understood as a bridge between a binding 2030 milestone and the next binding milestone that the EU is putting in place for 2040. The EU explicitly states that this range is based on linear trajectories: one runs from 2030 to the 2050 climate-neutrality objective, and the other runs from 2030 to the Council’s position for a 90% net reduction by 2040. That is why it is a range rather than a single point. The ‘indicative’ wording is also deliberate: it signals direction and consistency with the EU’s post-2030 legislative pathway, without claiming that 2035 itself is the legally binding anchor. The same logic also connects to the EU’s evolving approach to international cooperation: the Council’s post-2030 framework discussions include allowing, from 2036 onwards, a limited use of high-quality international credits as a contribution toward the 2040 target (while keeping the bulk of the reduction domestic), and the NDC notes that the origin and quality conditions for any such credits would be regulated in EU law.

Serbia. Serbia's updated Nationally Determined Contribution (NDC 2.0, August 2022) sets an economy-wide target of a 33.3 % reduction in GHG emissions by 2030 relative to 1990 (excluding LULUCF), tripling the ambition of its first NDC (9.8%). The 2024 Integrated National Energy and Climate Plan raised this to a 40.3% reduction, including LULUCF, and national emissions are already about 24.8% below 1990 levels (Government of the Republic of Serbia 2022; Republic of Serbia 2024; EEA 2025). As an EU candidate and Energy Community Contracting Party, Serbia is progressively aligning its climate and energy legislation with the EU acquis.

Serbia's mitigation challenge is structurally defined by a coal- and lignite-dominated power system (notably the Kolubara and Kostolac complexes), which concentrates emissions in a small number of significant assets. The principal mitigation levers are therefore coal phase-down, accelerated deployment of renewables (wind, solar and hydropower) and energy-efficiency improvements, supported by the Low Carbon Development Strategy (2023–2030). Carbon pricing is still under development; as a CBAM-exposed economy, Serbia has debated introducing a carbon tax or ETS-compatible instruments, but no economy-wide carbon price is in force yet (Energy Community Secretariat 2024). Implementation feasibility depends heavily on financing for the power-sector transition and on administrative capacity.

Slovenia. As an EU Member State, Slovenia's mitigation efforts are governed by the EU's collective NDC and implemented through the EU ETS and the Effort Sharing Regulation (ESR). Its 2030 ESR obligation is a 27% reduction in non-ETS emissions relative to 2005, with the updated National Energy and Climate Plan setting a marginally higher national ambition of at least 28% (Regulation (EU) 2023/857; European Commission 2024). The assessed centre of gravity for Slovenian decarbonisation is the power sector: a planned complete coal exit by 2033, anchored on the staged phase-out of the lignite-fired Šoštanj plant, is the single most consequential mitigation lever *(high confidence)*, with the Krško nuclear plant (shared with Croatia) and hydropower providing a considerably low-carbon baseload around which renewable expansion (solar, hydro, biomass), energy efficiency, and a possible extension of nuclear capacity act as complementary levers. Transport is assessed as the principal structural constraint on compliance, with sectoral emissions persistently lagging the required trajectory *(high confidence)*. On current evidence, Slovenia is not on track to meet its 2030 ESR target under existing measures, and even with additional measures, projected reductions only approach the target rather than clearly exceeding it, so attainment remains contingent on full and timely implementation of planned measures *(medium confidence)* (EEA 2025).

Tunisia. Tunisia's most recent entry in the UNFCCC NDC Registry (submitted on 22 September 2025) shares preliminary elements of NDC 3.0 ahead of COP30, outlining the mitigation architecture and the main quantitative milestones. The mitigation target remains framed in terms of carbon intensity (GHG emissions relative to GDP), with 2010 as the reference year, covering the main IPCC sectors (Energy, AFOLU, Industrial Processes, Waste) and gases such as CO_2, CH_4, N_2O, and HFCs. The headline mitigation objective is a 62% reduction in carbon intensity by 2035 vs 2010, defined over 2026–2035, and split explicitly into 31% unconditional and an additional 31% conditional on international support.

Tunisia also provides an intermediate mitigation waypoint for 2030, targeting a 46.2% reduction in carbon intensity vs 2010, with an unconditional 28% component. To translate the intensity framing into emissions magnitudes, the submission indicates that net emissions will fall from about 35 Mt CO_2eq (2010) to about 24 Mt CO_2eq (2035). It estimates that around 152 million t CO_2eq of cumulative avoided net emissions will be achieved over 2026–2035 relative to BAU, with most reductions attributed to the energy sector. On the investment side of mitigation delivery, Tunisia quantifies the mitigation envelope at about USD 25.55 billion within a total climate finance estimate of about USD 54.52 billion for 2026–2035.

The Mediterranean's mitigation strategy is driven first by the rapid decarbonisation of the power sector. Solar and wind resources across the region are among the strongest in the world, making renewable electricity the backbone of the transition. High solar irradiance across southern Europe, North Africa, and the eastern Mediterranean enables highly competitive deployment of utility-scale photovoltaics (PV), with average GHI exceeding 2,000 kWh m^{-2} yr^{-1} and PV yields surpassing 1700 kWh kWp^{-1} in key locations (Hajou and El Mghouchi 2025).

While PV is already well established in the region, several other strategic technologies must be reinforced and replicated to accelerate decarbonisation, including those that enhance system flexibility, provide dispatchable renewable power, and optimise the use of existing water and land resources.

Concentrating Solar Power (CSP) technology. Concentrating Solar Power (CSP) stands out as a strategic mitigation technology in the Mediterranean because it delivers firm, dispatchable renewable electricity using molten-salt thermal storage, enabling 6–8 hours of generation after sunset. Mediterranean CSP plants, most notably Morocco's Noor complex, combine parabolic trough and central-tower technologies to provide stable output that complements variable PV and wind, directly supporting grid reliability (Azouzoute et al. 2020). Advanced hybrid CSP–PV configurations demonstrated in recent regional assessments enhance system flexibility and reduce intermittency by integrating high-efficiency solar thermal storage with daytime PV production (Jbaihi et al. 2022). Given the region's high direct normal irradiance (DNI), CSP functions as one of the Mediterranean's most effective low-carbon technologies for replacing fossil-fuel peaking plants and securing renewable baseload power.

Offshore and Floating Renewable Technologies (FOW) (Marine Zones). Wind energy forms another essential pillar of mitigation, with more than 80 GW already installed in Mediterranean countries. The region's next frontier is Floating Offshore Wind (FOW), ideally suited to its deep maritime zones. Techno-economic analyses indicate that FOW can provide competitive energy costs while delivering major emission reductions, provided that marine spatial planning and ecological considerations are properly addressed (Avesani 2025; Travaglini et al. 2024).

Floating Photovoltaics (FPV) on Reservoirs: Interesting technology for the Mediterranean. A particularly innovative technology is Floating PV (FPV) deployed on dams and reservoirs. FPV simultaneously addresses energy production and water scarcity, a pressing issue in Mediterranean and semi-arid regions. Reservoir-scale studies show that FPV can reduce evaporation losses by nearly 50% at the Aswan High Dam (Ilgen 2024), and by up to 60% in Brazil's Passaúna Reservoir under certain configurations (Santos et al. 2022). Modelling research further confirms that FPV can maximise energy output while conserving water, as long as ecological thresholds—such as light penetration and aquatic habitat integrity—are respected (Farrar 2022). With existing grid connections, minimal land conflicts, and clear climate-water co-benefits, FPV represents an emerging flagship mitigation technology for the Mediterranean.

Green hydrogen technologies: interesting but challenging for the Mediterranean. Green hydrogen is rapidly gaining traction as a long-term decarbonisation vector for the region. Produced via electrolysis powered by solar and wind electricity, hydrogen offers a clean alternative for decarbonising heavy industry, fertilisers, chemicals, steel, and long-distance transport. Countries such as Morocco, Spain, Egypt, and Italy have adopted national hydrogen strategies to position the Mediterranean as a major supplier to growing European markets. The region's exceptional renewable resources and geographic proximity give it a competitive advantage, but challenges remain, including high electrolyser capital costs, the need for desalination in water-scarce regions, and limited transmission capacity for large-scale hydrogen clusters (IEA 2023; IRENA 2022).

Energy efficiency and low-carbon buildings. Technological solutions include deep renovation of building envelopes, improved insulation, solar shading, and passive design strategies. Studies show that optimising building orientation and envelope performance and integrating Building-Integrated Photovoltaics (BIPV)—solar modules incorporated directly into façades, roofs, or shading elements—can significantly reduce cooling loads and total energy consumption in Mediterranean climates (Vassiliades et al. 2024). At the urban scale, Energy Performance Certificate (EPC) based analyses in Valencia demonstrate that targeted renovation of priority districts can deliver substantial and cost-effective GHG reductions (Manso-Burgos et al. 2023). Digital solutions such as smart controls and AI-driven building energy management further enhance efficiency without requiring major structural interventions (Hajou et al. 2024).

Sustainable mobility technologies. Mediterranean cities are increasingly shifting toward low-carbon mobility technologies to cut transport emissions and improve urban air quality. Key technological solutions include the electrification of public transport fleets (e-buses, electric rail, charging infrastructure), deployment of smart mobility systems that optimise traffic and fleet management, and digital platforms that integrate multimodal transport options. These technologies are complemented by infrastructure-based mitigation tools such as metropolitan cycling networks, micro-mobility systems, and Low-Emission Zones (LEZs), which rely on real-time emissions monitoring to restrict high-polluting vehicles. Evidence from the Barcelona Metropolitan Area shows that superblocks, green corridors, and integrated cycling networks supported by digital mobility data reduce car dependency, lower CO_2 emissions, and improve public health outcomes (Sifuentes-Muñoz et al. 2025). Regional initiatives such as the Montpellier Declaration further underline the need for data-driven mobility technologies, from emissions tracking to digital route optimisation, to support effective and equitable decarbonisation across Mediterranean cities (Covenant of Mayors Europe 2023; MedCities 2022).

Table 5.11 | Illustrative case studies. Source: Mediterranean, between 2020 and 2025.

Location and site	Technology and approach	Key Results	Lessons learned	References
Sardinia (Italy)	Floating Offshore Wind (FOW)	• Competitive LCOEs at high-wind sites. • Several hundred kt CO_2 avoided. • Environmental risks require monitoring.	• FOW viable in deep Mediterranean waters. • Requires grid and port upgrades. • Spatial planning must consider ecological constraints.	Travaglini et al. (2024); Avesani (2025)
Valencia (Spain)	Building renovation + distributed PV/BIPV	• Deep retrofits significantly cut emissions. • Distributed PV reduces energy poverty.	• EPC-based mapping effective for renovation planning. • Combining renovation + PV maximises impacts. • Replicable in other Mediterranean cities.	Manso-Burgos et al. (2023); Vassiliades et al. (2024)
Barcelona Metropolitan Area (Spain)	Urban sustainable mobility: Superblocks, LEZ, cycling network	• Lower transport emissions. • Improved air quality and health. • Strong modal shift to active mobility.	• Urban redesign is powerful for mitigation. • LEZs require strong governance. • Cycling networks need metropolitan coordination.	Sifuentes-Muñoz et al. (2025); Covenant of Mayors Europe (2023)
Ouarzazate, (Morocco) (Noor Complex)	Concentrating Solar Power (CSP): parabolic trough + tower + storage	• >500 MW CSP with storage. • Dispatchable renewable electricity. • Major CO_2 reductions. • Supports Morocco's 52% RE target.	• Storage enables night-time supply. • Multiple CSP technologies increase reliability. • Large land footprint requires environmental planning. • PPP models accelerate deployment.	Azouzoute et al. (2020); Jbaihi et al. (2022)

5.2 Carbon removal and sequestration

Key messages

- Carbon removal can complement rapid emissions reductions. Their mitigation contribution depends on deliberate actions that deliver additional, durable and verifiable carbon storage or removal *(high confidence).*
- Monitoring and verification technologies, including field measurements, inventories, remote sensing, modelling and data assimilation, are essential for quantifying carbon stocks, fluxes, storage duration, uncertainty, and ecological side effects *(high confidence)*.
- Mediterranean terrestrial, coastal and marine ecosystems can support mitigation through carbon sequestration and storage, but they are also vulnerable to climate change and anthropogenic pressures. Governance must therefore protect ecosystem integrity and long-term carbon storage capacity under climate stress. *(high confidence).*
- Effective mitigation portfolios balance land-based measures (soils, trees, wetlands) with coastal and marine actions and use technology where it strengthens measurement and accountability. *(medium confidence).*

Aims: This section assesses mitigation-oriented carbon removal and sequestration options in the Mediterranean, focusing on management actions that protect, improve, or create additional, durable carbon storage or removal.

- Presents monitoring, reporting and verification approaches for carbon uptake, storage, sequestration and removal across terrestrial, coastal and marine systems, and how it can support credible accounting of carbon sequestration
- Explores the effectiveness of carbon sequestration through reforestation, soil management, land-based and coastal and marine-based strategies, as well as technological solutions.
- Addresses synergies and benefits to ecosystems, to ecosystem services, and to humans

5.2.1 Monitoring, reporting and verification of carbon sequestration in land, coastal and marine systems

Key messages

- Greenhouse gas monitoring is uneven across gases and sectors. CO_2 fluxes are well-covered at research sites, but monitoring of methane and nitrous oxide remains limited, especially in croplands and wetlands. This gap restricts countries' ability to design effective mitigation measures or participate confidently in carbon markets (*high confidence*).
- Carbon removal monitoring quality varies strongly by land system, with forests and shrublands having the most advanced disturbance-sensitive monitoring, croplands having strong SOC but weak N_2O coverage, and rangelands and wetlands remaining data-poor (*high confidence*).

As presented in Chapter 2, terrestrial, coastal and marine carbon uptake in the Mediterranean region is a key component of the carbon cycle and of climate-regulating processes. However, as further discussed in Chapter 3, these processes and the ecosystems that support them are vulnerable to climate change and anthropogenic pressures. Maintaining the integrity and functioning of these ecosystem services is therefore essential to avoid weakening their contribution to mitigation and to preserve their capacity to sequester carbon. Reaching climate mitigation targets can only be achieved by complementing emission reductions with negative emissions through carbon removals and sequestration.

The effectiveness of these mitigation services depends on interventions that protect, restore, or increase carbon storage or removal in a measurable, long-term way.

Moreover, assessing terrestrial and marine mitigation value requires understanding the magnitude of the processes involved, their scalability, their permanence over time, and their vulnerability to leakage, reversal or ecological disturbance. Robust technologies and tools are therefore essential for implementing these measures, monitoring their performance, verifying their outcomes, and certifying their effectiveness through credible MRV systems.

5.2.1.1 Land-based carbon monitoring

Across the Mediterranean, land-based MRV relies on a hybrid system that combines inventory-centred stock accounting under UNFCCC and IPCC guidelines with targeted flux observations (primarily CO_2 from eddy-covariance towers and selective CH_4 and N_2O measurements) and Earth-Observation-based mapping of biomass structure, disturbance and soil condition. CO_2 fluxes are comparatively well observed across research sites, while CH_4 observations remain limited to a small number of wet or organic soils, and N_2O is still considerably inferred from emission factors.

Aboveground biomass (AGB) in forests, shrublands and orchards is derived from national forest inventories (NFI) and EO-assisted maps. Over the past five years, research teams from across the Mediterranean have used GEDI LiDAR (canopy height and structure) and SAR (Sentinel-1; PALSAR-2) to improve AGB estimation in Mediterranean canopies and tree-crop mosaics. Plot allometry remains the calibration backbone. (Borsah et al. 2023; Velasco-Pereira et al. 2023; Xu et al. 2024; Contreras et al. 2025).

Soil organic carbon (SOC) stocks across Mediterranean land systems are derived mainly from field sampling and laboratory analysis following UNFCCC and IPCC guidance, providing depth-resolved measurements and bulk density required for national reporting (IPCC 2022b). EO and ML approaches do not measure SOC directly but support interpretation via salinity, soil moisture and vegetation-condition indicators, which help identify SOC-vulnerable areas under irrigation and drought stress (Stavi et al. 2021; Wang et al. 2024). Recent applications in Tunisia and the Nile Delta demonstrate the use of multi-temporal salinity mapping to guide SOC sampling and target high-risk parcels (Mohamed et al. 2023; Saad et al. 2024). Adoption is uneven: EU countries primarily use EO for stratification, whereas non-EU administrations increasingly rely on FAO SEPAL and Open Foris to integrate these indicators into land-monitoring workflows (FAO 2025). EO cannot replace sampling because it provides no depth or bulk-density information, and SOC–proxy relationships remain site-specific.

Flux measurements across the Mediterranean focus primarily on CO_2, with exchange processes such as net ecosystem exchange (NEE) and net biome production (NBP) routinely observed at research sites using eddy-covariance.

CH_4 monitoring across the Mediterranean is highly selective and is significantly restricted to wetland and organic-soil ecosystems, which occupy only a small fraction of the region. Long-term measurement records from these sites show clear time-dependent CH_4 dynamics following rewetting, with emissions typically declining over approximately 13 to 16 years as ecosystems transition from post-drainage recovery toward more stable hydrological conditions (Kalhori et al. 2024). However, such long-term CH_4 datasets are rare, and the spatial coverage of CH_4 flux measurements remains very limited at the Basin scale. Nitrous oxide (N_2O) monitoring is even sparser: in most Mediterranean croplands, N_2O emissions continue to be inferred from emission factors used in national greenhouse-gas inventories, rather than measured directly. Direct N_2O flux observations—obtained through flux towers or chamber networks—are available only at a small number of experimental or research stations, reflecting gaps in measurement capacity and infrastructure across both EU and non-EU regions (Nemitz et al. 2018; Nicolini et al. 2024).

Monitoring relies on *in situ* networks, where plot inventories (biomass and structure), soil sampling (SOC) and Eddy-covariance towers provide data 'on the ground', as well as remote sensing.

Disturbance monitoring across the Mediterranean relies heavily on Earth Observation (EO) time-series data, which are widely used to track the occurrence, severity, and spatial extent of wildfires, as well as the subsequent vegetation recovery.

Overall, EO provides the main spatiotemporal backbone for land monitoring in the Mediterranean, complementing in situ inventories and flux networks. Sentinel-1 and Sentinel-2 support consistent mapping of vegetation condition, soil-moisture stress and disturbance (EEA 2024). Active sensors such as GEDI LiDAR and SAR missions (ALOS-2/PALSAR-2) improve estimates of canopy structure and above-ground biomass (Velasco-Pereira et al. 2023; Xu et al. 2024; Contreras et al. 2025). UAV data provide fine-scale calibration and validation (Gomez-Casanovas et al. 2023).

Parcel-level geolocation capacity varies: EU countries rely on LPIS and IACS, while non-EU countries increasingly use SEPAL and Open Foris for land-cover monitoring and UNFCCC-aligned reporting (EEA 2024; FAO 2025).

Modelling frameworks integrate EO, plot and flux data to produce spatially explicit carbon budgets. Coupling EO with ecosystem and growth models, and with indices such as PRI, improves GPP and NPP estimation (Chirici et al. 2022; Bartkowiak et al. 2024; Chiesi et al. 2005). Dynamic Global Vegetation Models (e.g. ORCHIDEE, JSBACH) assimilate biomass, SOC and disturbance information to generate consistent carbon-cycle estimates, particularly in data-sparse regions (IPCC 2022b).

Model-assisted upscaling for Tier-2 and Tier-3 inventories is expanding but remains uneven, with many countries still relying on Tier-1 emission factors (EEA 2024). Full uncertainty-propagating MRV chains linking parcels, EO and models are emerging but not yet widespread (IPCC 2022b). EO-driven disturbance metrics (fire, drought) and cropland modelling (e.g. SOC responses to irrigation and salinity) further support operational assessments (Mohamed et al. 2023; Saad et al. 2024).

Box 5.2: What monitoring looks like on the ground

Forests and shrublands (fire-exposed)
In Mediterranean forests and shrublands, the main MRV challenge is a temporal mismatch between disturbance events and national reporting cycles. Fire, drought and partial canopy loss often occur more rapidly than the intervals at which biomass is re-measured, leading to systematic under- or over-estimation of stock changes even when EO disturbance layers are available (IPCC 2022a; JRC 2024). On the ground, reconciling stand-level canopy losses with parcel-based reporting is particularly difficult in open-canopy systems, where small disturbances propagate laterally and are not easily captured in standard forest-inventory designs (Velasco-Pereira et al. 2023; Xu et al. 2024).

Croplands (SOC change, N_2O uncertainty, irrigation and agrivoltaics)
In Mediterranean croplands, the dominant MRV constraint is attribution rather than measurement. SOC trajectories are strongly influenced by rapid shifts in irrigation intensity, fertiliser regimes, crop rotations, and salinity build-up, which evolve faster than typical soil-sampling intervals, making the rate of SOC change difficult to quantify with confidence (Stavi et al. 2021; Wang et al. 2024). Nitrous oxide (N_2O) uncertainty becomes most visible at field scale: farmers frequently adjust fertiliser doses and irrigation scheduling in ways not captured by national activity data, producing significant divergence between assumed emission factors and real emissions (Nemitz et al. 2018; Nicolini et al. 2024). Agrivoltaic systems add an additional layer of complexity: co-located photovoltaic structures alter microclimate, shading and soil-moisture patterns, improving water-use efficiency but creating non-linear SOC and N_2O responses that are not reflected in current reporting frameworks (Gómez-Casanovas et al. 2023; Fernandez-Solas et al. 2023; Scarano et al. 2025).

Rangelands and semiarid systems
MRV uncertainty is highest in Mediterranean rangelands due to extreme spatial heterogeneity and rapidly shifting shrub–grass mosaics. Degradation, partial recovery, and erosion processes occur along topographic gradients, drainage lines, or livestock movement corridors, which do not align with parcel boundaries and can generate considerable upscaling errors when sparse ground sampling or coarse EO inputs are extrapolated (IPCC 2022a; Toreti et al. 2024). Flux towers are rare in these systems, making it difficult to attribute carbon-cycle variations to drought, heat extremes or land-use pressures. SOC signals are often overwhelmed by surface-erosion redistribution, a process significantly invisible to standard inventory methods.

Agroforestry mosaics (tree–crop systems)

The central MRV difficulty in agroforestry systems arises from structural complexity. Multilayered canopies and frequent management interventions—pruning, thinning, re-spacing—introduce year-to-year variation in above-ground biomass that is larger than long-term trends yet poorly captured by standard inventory cycles. While EO (LiDAR/SAR) improves structural estimation, field experience shows that management shocks dominate carbon balance in many olive, almond and mixed tree–crop systems, and these are rarely recorded in national activity data (Contreras et al. 2025; Xu et al. 2024).

Wet and organic soils

For Mediterranean wetlands and organic soils, carbon monitoring is limited less by carbon measurements and more by hydrological uncertainty. Water-table depth (WTD) can vary over hours, yet most MRV relies on infrequent manual readings or proxies, making it difficult to distinguish real emission changes from short-term hydrological oscillations (UNEP 2025). Small on-farm hydrological interventions—ditch cleaning, unrecorded drainage, temporary pumping—have disproportionate effects, often shifting a parcel from sink to source or vice versa (Bowen et al. 2024). These 'micro-actions' are rarely documented but have major implications for permanence assessments, especially where long-term CH_4 trajectories following rewetting are used in reporting (Kalhori et al. 2024).

5.2.1.2 Blue carbon sink monitoring

At the global scale, the ocean absorbs about 23% of anthropogenic CO_2 emissions through air–sea gas exchange (Canadell et al. 2021) and stores part of this carbon through physical and biological processes. However, long-term sequestration occurs only when carbon is transferred to reservoirs that are isolated from atmospheric exchange over centennial to millennial timescales (Canadel et al. 2021; Friedlingstein et al. 2024). In the Mediterranean Sea, available evidence indicates that the basin is a weak net CO_2 sink, with net uptake of approximately 4–7 Tg C yr^{-1}. However, estimates remain uncertain due to limited observations and strong spatial and seasonal variability (Cossarini et al. 2021). While the open-sea sink contributes substantially to the regional carbon budget, Blue Carbon Ecosystems (BCEs) provide higher carbon sequestration rates per unit area than the open-ocean biological carbon pump. They can be enhanced through protection, restoration, and improved management (Zunino et al. 2026).

'Blue carbon (BC) sink' refers to coastal ecosystems that sequester atmospheric CO_2 and store it over relevant temporal scales, playing a key role in mitigating climate change (Macreadie et al. 2019). The ecological processes underlying carbon sequestration are closely linked to the ability of these systems to remain functional under changing environmental conditions, thereby linking their contribution to climate change mitigation to their role in enhancing adaptation (Serrano et al. 2019).

Substantial declines in BC ecosystems have been reported globally (*high confidence),* Lopes et al. 2021; Ren et al. 2024; Ju et al. 2025), prompting intensified efforts to systematically collect spatial and temporal data worldwide (Fabbrizzi et al. 2020; Jiang et al. 2022). (see Chapter 3). However, effective monitoring remains challenging due to logistical constraints and high costs (*high confidence).* In-field carbon budget monitoring relies on measurements of carbon flux and carbon stock. Flux measurements offer process-level insights essential for understanding carbon-cycle dynamics. In contrast, stock measurements capture annual-to-multi-annual changes but lack the temporal resolution needed to resolve seasonal patterns or identify the contributions of specific processes (Tang et al. 2018). Recent advances in remote sensing, ecological modelling and integrative monitoring frameworks have substantially improved the capacity to quantify carbon stocks, carbon fluxes and ecosystem status across extensive areas (Tang et al. 2018; Pham et al. 2019). As in forest ecosystems worldwide (Goetz et al. 2009), remote sensing-based approaches have proven highly suitable for mapping and monitoring BC ecosystems (Hossain et al. 2015; Pham et al. 2019), providing extensive spatial coverage, high repeatability, reduced costs, and increasing precision (Pettorelli et al. 2018), especially through multispectral, hyperspectral, LiDAR, and drone-based platforms. Among BC ecosystems, these techniques are most widely applied in salt marshes, seagrass meadows, macroalgal forests, and mangroves. Still, they can also be adapted to coralligenous reefs and maerl beds, albeit with additional methodological challenges *(medium confidence)*. Furthermore, modelling approaches are increasingly used to extrapolate fluxes and predict future trajectories under climate and land-use change scenarios, especially where observational datasets remain spatially limited (Martin et al. 2014). Integrating remote sensing data, modelling and in situ observations can provide a more comprehensive and reliable assessment of BC ecosystem extent, carbon stocks, and sequestration dynamics across spatial and temporal scales *(high confidence)*.

In this context, the ESA Coastal Blue Carbon Project integrates ESA satellite imagery and other remote sensing data with *in situ* observations from selected pilot sites where knowledge and databases on carbon storage in BCEs already exist, to improve monitoring and carbon accounting.

In the Mediterranean Sea, among the most dominant BC ecosystems are seagrass meadows, particularly *Posidonia oceanica* and *Cymodocea nodosa,* which can store substantial organic carbon in both biomass and sediment deposits (Hendriks et al. 2022). *Posidonia oceanica*, a priority habitat under the EU Habitat Directive (92/43/CEE), forms extensive meadows that can accumulate organic-rich deposits, such as leaf sheaths, rhizomes and root detritus, beneath the canopy, in the matte, capable of storing one of the highest sedimentary carbon stocks among seagrasses worldwide (Serrano et al. 2016). The mean total carbon fixation of *Posidonia oceanica*, including blades, sheaths, and rhizomes, ranges from 33.5 to 426.6 g C m^{-2} per year. The mean carbon sequestration (long-term carbon sequestration within the matrix) ranges from 7.7 to 84.4 g C m^{-2} yr^{-1}, both with a clear decline with increasing depth, reflecting the reduction in meadow density in deeper areas (Pergent-Martini et al. 2021). Monitoring Mediterranean seagrass meadows relies on standardised field protocols that include shoot density counts, permanent transects for depth-limit assessment, matte coring, and leaf biometry (Pergent-Martini et al. 2005). These methods are increasingly complemented by remote sensing tools such as multispectral and hyperspectral satellite imagery, acoustic mapping, and UAV-based photogrammetry (Marre et al. 2020; Rende et al. 2020; Tomasello et al. 2020; Ventura et al. 2020). Although generally less studied than seagrass meadows in the context of blue carbon, coralligenous reefs in the Mediterranean are increasingly recognised for their potential contribution to long-term carbon storage and climate regulation (Coppari et al. 2019). Coralligenous habitats receive targeted and robust legislative protection via the Marine Strategy Framework Directive 2008/56/EC, as they support high biodiversity and enhance ecosystem resilience, contributing to climate adaptation functions *(high confidence).* Monitoring these habitats remains methodologically challenging because of their structural complexity and depth distribution *(high confidence)*. Current approaches rely on integrated in situ surveys, photogrammetry, acoustic mapping, remotely operated vehicles (ROVs), and high-resolution imaging techniques *(high confidence)*. Despite increasing research efforts, quantitative estimates of carbon sequestration and long-term carbon storage in coralligenous habitats are still limited compared with other BC ecosystems (*medium confidence*).

Overall, given the accelerating loss of BC ecosystems, large-scale, long-term monitoring programs are crucial for supporting conservation, restoration, and evidence-based decision-making.

5.2.2 Land-based strategies for carbon removal

Key messages

- Carbon farming practices have the potential to increase soil organic carbon in Mediterranean mineral soils (*medium confidence*), although the balance between carbon stabilisation and decomposition is expected to respond unpredictably to intensified aridity.
- Tree planting and improved forest management can enhance carbon removal in Mediterranean landscapes, but their long-term effectiveness is strongly limited by drought, wildfire and management choices (*high confidence*).
- Mediterranean wetlands are decreasing; peatlands store significant amounts of carbon and should be managed and restored to avoid carbon losses (*high confidence*).

Following the approach of the European Carbon Removal and Carbon Farming Regulation (Regulation (EU) 2024/3012), land-based strategies for carbon sequestration encompass activities related to agriculture and agroforestry on mineral soils, tree planting, and the rewetting and restoration of wetlands. These activities refer to carbon farming, which has been defined as ‘the management of land-based GHG fluxes, including carbon pools and flows in soils, materials and vegetation, to reduce emissions and increase carbon removal and storage' (Nyssens 2021). This section focuses on the potential of carbon farming for increasing carbon removal in the Mediterranean region.

Agriculture and agroforestry on mineral soils

The soil carbon pool is the largest terrestrial carbon reservoir, with organic carbon representing approximately half of it. Net primary production (NPP) and the addition of organic amendments play a central role in the accumulation of soil organic carbon (SOC). In Mediterranean regions, NPP is inherently constrained by scarce rainfall and high evapotranspiration. Furthermore, SOC dynamics are highly climate-sensitive, and the balance between stabilisation and decomposition is expected to respond in unpredictable ways to the projected intensification of aridity. The potential increase in SOC in countries with Mediterranean climate (including Spain, Portugal, Greece, Morocco, Tunisia, California, south Australia, and southern France) in relation to carbon farming practices was estimated to be 29% by a meta-analysis conducted on 209 cases derived from 90 studies (Andrés et al. 2025).

A comprehensive, scientifically tested overview of the effects of farming practices on the environment at the European scale, including carbon sequestration in agricultural soils, greenhouse gas (GHG) balances, and soil fertility, is available in the JRC Farming Practices Evidence Library (Schievano et al. 2025).

Unfortunately, the database for the Mediterranean countries is not very extensive, and changes in SOC are difficult to assess due to the significant heterogeneity of the SOC pool, the long time required to detect changes, and the temporal scale of monitoring (Poeplau et al. 2022). Overall, agricultural and agroforestry carbon farming practices include increasing plant diversity, organic fertilisation, reduced tillage, and agroforestry.

5.2.2.1 Increasing plant diversity

Increasing plant diversity through crop rotation involves growing different crop species in a defined order over time. Mediterranean croplands are dominated by cropping systems based on winter cereals, summer-irrigated crops, forage-based systems, and mixed successions with periods of bare fallow. While summer fallowing can preserve soil moisture, release nitrogen from crop residues to promote growth in subsequent seasons and control weeds, excessive fallowing can lead to soil degradation and SOC losses. Alternatives to cereal–fallow monoculture include diversified cropping systems incorporating annual legumes, oilseeds and a variety of vegetables. Rotation can affect the entire cropping area and can also be organised within strip rotations. Data on the specific effects of crop rotation on SOC are difficult to interpret, since many other components of cropping systems, such as tillage regimes, fertilisation levels, and species types, are usually included in field trials and monitoring schemes. The positive effects of combining crop rotation with reduced tillage have been observed throughout the Mediterranean region (Jaziri et al. 2022; Mancinelli et al. 2023).

Increasing plant diversity can also be achieved by growing cover crops. Cover crops are intended to protect the soil and provide several ecosystem services, including weed control, pest and disease regulation, water supply and plant and soil biodiversity. Globally, cover crops have been shown to increase SOC compared to controls without cover crops (He et al. 2025; Jian et al. 2020; Poeplau and Don 2015). Global estimates indicate an average SOC increase of 4 to 15%, although several factors influence the effects of cover crops on SOC. Cover crop management, planting and termination date (i.e. growing window), annual cover crop biomass production, and soil clay content are among the main predictors of SOC response to cover cropping (McClelland et al. 2020). In particular, cover crop biomass production determines the amount of C input to the soil and is strongly related to the growing window and species selection (i.e. single species vs mixtures, mostly of grasses, legumes, and brassicas), and is expected to be negatively affected by increased aridity in the Mediterranean.

In the Mediterranean region, cover crops are most often found intercropped with woody crops, such as vineyards and olive and almond orchards, as permanent soil covers. Their inclusion in the rotation cycle of cereal crops during fallow periods between catch crops is also increasing. In general, perennial intercropped cover crops increase SOC stocks by 10% compared with conventional management. The SOC storage rate is in the range of 0.49 t C ha^{-1} yr^{-1} for a 20-year projection scenario for vineyards, with lower values (0.27 Mg C ha^{-1} yr^{-1}) observed by some authors (García et al. 2018; Aguilera et al. 2013b). On average, the C sequestration rate is 1.09–1.35 times greater under cover crops than under conventional management, including tillage, for Mediterranean woody crops (Vicente-Vicente et al. 2016). However, SOC accrual in these perennial cover crops is slow and only occurs in the top layers of soil (Ruiz-Colmenero et al. 2011). Furthermore, a review of the literature on 28 woody Mediterranean crops revealed that the positive impact of cover crops on SOC is evident in sloping areas but not in flat areas. The authors concluded that this effect is more attributable to soil protection against erosion than to the addition of carbon to the soil under cover crops (Novara et al. 2019; López-Vicente et al. 2020).

There is less agreement about the effects of temporary cover crops on soil carbon stocks when used in herbaceous crops, including during the rotation cycle, in the fallow period between two catch crops. The type of rotation (e.g. cereals only or cereals plus legumes) and the method of cover crop termination (e.g. burndown, roller-crimping or harvesting, with or without tillage to incorporate residues into the soil, or green planting) have a significant impact on the supply of C to the soil from living or dead plants. When cover crop termination involves incorporating residues into the soil as green manure through tillage, SOC accretion is greater than when the residues are left on the soil surface (Adetunji et al. 2020). Adding to the complexity of estimating the effects of temporary cover crops, it is worth noting that, due to the close interrelationship between the carbon and nitrogen cycles, competition with main crops for nitrogen can negatively impact yield if the introduction of cover crops is not carefully planned (García-González et al. 2018; Celette et al. 2009). In terms of the GHG balance, soil C sequestration may be offset, or even outweighed, by increased soil nitrogen emissions (N_2O) (Lugato et al. 2018). Therefore, the impact of cover crops on GHG emissions should be evaluated using a holistic approach.

5.2.2.2 Organic fertilisation

Organic fertilisation includes green manuring (i.e. crops grown specifically to build and maintain soil fertility, such as cover crops and temporary leys), the addition of animal manure, and plant residues produced on-farm or off-farm. Furthermore, other types of biomass, such as municipal waste, green waste or sewage sludge, can be transformed into soil amendments through composting. By-products of energy production, such as digestates from anaerobic digestion and biochar from pyrolysis, are also being used (Diacono and Montemurro 2011; Garbowski et al. 2023).

Organic fertilisation is used in a wide range of agricultural practices and crop systems, making it difficult to provide a quantitative estimate of its effectiveness at sequestering carbon. However, there is *high confidence* that in the Mediterranean region it can result in an average SOC accrual of about 31% (Chen et al. 2018; Morugán-Coronado et al. 2020). A meta-analysis by Aguilera et al. (2013b) showed that SOC concentration increased by 19.2% and that the C sequestration rate was 0.97 Mg C ha^{-1} yr^{-1} with organic fertilisation compared to mineral fertilisation. Furthermore, this relative increase in SOC was greater under irrigation (25%) than under rainfed conditions (13%).

In terms of organic fertiliser type, animal manure shows limited and variable SOC gains when used alone, with more consistent increases when combined with cover crops. Compost amendments generally lead to larger and more stable increases in SOC, although reported magnitudes vary and are not yet representative of the region. Digestate can improve soil fertility, but associated GHG emissions may offset SOC benefits (Badagliacca et al. 2022). Overall, organic amendments can contribute to SOC enhancement. Still, their net mitigation effect depends on whole-system GHG balances and supply-chain considerations, with substantial variability across Mediterranean conditions (*medium confidence*).

Biochar, a by-product of pyrolysis-based energy production, is promoted as a biomass-derived amendment. Its supposed high stability is key to its usefulness in SOC sequestration and the main reason for its use. However, biochar stability in soil can vary significantly due to diverse climatic conditions, soil characteristics, agricultural practices and biochar properties (Gurwick et al. 2013). Globally, the addition of biochar is more effective than cover crops or conservation tillage for increasing SOC content across all climates, soil types, pH levels, and textures (Beillouin et al. 2023). However, its effect is most significant in tropical and subtropical climates and in low-input agriculture (Bai et al. 2019). This is not the case for Mediterranean agricultural soils, where no significant effects are expected for either crop production or SOC sequestration. In this sense, applying biochar to soil alone had no effect on SOC in Mediterranean olive groves, tomato fields and arable crops. Still, it was effective for C sequestration when blended with compost (Sánchez-Monedero et al. 2019). Despite its many benefits, a literature review of 259 studies warns of adverse effects of biochar on soil, including physicochemical changes, reduced agrochemical efficiency, and the presence of potentially toxic substances (Brtnicky et al. 2021).

5.2.2.3 Tillage

In the Mediterranean region, intensive tillage with heavy machinery remains commonplace. This process physically disturbs the upper soil layers, facilitating soil aeration and water infiltration, while also inhibiting weed growth. However, tillage also results in significant losses of SOC because it disrupts soil aggregates and exposes organic matter to direct microbial attack, therefore facilitating its decomposition. It can also damage soil structure and harm soil organisms, leading to degradation of soil quality (Six et al. 2000). Reduced tillage frequencies and depths, as well as no-tillage (NT), are gaining acceptance as they may allow SOC stocks to recover. However, no-till farming has been found to increase soil compaction, limit seedling emergence, and ultimately reduce plant production (López-Garrido et al. 2014), thereby reducing the amount of carbon returned to the soil. The results of most NT studies show an unclear positive effect on SOC stocks, which can increase in the top cm of the soil but often decrease below that depth, leading to a neutral effect on the topsoil as a whole (0–30 cm). This decline can be avoided by combining no-till with other measures, such as green manuring, cover crops and compost addition (Nicoloso et al. 2018).

It is difficult to assess the effects of changes in tillage regimes, as they often form part of integrated strategies that combine diverse practices. A meta-analysis of 174 datasets from 79 references showed that both reduced tillage and no-till can enhance SOC stocks under Mediterranean conditions, with no-till resulting in an average increase of 11.4% and a C sequestration rate of 0.44 Mg C ha^{-1} yr^{-1}. Under reduced tillage, SOC content increased by 15%, and the C sequestration rate increased by 0.32 Mg C ha^{-1} yr^{-1}. However, in this study, the increase in SOC caused by NT was influenced by the inclusion of data from woody crops, where NT resulted in a 22.9% decrease in SOC stocks, compared with an 18.2% increase in herbaceous crops (Aguilera et al. 2013b).

5.2.2.4 Agroforestry

Agroforestry systems integrate perennial woody vegetation (trees or shrubs) with crops, pastures and livestock, storing carbon in above-ground biomass and soils. These practices are very diverse but can be grouped into five classes: silvopasture, forest farming (including both natural and planted forests), riparian buffer strips, improved fallow, and multipurpose trees (Mosquera-Losada et al. 2018)

Using the LUCAS database, den Herder et al. (2017) estimated the total area of agroforestry in the EU27 to be 15.4 million hectares, accounting for 3.6% of the total area and 8.8% of the cultivated area. The largest absolute area of land devoted to agroforestry is found in Mediterranean countries, including Spain (5.6 Mha), France (1.6 Mha), Greece (1.6 Mha), Italy (1.4 Mha), Portugal (1.2 Mha), Romania (0.9 Mha), and Bulgaria (0.9 Mha). Many of these silvopastoral systems are long-established and locally adapted and add significant value to the cultural landscape. Examples include the *dehesa* in Spain, the *montado* in Portugal, *bocage* agroforestry in France and *wood pastures* in Romania and Hungary. In the Mediterranean zone, the carbon mitigation potential has been estimated at 0.51-27.8 Mt of carbon per year when considering only above- and belowground wood (Kay et al. 2019). Regarding soil, a meta-analysis by Chatterjee et al. (2018) found that transitioning from agricultural to agrisilvicultural or silvoarable systems increases SOC stocks by 17.1% and 1.4%, respectively. Conversely, transitioning from pasture to silvopasture reduces these stocks by 1.6%. SOC accrual mainly occurs in the top 20 cm of the soil profile.

Mediterranean agroforestry systems are generally characterised by low productivity and quality due to shallow soils, limited water availability and scarce nutrients. However, pasture productivity and soil organic carbon concentration can be increased by sowing a legume-rich mixture. Grazing management is also influential, with evidence that rotational grazing by cattle and sheep can increase SOC stocks compared to continuous grazing in the Mediterranean region (Díaz de Otálora et al. 2021; Carrascosa et al. 2024).

5.2.2.5 Planting of trees and forest management

Planting trees and improving forest management can contribute to carbon removal in the Mediterranean region. Still, their effectiveness depends on the species, water availability, fire risk, soil carbon dynamics, and management practices. Properly managed forests can act as long-term carbon sinks, while poorly designed afforestation projects may even lead to temporary soil carbon losses (Ruiz-Peinado et al. 2017; Marques et al. 2026). Three categories are considered here: (1) woody forest type plantations, (2) urban forest areas, and (3) natural forests and shrublands. In each case, there are considerable ranges in the potential for carbon capture, with a critical role for management, including the application of fertiliser and thinning or clearing. Also, the age distribution of species and the size of vegetated patches determine the ability to capture carbon for long-term storage.

Recent evidence from the Mediterranean region indicates that afforestation and reforestation with woody species can provide substantial carbon removal through biomass accumulation and, over longer timescales, soil carbon storage, particularly on degraded or abandoned agricultural land (*high confidence*). Studies from Spain and other Mediterranean landscapes show significant increases in above- and below-ground carbon stocks following the establishment of native tree species plantations. However, early soil carbon losses may partially offset biomass gains during the first decades after planting (Renna et al. 2024). Furthermore, recent assessments emphasise that mixed-species plantations, adaptive silviculture, and fire-resilient stand structures enhance both sequestration rates and the permanence of carbon storage under increasing climate stress (FAO 2025). However, the magnitude and durability of carbon removal remain strongly influenced by drought, wildfire, and management practices (Menéndez-Miguélez et al. 2025).

Urban and peri-urban forests are increasingly recognised as nature-based solutions for climate mitigation in Mediterranean cities, where tree planting contributes to atmospheric CO_2 removal while also providing cooling, improved air quality, and climate adaptation benefits (Guarino et al. 2024). Recent life-cycle assessments from Mediterranean urban environments demonstrate that urban forests become net carbon sinks over time (*high confidence*). However, the transition may require more than a decade because emissions associated with nursery production, irrigation, maintenance, and soil respiration can initially offset sequestration benefits (e.g. Manzini et al 2025 found that 13 years were needed before 170 planted trees in Florence, Italy, became net carbon sinks). Carbon removal performance varies substantially among species, management regimes, and water availability, with broadleaf species often exhibiting greater net climate benefits than conifers (Muscas et al. 2024).

Natural and semi-natural Mediterranean forests are a current carbon sink on annual timescales (*high confidence*). Recent regional assessments show that forest carbon stocks have increased, yet the strength of the forest carbon sink is increasingly threatened by drought, heatwaves, wildfire, and tree mortality (FAO 2025). Over the last 30 years, forests in southern France have experienced relatively low harvest and have shown sustained carbon uptake, in contrast to a drop in carbon uptake by forests on Corsica during this period (Ciais et al. 2026). Evidence from Mediterranean forests suggests that sustainable management and post-fire restoration can help preserve long-term sequestration capacity (Moghli et al. 2025). Nevertheless, climate extremes are already weakening carbon sinks in some forest regions; for example, the 2022 summer drought affected forest areas in the European Mediterranean, leading to reduced carbon uptake (van der Woude et al. 2023). The combination of management and climate change affects the long-term carbon storage in Mediterranean forests (*medium confidence*). In contrast, integrated forest monitoring, including different data streams from local measurements and remote sensing, is essential for verifying long-term carbon storage (*high confidence*).

5.2.2.6 Rewetting and restoration of wetlands

Wetlands include ecosystems characterised by the presence of water during at least part of the year, except seas and oceans beyond 6m depth (Ramsar Convention on Wetlands [25]). Several types of wetlands exist in the Mediterranean region: marine and coastal wetlands (e.g. salt marshes, tidal flats and mudflats, coastal lagoons and brackish marshes, seagrass beds), inland freshwater wetlands (e.g. river and floodplain wetlands, lake and pond margin wetlands, marshes, peatlands), and human-made wetlands (rice fields, reservoirs and impoundments, constructed treatment wetlands). As reported by Perennou et al. (2020), based on data from the Mediterranean Wetlands Observatory, the total wetland area in the Mediterranean basin is 19–26 million ha. Using a sample of 400 sites, Mediterranean Wetlands were found to have lost 48% of their natural habitats between 1970 and 2013, as indicated by the Wetland Extent Trend Index. Wetlands (peatlands in particular) are among the largest natural carbon stores on land. Depending on how they are managed, they can act as a carbon sink or source. Peatlands consist of layers of partially decomposed plant matter. Waterlogged soils slow decomposition, so plant material accumulates as peat over time. Although they occupy just about 4% of Earth's land area, these landscapes hold twice the amount of carbon stored in all the world's forests. In the Mediterranean region, peatlands encompass ecosystems such as bogs, moors and mires. Within this category, mires are peatlands where peat accumulation is ongoing. The area of peatlands within EU Mediterranean countries is approximately 0.5 Mha (Tanneberger et al. 2017). According to IPCC AR6 WGIII, 'Peatland restoration involves restoring degraded and damaged peatlands, for example through rewetting and revegetation, which both increase carbon accumulation in vegetation and soils and avoid ongoing CO_2 emissions'. Although peatland rewetting can increase SOC, it can also lead to increased CH_4 emissions in the near-term (Bossio et al. 2020). Thus, the mitigation potential of peatland restoration is mostly related to reduced C losses rather than increased C removal.

5.2.3 Marine-based and coastal solutions for carbon sequestration with examples from the Mediterranean Sea

Key messages

- Blue carbon ecosystems can contribute to mitigation when they are protected, restored or sustainably managed through deliberate actions. In the Mediterranean, this has been estimated at 2.38 Tg C yr^{-1} and is mainly provided by seagrass meadows, especially *Posidonia oceanica* and *Cymodocea nodosa (low to medium confidence).*
- The low-risk, scalable, and community-engaging ways to mitigate marine carbon include reducing pressures on Mediterranean marine ecosystems through measures such as bottom-trawling restrictions and strengthening marine protected areas (MPAs); and large-scale restoration and protection of blue carbon ecosystems such as seagrass meadows, coralligenous, and maerl beds. These will contribute to carbon mitigation while delivering major biodiversity and resilience co-benefits (*high confidence).*
- The scalability of blue carbon restoration potential is uncertain. Restoration of *Posidonia oceanica* and other seagrass meadows may enhance carbon storage, but success depends on habitat conditions, slow growth rates, restoration methods, monitoring capacity, and the risks of permanence and reversibility *(high confidence).*
- CDR options (e.g. ocean alkalinity enhancement, fertilisation, artificial upwelling) show theoretical potential but remain highly uncertain. Applications in the Mediterranean Sea are currently limited by feasibility constraints, ecological risks, energy-intensive material requirements, and a lack of field-scale validation. Further research, including addressing effects on the marine ecosystems and all the processes involved (LCAs of CDR products, energy needs, potential environmental impacts…) *(high confidence).*

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- Some pathways, particularly OAE-related research, may offer future relevance, but mainly conditional and medium-term possibilities that depend on major advances in MRV, governance coordination, ecological risk assessment, and social legitimacy *(medium confidence).*
- At present, the strongest evidence supports a precautionary and exploratory approach to mCDR; current mitigation potential is constrained by institutional readiness *(high confidence)*. This should be followed by a research-first pathway rather than deployment.

Aim. Marine and coastal carbon storage and sequestration processes can be based on both green and grey infrastructures, namely, nature-based solutions that enhance the carbon sequestration ecosystem services provided by Nature-Based Solutions (NBS) and by specific plants to capture carbon. Some of the NBSs provide carbon sequestration ES as a co-benefit derived from actions devoted to reduce other anthropogenic pressures and improving conservation (such as fisheries regulation, improving MPAs…), others are specifically targeting carbon removal and sequestration (posidonia or blue carbon ecosystems protection) and provide also other co-benefits, others are manipulative (CDR solutions, such as alkalinisation and ocean fertilisation), and need the assessment of potential impacts.

All of them require a better understanding of scaling-up feasibility, efficiency, costs, and vulnerability to leakage and release of carbon. The main conservation, nature-based, and engineered marine carbon removal approaches discussed in this section, along with their mechanisms and implementation challenges, are summarised in Table 5.12.

5.2.3.1 Conservation actions and their effect on carbon mitigation

Several actions aimed at protecting marine biodiversity and ecosystem services are indirectly reducing disturbances that could mobilise stored carbon or impair the functioning of biological and sedimentary carbon pathways. These measures include establishing new MPAs and fisheries regulations to limit bottom trawling (Sala et al. 2021; Hiddink et al. 2023; Atwood et al. 2024), preventing sediment resuspension and associated carbon release, and rebuilding fish stocks whose trophic roles influence nutrient cycling, biomass accumulation, and carbon export.

5.2.3.2 Marine-based and coastal solutions for carbon sequestration mitigation measures: current state and future perspectives

BC sinks are increasingly recognised as nature-based solutions that may contribute to climate change mitigation, particularly by protecting and restoring carbon-rich coastal habitats. *Posidonia oceanica* seagrass is the dominant blue carbon asset in the Mediterranean and is considered one of the most efficient marine carbon removal systems in the region. A first estimate of the contribution of blue carbon mitigation in the Mediterranean Sea, based on habitat-specific carbon accumulation rates (CAR), gives 2.381 Tg C yr^{-1}, accounting for around 3% of global blue carbon removal (*medium confidence*). The Mediterranean BC sink is supplied by seagrass meadows, salt marshes, and tidal flats, which contribute 1.880, 0.347, and 0.155 Tg C yr^{-1}, respectively (Zunino et al. 2026). Globally, coastal blue carbon habitats are assumed to be able to mitigate only 0.5-0.8 % of 10 Gt yr-1 of anthropogenic emissions (Hilmi et al. 2021; Zunino et al. 2026), but their importance is not limited to carbon sequestration and includes multiple ecological co-benefits. Co-benefits include biodiversity conservation, coastal protection, nursery habitat provision, water-quality regulation, drawing growing interest from policymakers, scientists, and the public (Macreadie et al. 2021; de Paula Costa and Macreadie 2022; Gao et al. 2022).

Conservation and management strategies focus primarily on the protection, restoration, and sustainable governance of BC ecosystems. A cornerstone of these strategies is the establishment of the '30x30' Biodiversity Strategy, which aims to protect at least 30% of marine and coastal areas by 2030. As of June 2025, only 9.6% of the global ocean is designated as marine protected areas (MPAs), with 8.7% in national waters and 0.9% in the high seas (Blue Marine Foundation 2025). MPAs are recognised as highly effective tools for marine conservation (Lester et al. 2009), with an important role in enhancing blue carbon storage and ecosystem resilience to climate impacts (McLeod et al. 2009). Prioritising the protection of BC ecosystems within MPAs may significantly contribute to global carbon mitigation while generating substantial co-benefits to the marine environment and human well-being (Howard et al. 2017; Jankowska et al. 2022).

However, protection alone is insufficient (*high confidence*). Recorded regression of seagrass meadows, mangroves, macroalgal forests and coralligenous assemblages has been related to climate change and multiple anthropogenic stressors (Pergent et al. 2015; Piazzi et al. 2021; Tang and Hadibarata 2022; Gouvêa et al. 2022; Valdazo et al. 2024), making ecological restoration a key component of BC strategies. This need for large-scale restoration has been recognised at the highest policy level through the recently adopted EU Nature Restoration Regulation (EU 2024/2235), which sets legally binding obligations for Member States to restore degraded ecosystems, including coastal and marine habitats, to reverse biodiversity loss, enhance carbon sequestration, and strengthen ecosystem resilience. Models based on the growth, survival and density of restored seagrass patches of five species indicated that the cumulative C sequestered in restored meadows increases rapidly over time. This increase rises with cutting density to reach an asymptote at 100 units ha^{-1}, where the modelled cumulative C sequestered ranges from 58 to over 194 tons CO_2 ha^{-1} after 20 years (Duarte et al. 2013), with some species expected to accumulate carbon at a rate that is comparable to measured ranges in natural seagrass meadows only within 12 years (Greiner et al. 2013).

However, whereas considerable, climax species, such as *Posidonia oceanica* and *Thalassia testudinum*, have the potential for significant below-ground C storage computed in 1.38 Mg C ha^{-1} yr^{-1} (Fourqurean et al. 2012), their restoration potential is limited by their slow clonal growth rates, particularly in the case of *P. oceanica*, the slowest growing seagrass species (about 2 cm $year^{-1}$, Duarte 1991). In the Mediterranean Sea, numerous efforts have focused on the restoration of *P. oceanica* (De Luca et al. 2024; Robello et al. 2024; Bacci et al. 2025; Stipcich et al. 2025). However, available information remains fragmented, partly due to the variety of practices and methodologies adopted under different environmental conditions (Pansini et al. 2022). Establishing standardised and evidence-based restoration protocols is therefore an urgent research priority (*high confidence*).

The ambitious goals of the Nature Restoration Regulation require a deep knowledge of the extent, condition, and spatial distribution of degraded habitats. Marine habitat mapping provides a comprehensive representation of habitat distribution, ecological status, associated biological communities, and biophysical characteristics (Fraschetti et al. 2024). It serves as an essential tool for spatial planning, conservation prioritisation, and restoration targeting (*high confidence*).

On the scientific side, integrating blue carbon into climate mitigation policies demands robust data and mensurative or manipulative experiments in the fields or in mesocosms are focusing on the effects of multiple stressors, such as warming, acidification, eutrophication, and physical disturbance, on the performance and carbon sequestration capacity of BC ecosystems (Stipcich et al. 2022; Duarte et al. 2021; Lacoste et al. 2023). Protection measures (e.g. anchoring restrictions, wastewater treatment, marine protected areas) prevent the resuspension and remineralisation of significant legacy carbon stocks stored in the sediments beneath mature seagrass meadows. Restoration of degraded meadows (re-planting, erosion control, reducing local stressors) can gradually rebuild biomass and sediment carbon, but the timescale for meaningful additional sequestration is multi-decadal, so near-term gains are modest compared with simply halting loss (IUCN 2021).

Marine-based and coastal blue carbon solutions, when supported by protection, restoration, sustainable management, and coherent policy frameworks, represent a promising multifaceted pathway for climate mitigation, biodiversity conservation, and coastal resilience (Hilmi et al. 2021). Continued advancements in monitoring, mapping, ecological modelling, and restoration science will be critical for scaling up their contribution to global climate targets.

5.2.3.3 Marine Carbon Dioxide Removal, mCDR

Marine carbon dioxide removal (mCDR) encompasses various geochemical and biological approaches aimed at enhancing the ocean's natural capacity for carbon uptake. The more frequently referenced chemical techniques include ocean alkalinity enhancement (OAE), which accelerates the conversion of dissolved CO_2 into stable bicarbonate or carbonate ions; and direct ocean capture (DOR), which encompasses technologies that strip dissolved inorganic carbon from seawater, usually via electrochemical or related separation processes, and return CO_2-depleted water to enhance ocean–atmosphere CO_2 drawdown. While these techniques offer theoretical potential for negative emissions, they also entail significant uncertainties regarding cost, scalability, ecological side effects, timescales, risk assessment, and transboundary governance. Their application remains in the research and pilot-testing phase and would require robust regulatory frameworks, independent monitoring, and adherence to the precautionary principle (Gattuso et al. 2018; Williamson et al. 2026).

5.2.3.4 Assessment of marine CDR mitigation potential in the Mediterranean Sea

A literature review, supported by a Mediterranean-wide expert survey (Bednaršek et al., in prep.), indicates that marine carbon dioxide removal (mCDR) in the Mediterranean Sea currently has limited near-term realisable mitigation potential, despite some potentially relevant biogeochemical and ecosystem-based opportunities *(high confidence)*. The main constraints include governance fragmentation, weak monitoring, reporting, and verification (MRV) capacity, ecological uncertainty, and uneven institutional readiness across the basin. Barriers are perceived as more institutional, regulatory, financial, and social than technical, and respondents generally favour a research-first, precautionary pathway rather than implementation over the next 2-5 years. Even where biogeochemical potential exists, realisable mitigation depends on verifiable carbon removal, durability, governance legitimacy, and operational capacity, all of which are currently assessed as inadequate in the Mediterranean context (Bednaršek et al., in prep.).

Although Mediterranean mCDR is attracting interest, including from emerging industrial actors exploring approaches such as ocean alkalinity enhancement (OAE), wastewater-based CO_2 removal, and coastal OAE, the region's credible near-term mitigation potential remains limited (Bednaršek et al., in prep.). The number of options that can currently be deployed in a way that is demonstrably effective, environmentally safe, and verifiable is small, so the overall near-term mitigation contribution of mCDR in the Mediterranean should be considered low *(high confidence)* Johnson et al. 2024; Morrison et al. 2025; Bednaršek et al., in prep.).

5.2.3.5 Ocean alkalinity enhancement (OAE)

The Mediterranean's naturally high total alkalinity and pronounced west-east and coastal-open ocean gradients make it a potentially valuable natural analogue and experimental setting for studying alkalinity perturbations and carbonate system responses (Gemayel et al. 2015; Butenschön et al. 2021; Caserini et al. 2021; Bednaršek et al., in prep.).

OAE methods include adding alkaline minerals to seawater or coastal environments, either along the coast, from maritime vessels, or at point sources, to increase CO_2 uptake. This not only increases buffering capacity but also temporarily alleviates ocean acidification (Cossarini et al. 2015 2021; Butenschön et al. 2021; Bednaršek et al., in prep.; van de Mortel et al. 2025). The Mediterranean could offer a modest medium-term mitigation contribution from selected mCDR pathways. Available assessments based on logistical analyses and modelling studies (Caserini et al. 2021; Butenschön et al. 2021) for the Mediterranean Sea show some efficacy of the treatment. OAE via ship-based slaked lime discharge could improve marine CO_2 uptake and reduce surface marine acidification. Still, applications are constrained by the need for an order-of-magnitude expansion of OAE compound production, associated energy and environmental burdens, uncertain ecological impacts along discharge zones, and the absence of field-scale validation (high agreement), as well as temporal and spatial uncertainty around OA mitigation capacity. However, the approach remains limited by uncertainties in material sourcing, costs, dissolution rates, permanence, life-cycle impacts, and potential ecological responses. The feasibility of large-scale production also presents significant challenges, as it requires high energy requirements and substantial industrial transformation while avoiding adverse environmental impacts.

The expert community consulted in the survey (Bednarsek et al., in prep) views the Mediterranean as unsuitable for near-term OAE implementation and instead supports a research-first, precautionary trajectory focused on controlled experiments and observation rather than deployment *(high confidence)* (Bednaršek et al., in prep.). Key limitations include the absence of standardised, basin-wide MRV protocols for quantifying alkalinity additions, CO_2 removal efficiency, and storage durability, as well as limited capacity for sustained ecological monitoring to detect biological and ecosystem impacts (Oschlies et al. 2023; Johnson et al. 2024; Bednaršek et al., in prep.).

At present, the mitigation potential of ocean alkalinity enhancement (OAE) is low, and OAE is not ready for operational scaling. It requires a substantially deeper understanding of its impacts on marine ecosystems before any large-scale deployment can be justified *(high confidence)* (Gattuso et al. 2018; Oschlies et al. 2023; Bednaršek et al., in prep.). The current technology readiness levels for OAE approaches (approximately TRL 2--6, depending on the specific configuration) remain too low for OAE to be considered a scalable and widely applicable mitigation solution (Gattuso et al. 2018; Johnson et al. 2024; Morrison et al. 2025; Bednaršek et al., in prep.).

5.2.3.6 Blue carbon and ecosystem restoration approaches

Among Mediterranean mCDR options, blue carbon and ecosystem restoration approaches appear to have the strongest social and policy support. However, their net mitigation contribution remains low and uncertain due to unresolved issues with additionality, permanence, scalability, and accounting *(medium confidence)* (high alignment on value, but high uncertainty on mitigation magnitude). The literature identifies *Posidonia oceanica* restoration and maintenance as the most advanced in terms of implementation. These approaches are viewed positively because they align with existing conservation, adaptation, and blue economy goals, while also offering co-benefits for biodiversity, fisheries, coastal protection, and water quality, integrating along the mitigation--adaptation--ecosystem benefits interface (see Chapter 4).

5.2.3.7 Direct ocean capture (DOC)

Direct ocean capture (DOC) and related electrochemical marine CDR approaches are emerging as a potentially high-integrity option for the Mediterranean. They concentrate CO_2 into a pure stream that can be directly measured and stored and localise chemical manipulation inside engineered plants rather than perturbing basin-scale carbonate chemistry (Eisaman et al. 2024). This provides greater control and reduces ecological side effects. At the same time, deployment is constrained by high and uncertain costs, substantial low-carbon electricity requirements, site-specific discharge and siting challenges at coastal facilities, and the absence of clear regulatory and accounting frameworks for integrating DOC into national and regional mitigation portfolios (Refaie et al. 2026; Aleta et al. 2023). As a result, DOC is assessed here as a promising but still emerging option whose near-term contribution lies primarily in technology development and demonstration, rather than in large-scale delivery of negative emissions in the Mediterranean.

5.2.3.8 Other engineered marine CDR approaches

The available evidence is insufficient to support a robust assessment of the mitigation potential of other engineered mCDR pathways in the Mediterranean *(high confidence)*.

Governance fragmentation appears to be the dominant constraint on Mediterranean mCDR mitigation potential *(high confidence)*. The literature identifies overlapping jurisdictions, uneven enforcement, lack of a unified framework, uncertain permitting, and weak cross-border coordination as major barriers. Existing regional instruments may be relevant, but they remain insufficiently adapted, unevenly implemented, and often weakly enforced. Even if technical removal were feasible, mitigation could not be credibly realised at scale without institutions capable of authorising, monitoring, verifying, and enforcing activities across a transboundary basin.

5.2.3.9 Ecological uncertainty

Ecological uncertainty substantially constrains the acceptable and governable mitigation potential of mCDR in the Mediterranean *(high confidence)*. Further research is needed to understand how mCDR would interact with warming, ocean acidification, deoxygenation, fishing, and pollution. Mitigation potential is determined not only by chemical properties but also by the ability to avoid ecological risk and to define appropriate ecological and ecosystem measurements.

5.2.3.10 The social feasibility

The social feasibility of Mediterranean mCDR is likely to be higher for restoration-based pathways than for industrial-scale engineered interventions, although distributive justice concerns may still strongly constrain implementation *(high confidence)*. Respondents report greater social acceptability of blue carbon and ecosystem restoration than of interventions that add substances to seawater. At the same time, the text highlights the risk that wealthier northern or western countries could capture the benefits. In contrast, southern or eastern countries may bear disproportionate risks or remain excluded from returns. Even technically viable approaches may face low uptake if they are perceived as inequitable, externally imposed, or inconsistent with local livelihoods and cultural values.

Table 5.12 | Summary of carbon removal solutions and their respective challenges

Solution	Mechanism	Key challenges
Bottom-trawling restrictions	Reduces sediment resuspension and carbon release	Enforcement challenges: socioeconomic resistance
Marine Protected Areas (MPAs)	Limits pressure on carbon-rich habitats; supports ecosystem stability	Governance capacity; monitoring effectiveness
Fish Stock Rebuilding	Restores nutrient cycling, biomass, and carbon transfer	Slow recovery; compliance issues
Habitat Conservation Measures	Prevent habitat degradation and maintain carbon functions	Long-term management; competing maritime uses
CATEGORY: Nature-Based Solutions (Blue Carbon and Marine Forestry)		
Seagrass Restoration	Enhances sedimentary and biomass carbon storage	High variability; high local adaptation; disturbance sensitivity
Seaweed Cultivation	Grows seaweed biomass to enhance carbon uptake	Storage time, ecological risks, durability, effectiveness
Ecosystem Recovery (including coralligenous, Maerl and corals)	Restores degraded habitats and carbon sequestration capacity	Slow recovery; quantification limits
Coastal Wetland Expansion	Restores hydrology to support carbon burial	Land availability; engineering needs
CATEGORY: Manipulative / Engineered CDR Approaches		
Nutrient Fertilisation	Stimulates phytoplankton growth	Ecological risks; effectiveness, regulatory constraints
Artificial Upwelling/Downwelling	Moves water masses and affects carbon cycles	Ecological risks; uncertain benefits
Alkalinity Enhancement	Adds minerals to increase CO_2 uptake	Material sourcing; ecosystem responses, permanence, life cycle, co
Electrochemical CO_2 Removal	Alters seawater chemistry to extract CO_2	Energy-intensive; costly

5.2.4 Technological solutions

Key messages

- CCUS is the most relevant technological option for hard-to-abate Mediterranean sectors, especially cement and municipal waste incineration with energy recovery, but it is still mainly in the phases of planning, piloting, regulatory preparation, and storage validation *(low to medium confidence)*.

- The scalability of CCUS in Mediterranean countries depends mainly on shared CO_2 transport and storage infrastructure, including hubs, shipping, liquefaction chains and cross-border agreements, rather than on isolated capture plants (*medium confidence).*
- Offshore power-to-methanol systems based on green hydrogen and marine CO_2 capture remain innovative but early-stage options; their mitigation value depends on full renewable energy supply and verified net-zero carbon accounting *(low confidence)*.
- The main gaps across these solutions are technological scale-up, monitoring, reporting, and verification, infrastructure financing, cross-border regulation, storage validation, public acceptance, and long-term carbon permanence.

5.2.4.1 Carbon capture use and storage in the Mediterranean: state of the art, scalability, efficiency, and gaps

Key message: CCUS is a credible but still in the research-and-evaluation phase as a mitigation option for hard-to-abate sectors in the Mediterranean, especially cement and waste-to-energy. This option can be implemented if gaps in storage validation, cross-border regulation, infrastructure financing, MRV, and public engagement are addressed. Overall confidence in this solution is medium to low.

Globally, CCS is expanding, with 77 commercial projects in operation and 734 facilities in the development pipeline in 2025 (GCCSI 2025). In the Mediterranean Sea, CCUS represents an emerging mitigation pathway comprising planned hubs, pilot-scale demonstrations, regulatory preparation, and early storage development (GCCSI 2025). CCUS around the Mediterranean is still in its early stages, particularly in Italy and Greece, but interest in cross-border cooperation among Greece, Cyprus, France, Egypt and Saudi Arabia for future CO_2 transport, export and storage corridors is growing. The most advanced pilot projects in the Mediterranean area are developing around the Mediterranean CCS Plan and the CALLISTO Mediterranean CO_2 Network. CALLISTO is an open-access, multimodal CO_2 network using onshore transport and shipping routes from emitters in Italy and France, with final geological storage at the Ravenna CCS hub. The project is expected to become operational from 2027 and is linked to an estimated offshore storage capacity of 500 Mt CO_2 at Ravenna (SNAM; D8.1). The HERCCULES case studies also identify Ravenna, Italy, and Prinos, Greece, as the key offshore storage regions: Ravenna uses depleted offshore gas reservoirs. At the same time, Prinos is based on an almost depleted offshore oil field (D8.2).

The evidence suggests that the scalability of Mediterranean CCUS depends less on single capture plants and more on shared transport-and-storage infrastructure. This is consistent with global trends, in which the expansion of dedicated CO_2 transport and storage networks is driven by cost reductions and the availability of storage services to emitters (GCCSI 2025).

The Mediterranean CCS plan is expected to be scalable, enabling additional projects in the region and allowing other Mediterranean countries to join later. This hub-based model is important because not all countries have adequate domestic geological storage; therefore, the liquefaction, shipping, transport, and storage value chains need to be organised at a regional scale (D8.1).

Geological storage estimates support the possibility of scale-up, but with important uncertainty. Italy is reported to have very good geological options, with EU GeoCapacity estimates of 4669 Mt CO_2 in deep saline aquifers and 1810 Mt CO_2 in hydrocarbon fields, while ENI portfolio analyses identify around 750 Mt in Italian oil and gas fields. Greece has reported a theoretical storage capacity of 2190 Mt CO_2 in deep saline aquifers and hydrocarbon fields. However, the Prinos project is still presented as a candidate storage site under exploration and permitting (D8.1).

Evidence on efficiency is more limited and technology-specific. For cement, HERCCULES modelling of a 1.5 MWth oxy-fuel pre-calciner indicates that the preliminary design can achieve the target calcination degree of 90% and produce a CO_2-rich gas stream, but this is based on modelling and CFD simulations rather than long-term industrial operation (D2.1). For utilisation/mineralisation, zeolite-based CO_2 uptake tests show promising but still early-stage results: natural zeolites reached about 3–4 wt% CO_2 loading, while several synthetic zeolites exceeded 10 wt%; however, moisture reduced adsorption capacity by about 40–50%, and synthetic zeolites require granulation or pelletisation before direct use in the pilot plant (D4.2). Therefore, the confidence in technical feasibility is medium, while confidence in full-chain industrial efficiency in Mediterranean conditions remains low to medium.

The main gaps are regulatory, technical, economic and social. Regulatory gaps include transboundary CO_2 transport, third-party access to storage and transport networks, and incomplete alignment with the London Protocol framework. Italy is more advanced because it is a party to the London Protocol and intends to apply the Article 6 amendment and negotiate bilateral agreements with France and Greece; Greece has transposed the EU CCS Directive but is not a party to the London Protocol, and further regulatory development is needed on transboundary issues and third-party access (D8.1). Planning gaps are also evident: Italy's draft NECP identifies CCUS as necessary for hard-to-abate sectors but lacks 2030 data on capture volumes, storage availability, injection capacity and domestic transport; Greece has not yet officially designated specific storage areas beyond preliminary qualitative assessment, and social acceptance and competing land and marine uses have not yet been fully addressed (D8.1).

Socially, awareness remains low: in the HERCCULES surveys, more than 50% of respondents had never heard of CCUS. Acceptance is also shaped by perceived risks, trust, fairness and the quality of engagement, especially near storage sites (D8.2; D8.3).

Confidence in the existence of the Ravenna and Prinos focus, the CALLISTO plan, and the identified regulatory gaps is high because these are directly documented. Confidence is medium for scalability, because storage potential and hub design are promising but considerably based on estimates, plans and permitting processes. Confidence is low to medium for efficiency because the available evidence is mainly derived from models, lab testing, and pilot preparation, and is not yet operational.

Nature-Based Solutions (NBS) enhanced by technology. Nature-based solutions also play a technological role through enhanced monitoring, modelling, and restoration tools. Innovations in reforestation, agroforestry, and landscape restoration enable degraded lands to become net carbon sinks, with measurable mitigation benefits demonstrated in Mediterranean agricultural landscapes (Brandolini et al. 2025). Coastal wetland restoration—supported by hydrological modelling and blue-carbon accounting offers substantial carbon sequestration while protecting communities from sea-level rise and flooding (Union for the Mediterranean and Plan Bleu 2022; Fundación Global Nature 2024). These ecosystem-based technologies provide essential co-benefits for biodiversity, soil health, and climate resilience.

Offshore power-to-methanol systems based on green hydrogen and marine CO_2 capture. Recent studies have examined offshore technological systems for the Mediterranean Sea that combine floating solar and wind energy with the extraction of dissolved CO_2 from seawater to produce synthetic fuels such as methanol. These so-called 'methanol islands' use renewable electricity to power desalination, hydrogen production via electrolysis, and CO_2–H_2 synthesis, thereby indirectly capturing atmospheric CO_2 via the ocean and converting it into an energy carrier. Although the methanol produced releases CO_2 upon combustion, the system's overall mitigation potential depends on a net-zero approach, in which the carbon emitted during fuel use is offset by carbon previously captured from the atmosphere, provided the process is entirely powered by renewable energy (Keller et al. 2022).

Table 5.13 | Illustrative case studies. Source Mediterranean between 2020 and 2025.

Location and site	Technology and approach	Key Results	Lessons learned	References
Mediterranean coastal wetlands (Morocco, Tunisia, southern Europe)	Wetland restoration and blue-carbon management	• High carbon sequestration. • Reduced GHGs from degraded soils. • Provides flood protection and biodiversity benefits.	• Wetlands are high-impact NBS. • Restoration requires hydrology planning. • Blue-carbon methods strengthen climate strategies.	UfM and Plan Bleu (2022); Fundación Global Nature (2024)

1 **Table 5.14 | Characteristics of carbon dioxide removal (CDR) methods.** Termination effects refer to the possible effects of a hypothetical, sudden and sustained termination of
2 the CDR method. Source: IPCC 2026.

Category	Method	Section	Nature of CO_2 Removal Process / Storage Form	Description	Time Scale of Carbon Storage	Factors that Affect Carbon Storage Time Scale	Termination Effects	Source
Enhanced biological production and storage on land (in vegetation, soils or geologic formations)	Afforestation, reforestation and forest management	5.6.2.2.1	Biological / organic	Store carbon in trees and soils by planting, restoring or managing forests	Decades to centuries (Cooper, 1983)	Disturbances (e.g. fires, pests), extreme weather	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage on land (in vegetation, soils or geologic formations)	Soil carbon sequestration	5.6.2.2.1	Biological / organic	Use agricultural management practices to improve soil carbon storage	Decades to centuries (Dignac et al. 2017)	Soil and crop management	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage on land (in vegetation, soils or geologic formations)	Biochar	5.6.2.2.1	Biological / organic	Burn biomass at high temperature under anoxic conditions to form biochar and add to soils	Decades to centuries (Campbell et al. 2018)	Fire	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage on land (in vegetation, soils or geologic formations)	Peatland restoration	5.6.2.2.1	Biological / organic	Store carbon in soil by creating or restoring peatlands	Decades to centuries (Harenda et al. 2018)	Peatland drainage, fire, drought, land-use change	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage on land (in vegetation, soils or geologic formations)	Bioenergy with carbon capture and storage (BECCS)	5.6.2.2.1	Biological / inorganic	Production of energy from plant biomass combined with carbon capture and storage	Potentially permanent – analogous to direct air carbon capture with carbon storage (DACCS) (Szulczewski et al. 2012)	Leakage	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage in coastal and open ocean	Ocean fertilization	5.6.2.2.2	Biological / organic	Fertilise upper ocean with micro (Fe) and macronutrients (N, P) to increase phytoplankton photosynthesis and	Decades to millennia (Oschlies et al. 2010a; Robinson et al. 2014)	Ocean stratification and circulation (Robinson et al. 2014); efficiency of carbon sequestration in deep ocean (Yoon et al. 2018)	Uncertain (Keller et al. 2014)	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/

Category	Method	Section	Nature of CO_2 Removal Process / Storage Form	Description	Time Scale of Carbon Storage	Factors that Affect Carbon Storage Time Scale	Termination Effects	Source
				biomass and deep ocean carbon storage through the biological pump				
Enhanced biological production and storage in coastal and open ocean	Artificial ocean upwelling	5.6.2.2.2	Biological / organic	Pump nutrient-rich deep ocean water to the surface to increase carbon uptake and storage through the biological pump.	Centuries to millennia (Oschlies et al. 2010b)	Ocean circulation; dissolved inorganic carbon content of upwelled waters (Oschlies et al. 2010b)	Warming beyond temperatures experienced if artificial ocean upwelling had not been deployed (Keller et al. 2014)	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced biological production and storage in coastal and open ocean	Restoration of vegetated coastal ecosystems ("blue carbon")	5.6.2.2.2	Biological / organic	Manage coastal ecosystems to increase net primary production and store carbon in sediments	Decades to centuries if functional integrity of ecosystem maintained (McLeod et al. 2011)	Land-use change of coastal ecosystems; extreme weather (e.g. heatwaves); sea level change (NASEM 2019)	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced geochemical processes on land and in ocean	Enhanced weathering	5.6.2.2.3	Geochemical / inorganic	Spread alkaline minerals on land to chemically remove atmospheric CO_2 in reactions that form solid minerals (carbonates and silicates) that are stored in soils or in the ocean	10,000 to 10^6 years (Fuss et al. 2018)	Storage in soils or ocean (Fuss et al. 2018)	None	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/
Enhanced geochemical processes on land and in ocean	Ocean alkalinisation	5.6.2.2.3	Geochemical / inorganic	Increased CO_2 uptake via increased alkalinity by deposition of alkaline minerals (e.g. olivine).	10,000 to 100,000 years (Keller 2019)	Carbonate chemistry; ocean stratification and circulation (Keller 2019)	Higher rates of warming and acidification than if alkalinization had not begun	https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-5/

Category	Method	Section	Nature of CO_2 Removal Process / Storage Form	Description	Time Scale of Carbon Storage	Factors that Affect Carbon Storage Time Scale	Termination Effects	Source
							(under a high emissions scenario) (González et al. 2018)	
Chemical	Direct air carbon capture with storage (DACCS)	5.6.2.2.4	Chemical / inorganic	Direct removal of CO_2 from air through chemical adsorption, absorption or mineralization, and storage underground, in deep ocean or in long-lasting usable materials	Potentially permanent	Leakage	None	https://www.ipcc.ch/report/ar6/wg1/chapter-5/

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5.3 Carbon trading mechanisms in the Mediterranean region

Key messages

- Carbon trading in the Mediterranean is markedly asymmetric. EU Mediterranean states operate inside a mature, legally binding EU ETS; Montenegro runs a small national system; Türkiye launched a pilot ETS in 2026; and most southern and eastern Mediterranean countries rely on readiness processes, voluntary markets or Article 6 cooperation rather than compliance trading *(high confidence).*
- The strongest evidence of mitigation effectiveness concerns the EU ETS. Emissions from stationary installations covered by the system fell by about 50% between 2005 and 2024, and firm-level studies find reductions in regulated emissions without systematic competitiveness losses *(high confidence* for covered sectors*; medium confidence* for attribution across drivers*).*
- Evidence for emerging systems outside the EU remains limited. Observable effects so far lie in institutional preparation, MRV upgrading and registry development rather than in measured emissions reductions *(medium confidence).*
- CBAM has become a major external driver of carbon accounting and policy diffusion around the basin. Its definitive regime began in January 2026, strengthening incentives for product-level emissions measurement in covered sectors, although its distributional consequences for middle-income exporters remain contested *(high confidence* for MRV effects*; medium confidence* for mitigation effects).
- Voluntary and blue carbon markets can mobilise finance, but their climate value is conditional. A systematic review of crediting projects estimates that fewer than 16% of issued credits, roughly one in six, correspond to a real emissions reduction, which sets a high bar for additionality, permanence and conservative accounting *(medium confidence* for finance mobilisation*; low to medium confidence* for net mitigation*).*
- Near-term regional integration is more plausible through staged convergence on MRV, registries, Article 6 authorisation and high-integrity credit standards than through full Mediterranean ETS linkage. The agenda intersects with a regional carbon budget projected to be exhausted around 2035 on current trajectories *(medium confidence).*

5.3.1 Current carbon trading mechanisms in the Mediterranean

The Mediterranean carbon-market landscape is best read as a set of interacting policy spaces rather than a single regional market. EU member states around the basin are covered by the EU ETS and therefore share a common cap, harmonised monitoring rules, a common registry architecture, and EU-level enforcement. Neighbouring non-EU economies are affected indirectly, through trade exposure in carbon-intensive sectors covered by the Carbon Border Adjustment Mechanism (CBAM) and through accession or association processes that encourage convergence with EU climate legislation. A third group is building carbon-market capacity through voluntary crediting, Article 6 cooperation and national registries rather than through compliance trading. The distinction matters because the evidence base is strongest where compliance obligations have been enforced over a long period and remains weak where instruments are at readiness or pilot stage (European Commission 2025b; ICAP 2025a; World Bank 2026).

For assessment purposes, the existence of an instrument is not itself evidence of mitigation. A compliance ETS reduces emissions only when the cap binds, allocation rules do not neutralise the price signal, covered entities face credible penalties and emissions are independently verified. A voluntary framework mobilises finance only when credits are additional, conservatively quantified and protected from double counting. Article 6 cooperation supports mitigation and sustainable development only when authorisation, corresponding adjustments and reporting are transparent. The section, therefore, separates operational markets, ETS readiness, crediting infrastructure, and externally induced MRV upgrading rather than grouping them under a single label (ICVCM 2024; UNFCCC 2025a).

Globally, this is a maturing field. The World Bank counted 87 direct carbon-pricing instruments in operation in 2025, covering close to 30% of global greenhouse gas emissions and raising more than USD 107 billion, with all considerable middle-income economies either operating a carbon-pricing instrument or planning to introduce one (World Bank 2026). The Mediterranean mirrors this pattern at a smaller scale. The basin also faces an unusually tight constraint: an assessment for the Barcelona Convention estimates that the Mediterranean’s remaining carbon budget consistent with the 2°C goal would be exhausted around 2035 on current emission levels, implying average reductions of roughly 6% per year between 2030 and 2050 (Román et al. 2025). This raises the stakes for whether carbon-market instruments deliver measurable abatement rather than only accounting capacity.

Three forces shape the regional landscape and recur throughout this section. The first is the EU ETS, which directly regulates EU Mediterranean member-state installations and indirectly sets reference points for technical standards, monitoring methodologies and registry practices that neighbouring systems may need to align with if they seek interoperability or recognition. The second is trade exposure to the EU, channelled through CBAM, which raises the value of verified installation- and product-level emissions data and can strengthen the case for explicit domestic carbon pricing in export-oriented sectors. The third is the search for climate finance through voluntary markets and Article 6 cooperation, especially in jurisdictions where compliance pricing remains politically or institutionally less advanced. The relevant assessment question is therefore not whether a uniform regional market exists, because it does not, but whether these different forms of carbon pricing, trading and crediting are delivering measurable mitigation, improving the credibility of emissions accounting and mobilising finance without creating regressive or inequitable effects (European Commission 2025b; ICAP 2025a; World Bank 2026). There are now 80 direct carbon pricing instruments in operation around the world, 37 ETSs and 43 carbon taxes (Figure 5.10).

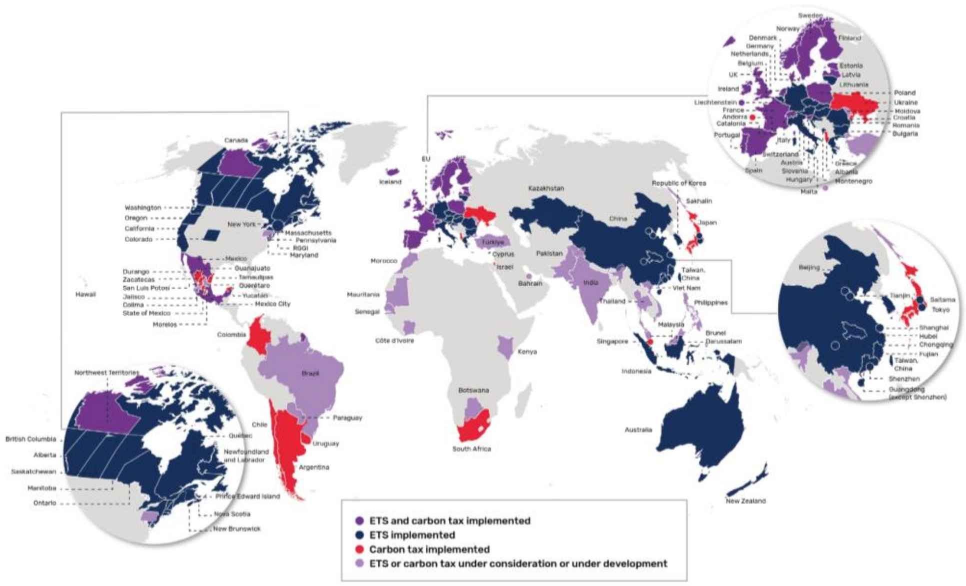

Figure 5.10 I Carbon pricing instruments. Source: World Bank 2026

5.3.1.1 Implementation status and market clusters

The current regional landscape falls into four clusters. The first is the EU Mediterranean group, including Spain, France, Italy, Greece, Croatia, Slovenia, Cyprus and Malta, fully integrated into EU ETS rules on cap setting, MRV, allocation, auctioning and compliance. The second group comprises EU-accession or EU-aligned systems, principally Montenegro, which operates a small ETS with explicit alignment objectives, alongside Türkiye, which has moved from preparation to a pilot phase. The third group includes North African and eastern Mediterranean countries, for example, Morocco, Egypt and Tunisia, where activity is concentrated in carbon-pricing preparation, Article 6 cooperation, voluntary markets and product-level carbon accounting. Finally, the fourth group comprises countries where explicit carbon trading is absent or severely constrained by conflict, energy subsidies, institutional fragility or political instability, including Libya and Syria, while Algeria and Lebanon also lack mature instruments at present (ICAP 2025a 2025b 2025c; UNFCCC 2025a).

5.3.1.2 Compliance markets and EU-aligned systems

The EU ETS remains the central mechanism affecting the EU Mediterranean countries. It covers electricity and heat generation, energy-intensive industry, and intra-European aviation, and since 2024, it has been extended to maritime transport. Its relevance to the Mediterranean countries is both direct, through installations and operators in member states around the basin, and indirect, because CBAM links access to the EU market with verified embedded emissions and, where applicable, carbon prices paid in the country of origin (European Commission 2025b; European Parliament and Council 2023c 2023a).

The ET system has evolved from an over-allocated early market into a tighter framework with a declining cap, extensive auctioning, the Market Stability Reserve and stricter rules for free allocation. The 2023 revision aligned it with the EU climate-neutrality framework by tightening the cap to deliver a 62% reduction in covered emissions by 2030 relative to 2005, raising the linear reduction factor and making free allocation conditional on decarbonisation (European Commission 2025b; European Parliament and Council 2023a). For neighbouring economies, the EU ETS serves as a technical reference point: its monitoring methodologies, registry architecture, and verification rules define the standards against which convergence, recognition, or linkage would be assessed.

Montenegro is the only non-EU country in the basin with an ETS already in force. It covers a small number of power and industrial installations, applies a reserve price and a linear reduction factor, and is best interpreted as a capacity-building and alignment instrument rather than a source of independent mitigation evidence. Small national systems of this kind can build useful MRV and compliance capacity, yet they face constraints on liquidity, volatility, and administrative costs unless linked to broader frameworks (ICAP 2025b). Its cap structure has been framed explicitly as readiness for eventual EU ETS alignment in the context of accession, rather than as a mechanism designed to transform a significant industrial base, which is why its significance lies in institutional convergence rather than market depth. The wider Western Balkans remain at a preparatory stage, with most economies developing MRV and pricing options under the Energy Community and accession dynamics rather than operating functioning markets, and analytical work has suggested that a coordinated regional arrangement would be more efficient than several very small, illiquid systems operating in parallel.

Türkiye is the most consequential emerging case because of its industrial scale, trade exposure and a decade of mandatory installation-level monitoring covering more than 800 facilities. Climate Law No. 7552, enacted in July 2025, established the legal basis for a national ETS, created a Carbon Market Board and earmarked up to 10% of revenues for just-transition measures; the pilot phase began in 2026, initially covering cement, iron and steel, aluminium and fertiliser installations above 50,000 t CO_2eq, with full free benchmark-based allocation and no offsetting during the pilot (Directorate of Climate Change of Türkiye 2025; ICAP 2025c). The system is operated through the national energy exchange under market oversight by the energy regulator, and its design is explicitly calibrated to CBAM and to the 2053 net-zero strategy. Türkiye submitted an updated nationally determined contribution in November 2025 and will host the 2026 UN climate conference, which raises the visibility of its carbon-market choices. Because compliance-period data do not yet exist, the assessment is forward-looking: the pilot signals institutional direction more than measured abatement *(medium confidence)*.

5.3.1.3 Carbon-pricing preparation and Article 6 readiness in the southern and eastern Mediterranean

Morocco, Egypt and Tunisia illustrate a different pathway. Rather than operating mature compliance systems, they are building infrastructure through pricing proposals, voluntary platforms, Article 6 cooperation, credit registries, verifier rules and product-level accounting. Institutional readiness can precede explicit pricing, which means observed mitigation should not be overstated; at present, these instruments are more convincingly read as capacity-building and climate-finance channels than as evidence of economy-wide abatement (UNFCCC 2025a; World Bank 2026).

Morocco has substantial experience with project-based mechanisms and has signalled interest in pricing and cooperation, particularly in CBAM-exposed value chains such as cement and fertilisers. Its comparative advantage lies in renewable deployment, phosphate and fertiliser industries and proximity to EU markets. The policy challenge is to translate accounting and crediting capacity into measures that reduce emissions in high-emitting sectors, rather than merely documenting exposure to border charges (*medium confidence* in institutional convergence; *low to medium confidence* in observed mitigation from market instruments).

Egypt has built a regulatory framework for a voluntary carbon market through its Financial Regulatory Authority and the national exchange, with rules for verification and validation bodies, registries, listing and trading. This gives voluntary credits a supervised market structure, which is institutionally significant because it places project documentation, validation and clearing under a financial regulator rather than leaving them to bilateral arrangements. It does not, by itself, guarantee national mitigation: climate value depends on project quality, baseline conservatism, independent verification, transparency, and rules that prevent double-counting (Financial Regulatory Authority of Egypt 2024; ICVCM 2024; Probst et al. 2024). In effect, Egypt is positioning itself as a regional carbon-finance venue, while the mitigation value of the credits transacted will depend on the integrity standards enforced.

Tunisia is positioning itself for Article 6 cooperation rather than a domestic ETS. Its bilateral cooperation with Switzerland under Article 6.2 creates a framework for internationally transferred mitigation outcomes and corresponding adjustments, which can mobilise finance and support mitigation in energy efficiency, waste or industrial gases. It also raises governance requirements: national authorisation, registry capacity, transparent reporting, benefit-sharing, and sustainable development safeguards (Swiss Federal Office for the Environment 2025; UNFCCC 2025a). The Swiss procurement approach tends to emphasise high additionality and sustainable-development co-benefits, so a bilateral relationship of this kind can transmit stricter governance norms to the host country through authorisation criteria and monitoring requirements. Without robust corresponding adjustments and disclosure, however, Article 6 transactions risk producing accounting benefits abroad without commensurate local mitigation or equity outcomes, which is why the governance conditions, rather than the existence of the agreement, determine the assessment *(medium confidence).*

Several countries remain outside explicit carbon pricing or trading. Algeria, Libya, Lebanon and Syria operate no mature national instrument at scale, for reasons that should not be reduced to a single explanation: fossil-fuel dependence, energy-subsidy structures, macroeconomic fragility, conflict, reconstruction needs, limited administrative capacity and political instability each constrain adoption. Yet absence of a domestic market does not mean absence of exposure, since trade, finance and supply-chain reporting requirements increasingly transmit carbon-accounting pressures across borders. In this sense, CBAM and Article 6 can affect countries that have not formally adopted carbon trading, with the strength of the effect depending on export composition and institutional readiness *(low to medium confidence).*

5.3.1.4 Voluntary and blue carbon markets

Voluntary markets are present across the basin through projects in renewable energy, waste, energy efficiency, forestry, agriculture, and coastal ecosystems. They can mobilise private finance and help build MRV and registry capacity where compliance instruments are politically difficult to implement. The assessment literature is nonetheless clear that quality varies sharply: a systematic synthesis of 2346 projects covering roughly one billion tonnes of CO_2eq estimates that fewer than 16% of issued credits correspond to real reductions, with about 11% for cookstoves and 25% for avoided deforestation, and no statistically significant reductions for wind-power or improved-forest-management projects (Probst et al. 2024). Voluntary credits should therefore not be treated as equivalent to emissions reductions unless they satisfy stringent integrity criteria (ICVCM 2024).

Price signals in voluntary markets increasingly reflect these concerns. Market data show a widening gap by credit type, with nature-based removal credits and highly rated forest-conservation and reforestation projects commanding a premium while renewable-energy credits trade at the bottom of the range, evidence that buyers no longer treat all credits as equivalent and are pricing permanence and perceived quality (World Bank 2026). For Mediterranean project developers, these rewards place higher value on higher-integrity coastal and land-based removals than on avoided-emissions claims, making revenue from low-quality categories an unreliable basis for investment.

Blue carbon is especially relevant because Mediterranean seagrass meadows, coastal wetlands, and salt marshes store carbon and provide biodiversity and coastal protection co-benefits. Methodological work in Andalusia under the LIFE Blue Natura project developed approaches for estimating stocks and fluxes in seagrass and tidal-marsh ecosystems. It supported a regional blue carbon standard, a useful precedent for linking coastal conservation with climate finance. Yet blue carbon crediting faces high measurement, permanence and leakage risks: stocks can be degraded by warming, coastal development, pollution, anchoring, trawling and storms. The cautious conclusion is that blue carbon can support conservation finance and adaptation-mitigation co-benefits, but its use as a tradable offset requires conservative accounting and long-term stewardship (LIFE Blue Natura 2022; Macreadie et al. 2019; Probst et al. 2024. IUCN 2025).

Table 5.15 I Comparative assessment of carbon trading mechanisms in Mediterranean countries and country groups. Source: assessment based on World Bank (2026), ICAP (2025a 2025b 2025c), European Commission (2025a), UNFCCC (2025a), European Parliament and Council (2023a 2023b) and national and institutional sources.

Regional cluster	Main instrument / status	Implementation evidence	Main assessment	Confidence
EU Mediterranean countries	EU ETS in force since 2005; CBAM definitive regime from 2026; ETS2 for buildings and road transport from 2028	Binding cap, harmonised MRV, verified compliance, auction revenues; power, industry, aviation and (from 2024) maritime	Only mature regional benchmark with strong evidence of reductions in covered sectors	*High*
Montenegro	National ETS in force; explicit EU-alignment objective	Few installations; accession and Energy Community dynamics drive convergence	Useful accession instrument; small size limits liquidity and independent mitigation evidence	*Medium-low*
Türkiye	Pilot ETS launched in 2026 under Climate Law No. 7552	Decade-long installation-level MRV; pilot covers cement, steel, aluminium, fertilisers above 50,000 t CO_2eq; design linked to CBAM	Major potential impact given industrial scale; mitigation not yet observable in compliance data	*Medium*
Morocco, Egypt, Tunisia	No mature compliance ETS; pricing or crediting readiness, voluntary markets, Article 6, registries	Activity in MRV, crediting, certificates and bilateral cooperation	Near-term effects institutional and financial; mitigation depends on credit integrity and policy follow-through	*Medium-low*
Algeria, Libya, Lebanon, Syria	No explicit mature carbon-trading mechanism at national scale	Indirect exposure via EU trade, energy-sector emissions and potential future crediting	Development constrained by political economy, subsidies, conflict or weak institutions	*Low to medium*

5.3.2 Effectiveness: emissions and economic impacts

Effectiveness is assessed through three lenses. Environmental effectiveness concerns whether covered emissions fall relative to a credible counterfactual. Economic effectiveness turns on whether reductions are achieved without disproportionate losses in output, employment or competitiveness, and on whether the instrument induces low-carbon investment. Institutional effectiveness is about whether the system builds durable data, verification capacity, revenue channels and compliance expectations. The three dimensions matter in the Mediterranean because many non-EU initiatives have not yet produced observable emissions outcomes yet plausibly create institutions that shape future mitigation capacity.

5.3.2.1 Environmental effectiveness

The EU ETS provides the strongest evidence base, but the claim must be stated carefully. Official reporting and the European Environment Agency indicate that emissions from stationary installations covered by the system fell by about 50% between 2005 and 2024, with a record annual fall in the stationary sector in 2023 and a further decline of close to 11% in the power sector in 2024, and that the system is on track for the 2030 target of a 62% reduction; cumulative auction revenue exceeds EUR 250 billion (European Commission 2025b; European Environment Agency 2025). This supports a high-confidence conclusion that the EU ETS is associated with substantial reductions in covered emissions. It does not justify attributing the entire decline to carbon pricing alone, since renewable deployment, coal-to-gas switching, energy price changes, efficiency policies, national coal phase-outs, and economic cycles interacted with the price signal. On a careful reading, the EU ETS is best understood as a binding component of a broader decarbonisation package *(high confidence that the EU ETS reduced covered emissions; medium confidence that the aggregate decline can be precisely allocated among drivers).*

Firm-level studies sharpen this interpretation. Reviews of the first decade concluded that the system reduced emissions at regulated firms, though early effects were muted by over-allocation and low prices (Martin et al. 2016). More recent causal evidence finds that regulated firms cut emissions by 14-16% in French manufacturing, without detectable losses in employment, revenue, or profits (Dechezleprêtre et al. 2023; Colmer et al. 2025). Evidence on innovation indicates that the EU ETS raised low-carbon patenting among regulated firms by roughly 10% without crowding out other inventive activity (Calel and Dechezleprêtre 2016). These identification-based results provide a stronger basis for assessment than aggregate trends alone.

The price signal underpinning these effects has strengthened markedly. The EU allowance price averaged around EUR 65 per tonne in 2024, compared with roughly EUR 25 per tonne in 2020 and EUR 5 per tonne in 2017, and auction revenue reached about EUR 24 billion in 2024 (European Environment Agency 2025). A credible, rising price is the channel through which the cap translates into investment decisions, and its level matters for the Mediterranean because it sets the reference against which CBAM charges and any domestic carbon price in neighbouring economies is measured. By comparison, emerging systems are far from this level: a small market such as Montenegro's clears near its reserve price, and Türkiye's pilot begins with full free allocation, so neither yet generates a scarcity signal comparable to the EU benchmark.

The system is also tightening the protections that previously softened the price signal. In aviation, free allowances were reduced to half in 2025 and removed entirely from 2026, with a separate per-tonne support introduced for sustainable aviation fuels, so that intra-European flights, including the many tourism routes across the basin, increasingly face the full carbon price (European Commission 2025b). In the industry, free allocation is being phased down in parallel with the introduction of CBAM, so that a charge on imports gradually replaces the protection given to trade-exposed installations. For the Mediterranean, this matters in two ways: it raises the effective carbon cost faced by aviation and industry within EU members, and it signals to neighbouring exporters that reliance on free allocation as a competitiveness cushion is being withdrawn, reinforcing the incentive to measure emissions and, where advantageous, to price them domestically *(medium confidence)*.

National outcomes within the EU system are sensitive to industrial structure. In several Mediterranean member states, a small number of installations account for a considerable share of covered emissions, so the retirement of a single dominant source can produce an abrupt fall in national ETS emissions. At the same time, a plant that continues to purchase allowances rather than abate locally can keep national emissions high even as the EU-wide cap binds, and reductions occur elsewhere. This is a feature of cap-and-trade rather than a failure of it: the environmental outcome is fixed at the EU scale through the cap, while the allowance market determines the location of abatement. For states seeking domestic decarbonisation, it nonetheless strengthens the case for complementary measures, such as renewable targets, grid investment and industrial efficiency standards, that translate the EU-level signal into faster local abatement.

For emerging Mediterranean systems, ex post evidence is thin. Montenegro shows that a small country can establish ETS institutions, but the scope is too narrow to draw high-confidence conclusions about emissions. Türkiye has greater mitigation relevance due to its industrial scale, yet its pilot has not generated compliance-period data. The appropriate assessment is conditional: an ETS could support mitigation if coverage, benchmarks, allocation, cap trajectory and enforcement become stringent; at present, the observable outcome is institutional readiness rather than verified abatement *(low to medium confidence for current mitigation outside the EU ETS; medium confidence for institutional readiness).*

5.3.2.2 Country evidence within the EU Mediterranean

Within the EU cluster, the clearest abatement has come from power-sector coal-to-clean substitution, which the carbon price reinforces alongside renewable support and falling technology costs. Across the EU, power-sector emissions covered by the system fell by nearly 11% in 2024 alone, and the share of emissions from hard-coal combustion reached a historical low, as wind and solar expanded and gas continued to displace coal (European Commission 2025b). The Mediterranean members are central to this trend: between 2015 and 2024, emissions from coal power fell by about 95% in Spain and about 89% in Italy, and both countries ended mainland coal generation in 2025, while Greece has committed to closing its lignite fleet (Ember 2024; European Commission 2025b). These outcomes illustrate the cap-and-trade logic in practice. Still, they also show that the carbon price operated within a package: renewable deployment, national coal phase-out commitments and demand changes were decisive, which is why attribution to pricing alone is not warranted *(high confidence that covered power-sector emissions fell; medium confidence on the precise contribution of the price signal).*

5.3.2.3 Investment, innovation and economic effects

Carbon markets can support investment and innovation when prices are credible, and policy design limits arbitrary intervention. The EU ETS has generated substantial auction revenues that feed into EU innovation and modernisation funds, and member states report directing most of the revenue to renewables, grids, energy efficiency, and clean mobility (European Commission 2025b). Effect sizes depend on price expectations, sectoral exposure, complementary innovation policy and access to finance.

Economic outcomes hinge on allocation and the use of revenue. Free allocation can reduce leakage risk and protect employment in trade-exposed sectors. Still, it can also generate windfalls where firms pass through the opportunity cost of allowances received for free. Auctioning improves fiscal transparency and allows revenues to be recycled into decarbonisation, household support or just-transition funds. The gradual replacement of free allocation by CBAM in covered sectors is a major design shift: it lowers reliance on free allocation while extending carbon-cost accounting to imports, transferring part of the distributional question from domestic firms to trade partners (Evans et al. 2021; European Parliament and Council 2023a,2023c)

Revenue scale gives this a concrete dimension. The EU system has generated cumulative auction revenue exceeding EUR 250 billion, of which a significant majority is reported by member states as spent on climate and energy purposes, and part is channelled through dedicated EU-level instruments such as the Innovation Fund and the Modernisation Fund that finance clean-technology demonstration and energy-system upgrading (European Commission 2025b). For Mediterranean members this provides a fiscal channel that links the carbon price to investment in renewables, grids and efficiency, and the same logic applies to neighbouring economies considering domestic pricing: the developmental value of an instrument depends heavily on whether the revenue it raises, or the CBAM bill it would otherwise cede to the EU, is recycled into industrial modernisation and the protection of vulnerable households rather than absorbed into general expenditure *(medium confidence).*

Cost-effectiveness is the core economic rationale of trading: a binding cap is met by allocating abatement to where it is cheapest. A firm with low-cost options can abate and sell allowances, while one facing high short-term abatement costs can purchase them, so that reductions occur where marginal costs are lower than under uniform mandates. The advantage erodes when markets are small or illiquid: in a system with few regulated sources, price formation is thin. It can be dominated by administrative features such as a reserve price, raising compliance costs for the few participants relative to a deeper market. This is one reason regional integration and linking are argued to improve efficiency, by widening the pool of abatement opportunities and strengthening price discovery *(medium confidence).*

For southern and eastern Mediterranean economies, the calculus differs. Markets may mobilise finance and improve access to green investment, but they also impose administrative burdens and expose exporters to compliance costs. The net effect depends on whether revenues, climate finance and technical assistance support industrial upgrading; without such support, diffusion may deepen asymmetries between the northern and southern shores *(medium confidence).*

5.3.2.4 Institutional effectiveness

The third lens is often the most relevant for the non-EU Mediterranean, because many initiatives there have not yet produced measurable emissions outcomes but are visibly building institutions. Institutional effectiveness concerns whether an instrument creates reliable emissions data, accredited verification, functioning registries, revenue channels and a compliance culture that can support stronger policy later. On this measure, the regional picture is more encouraging than the emissions record alone suggests: Türkiye has a decade of installation-level monitoring and a newly constituted market authority; Montenegro has built MRV, a registry and compliance routines despite its small size; and Egypt, Morocco and Tunisia are developing verifier rules, registries and product-level accounting under the pressure of CBAM and the opportunity of Article 6 (Financial Regulatory Authority of Egypt 2024; ICAP 2025b 2025c; UNFCCC 2025a). These developments are genuine gains in effectiveness, since a credible compliance architecture is a precondition for durable emissions constraints, even though they should not be presented as abatement in themselves *(medium confidence).*

Table 5.16 | Evidence assessment for carbon trading effectiveness. Source: assessment based on Calel and Dechezleprêtre, (2016); Colmer et al. (2025); Dechezleprêtre et al. (2023); European Commission (2025); European Environment Agency (2025); Martin et al. (2016); Probst et al. (2024); World Bank (2026)

Assessment dimension	Evidence from implementation	Mediterranean interpretation	Confidence
Environmental effectiveness	EU ETS-covered emissions fell by about 50% between 2005 and 2024; attribution shared with fuel switching, renewables, efficiency and demand	High confidence for EU ETS power and industry; weak for emerging schemes that remain pilot, readiness or crediting arrangements	*High* for EU ETS; *medium-low* elsewhere
Economic impacts and competitiveness	Firm-level studies find limited average adverse effects on regulated firms; allocation, auctioning and CBAM shape leakage and distribution	Pricing can support competitiveness where revenues, allocation and transition finance link to verified decarbonisation in cement, steel, aluminium and fertilisers	*Medium-high*
Investment and innovation	EU ETS evidence indicates higher low-carbon patenting and significant auction revenues for innovation and modernisation funds	Investment effects depend on price credibility, MRV quality, finance access and whether revenues or Article 6 income support upgrading	*Medium*
Voluntary markets and Article 6	Crediting can mobilise finance, but quality varies; fewer than 16% of issued credits estimated to be real reductions	Useful complements, not substitutes for direct sectoral reductions or robust domestic policy	*Medium-low*
Blue carbon and ecosystem credits	Co-benefits for mitigation and adaptation, but MRV, permanence, ownership and stewardship remain constraints	Relevant for wetlands and seagrass; market scale and accounting certainty limited versus compliance ETS	*Medium-low*
Regional integration potential	Linkage experience shows compatibility of caps, MRV, registries, enforcement and credit rules is a prerequisite	Immediate region-wide linkage unlikely; staged convergence more plausible	*Medium*

5.3.3 Equity implications and distributional considerations

Equity is not an external consideration added after market design; it is a determinant of political durability and implementation feasibility. Carbon markets redistribute costs and benefits through energy and product prices, allocation, auction revenue, credit income and investment flows. In the Mediterranean, these effects intersect with income inequality, cooling demand, transport dependence, energy poverty, regional unemployment and uneven state capacity. An environmentally coherent price can still face resistance if households perceive it as unfair or if industrial regions fear job losses without credible transition support.

5.3.3.1 Within-country equity

Distributional impacts differ by sector. Power-sector pricing affects electricity bills, although regulation, tariff structures and public support mediate pass-through. Transport and building fuels are more directly household-facing and therefore more politically sensitive. The EU response is visible in ETS2 and the Social Climate Fund, designed together because extending pricing to buildings and road transport creates explicit social risks for vulnerable households, micro-enterprises and transport users. This is directly relevant in a region where heat exposure and cooling needs make energy affordability a resilience issue as much as a mitigation issue (European Parliament and Council 2023b).

The scale and design of this response are instructive for the region. The Social Climate Fund is intended to mobilise at least EUR 86.7 billion over 2026 to 2032, combining revenues from ETS2 and the existing ETS with a national co-financing requirement of at least 25%, and it runs from 2026 so that support can precede the carbon-price signal; member states must set out measures in national social climate plans, and a capped share may be used for temporary direct income support while the balance funds structural investments such as building renovation, efficient heating and clean transport (European Commission 2025c; European Parliament and Council 2023b). The sequencing is the key lesson: compensation is timed to arrive before or alongside higher fuel costs, and most resources are directed to investments that lower future energy bills rather than to open-ended subsidies. The recent decision to postpone the start of ETS2 to 2028 also signals the political sensitivity of pricing household fuels. It underscores that the legitimacy of extending carbon costs to consumers depends on visible, well-targeted revenue recycling *(medium to high confidence).*

Allocation and transitional protection raise a second issue. Free allocation can be justified as leakage prevention, especially in cement, steel, aluminium and fertilisers, yet it can create windfalls or weaken incentives where benchmarks are loose. Transitional support is more defensible when it is temporary, transparent and conditional on verified decarbonisation, worker protection and regional diversification *(medium to high confidence).*

Distributional effects are not uniform across social groups, and the design of compensation must reflect this. Higher fuel and electricity costs weigh most on low-income households, but exposure is compounded for specific groups: older people face elevated heat and cooling vulnerability and often live on fixed incomes; rural households depend more on private transport with fewer low-carbon alternatives; and women and youth are over-represented among lower-income and energy-poor groups in parts of the basin. The Social Climate Fund is structured around this logic by targeting support to vulnerable households, micro-enterprises and transport users rather than spreading relief uniformly (European Commission 2025c; European Parliament and Council 2023b). The implication is that the equity performance of carbon pricing depends less on the instrument than on whether revenue is channelled to the groups most exposed to its cost *(medium to high confidence for differentiated impacts; medium confidence for the effectiveness of current targeting).*

5.3.3.2 Equity between countries

Between countries, the central issue is asymmetry. EU Mediterranean states have greater fiscal capacity, access to EU funds, and mature MRV institutions; many southern and eastern Mediterranean countries face tighter constraints, industrial upgrading needs, and higher sensitivity to energy price increases. CBAM makes this asymmetry visible: it is designed to reduce leakage and align carbon costs for imports, but it also imposes reporting and eventual financial obligations on exporters from countries with lower administrative capacity and lower historical per-capita emissions (Eicke et al. 2021; Magacho et al. 2024).

The implication is not that CBAM is irrelevant to mitigation. It can accelerate carbon accounting, improve product-level data and create incentives for domestic pricing. But its developmental effect depends on whether partner countries can access technical assistance, concessional finance, verification capacity and decarbonisation investment. If compliance costs are disconnected from such support, the policy may be perceived as a trade burden rather than a cooperative instrument *(medium confidence).*

The framing of differentiated responsibilities sharpens this tension. southern and eastern Mediterranean economies generally have lower historical and per-capita emissions than EU members, so a border charge that treats all exporters alike can appear inconsistent with the principle that countries should contribute according to differing responsibilities and capabilities, a concern voiced strongly in regional debates (Eicke et al. 2021; Magacho et al. 2024). The assessment does not resolve this normative question. Still, it identifies the practical hinge: where the EU pairs CBAM with finance, technology transfer and recognition of credible domestic carbon prices, the mechanism can function as a lever for cooperative decarbonisation; where it operates as an unaccompanied charge, it risks entrenching the very asymmetry it is criticised for and may push exposed producers toward markets with weaker climate requirements rather than toward abatement *(medium confidence).*

5.3.3.3 Intergenerational and local equity

Intergenerational equity gives pricing a long-term rationale: near-term mitigation reduces future damages that fall disproportionately on younger cohorts and vulnerable communities. This is especially salient in a basin exposed to drought, fire and marine degradation, where the remaining carbon budget is projected to be exhausted around 2035 on current trajectories (Román et al. 2025). The rationale strengthens the case for transparent revenue recycling into efficient housing, clean public transport, worker retraining, industrial modernisation, ecosystem restoration and adaptation to heat and water stress. For Article 6 and voluntary crediting, local equity also depends on stakeholder consultation, land and resource rights, benefit sharing, and grievance mechanisms, since weak contracts can allow intermediaries to capture credit revenues while communities bear opportunity costs. Conservative treatment of removals and nature-based credits is therefore an equity matter as well as an accounting one: it protects future generations from overestimated mitigation claims and from the loss of ecosystem services that are difficult to restore *(medium confidence).*

5.3.4 Technical and governance features

Technical design determines whether a carbon market represents credible scarcity or merely an administrative signal. The core features are monitoring, reporting, and verification (MRV); cap setting and coverage; allocation and auctioning; registries and oversight; and crediting and transfer rules. Across the Mediterranean, the dominant finding is heterogeneity: EU member states operate a sophisticated harmonised regime, while emerging systems are still building the foundations of credibility.

5.3.4.1 MRV and product-level emissions accounting

MRV is the foundation of compliance markets. The EU ETS requires covered installations to monitor emissions using approved methodologies, submit verified annual reports, and surrender allowances, accordingly, thereby embedding measurement directly into compliance; an installation cannot surrender allowances in the registry without a verified report, which reduces the scope for discretionary enforcement. For non-EU countries, the importance of MRV has risen sharply because CBAM requires reporting of embedded emissions in covered imports; MRV is therefore becoming a condition of competitiveness in trade-exposed sectors, not only a domestic policy choice (European Commission 2025; European Parliament and Council 2023).

The most visible and credible near-term outcome of diffusion in Türkiye, Morocco, Egypt and Tunisia is MRV development itself, which can improve inventories, support benchmarking, enable access to carbon finance and reduce investor uncertainty. Türkiye is illustrative: a mandatory installation-level monitoring regime covering more than 800 facilities has operated since 2015, providing the empirical basis for setting caps and allocations. The key risk is fragmentation: if each country develops incompatible registries, verification rules, and product-carbon methodologies, transaction costs will rise, and coordination will remain weak *(high confidence in the importance of MRV; medium confidence in the current quality of implementation outside the EU).*

CBAM sharpens this incentive through the way it treats missing data. Once the definitive regime requires verified embedded-emissions data, importers that cannot supply installation-specific figures must rely on default values designed to be conservative, so that poorly documented production is treated as relatively emissions-intensive (European Commission 2025b; European Parliament and Council 2023c). For Mediterranean exporters in cement, fertilisers, steel and aluminium, this creates a direct commercial reason to measure and verify actual emissions rather than accept a penalising default, and therefore a reason to build domestic MRV capacity that can also support a future domestic carbon price. For the near term, this makes the diffusion of measurement a more reliable consequence of the EU framework than the diffusion of pricing itself, and this measurement capacity is a precondition for both recognition under CBAM and any later market cooperation *(high confidence for the measurement incentive; medium confidence for whether it translates into abatement).*

5.3.4.2 Caps, allocation and price stability

An ETS delivers environmental certainty only when the cap binds, and its decline is consistent with mitigation objectives. Early EU ETS phases illustrate the cost of over-allocation: a loose cap produced low prices and weak abatement incentives, and later reforms, including a tighter cap and the Market Stability Reserve, restored the scarcity signal. Emerging systems can draw on this lesson by avoiding excessive free allocation, introducing transparent benchmarks and designing mechanisms to dampen extreme volatility.

The allocation method shapes incentives and distribution. The EU system has shifted toward auctioning as the principal method, with free allocation reserved for trade-exposed industry and declining over time, and with benchmark-based allocation preferred to grandfathering because it rewards lower-emission production within a sector and preserves the opportunity cost of allowances. This is directly relevant to cement, steel, aluminium, and fertilisers across the basin, where CBAM exposure pushes toward product-level reductions rather than only facility-level reporting (European Parliament and Council 2023 2023).

Scale conditions the choice of instrument. In a small stand-alone system such as Montenegro's, few installations make price discovery thin and volatile; reserve prices, corridors, banking or staged linkage can help, but cannot replace market depth. Türkiye's pilot uses benchmark-based free allocation, which eases competitiveness concerns in a growing economy while giving less certainty over absolute emissions than a fixed cap; convergence toward tighter benchmarks or an absolute cap would raise environmental credibility over time *(medium confidence).*

The choice between an ETS and a carbon tax is itself part of the design question. Evidence from the World Bank suggests that both can be effective when the price is meaningful. Coverage is broad: of the 87 instruments now in operation worldwide, carbon taxes and emissions trading systems are present in broadly comparable numbers, with most new and planned instruments being ETSs, often adopted in response to border measures (World Bank 2026). For smaller or capacity-constrained Mediterranean economies, a tax can be administratively simpler and provide price certainty, whereas an ETS provides quantity certainty and integrates more naturally with EU rules and potential future linkage; hybrid designs with price floors or corridors combine elements of both. The effectiveness of any of these depends on the same conditions: a price high enough to change behaviour, coverage of major sources, credible enforcement and transparent use of revenue *(medium confidence).*

5.3.4.3 Registries, crediting and Article 6 accounting

Registries are essential to prevent double issuance, track ownership, record cancellations and support compliance reconciliation. The EU operates a centralised registry whose security was strengthened after early cyber-theft incidents, and registry coordination underpins its linkage with the Swiss system. For newer systems, registry development is a major institutional undertaking. In Article 6.2 cooperation, registries must also distinguish mitigation outcomes authorised for international transfer from those counted toward the host-country NDC, with corresponding adjustments applied transparently. UNFCCC guidance sets out transparency and reporting requirements, including technical expert review, but the quality of implementation depends on national capacity (UNFCCC 2025a 2025b).

For voluntary and Article 6 crediting, the central question is whether credits represent real, additional, permanent and conservatively quantified mitigation. The ICVCM Core Carbon Principles provide an integrity benchmark covering governance, emissions impact, sustainable development and safeguards (ICVCM 2024). Independent evidence nonetheless shows persistent over-crediting across several project categories (Probst et al. 2024). Countries entering credit markets should separate two roles: using carbon finance to support projects, which can be valuable, and allowing credits to offset emissions elsewhere, which requires far stronger integrity conditions *(high confidence for integrity risks; medium confidence for the effectiveness of emerging safeguards).*

5.3.4.4 Market oversight and financial regulation

As carbon markets mature, they raise the same integrity questions as other traded markets: manipulation, opaque pricing, conflicts of interest and concentration. The EU has progressively integrated allowances into financial market regulation, treating them as financial instruments and applying market abuse and transparency rules, with periodic assessments of market functioning by the European Securities and Markets Authority (European Commission 2025b). Emerging Mediterranean systems have not yet established comparable oversight, and design choices remain open: Türkiye, for example, must determine the roles of its capital markets and energy regulators in supervising the new market, while intensity-based or benchmark designs place a premium on robust baseline rules to prevent exploitable loopholes. In voluntary markets, where transactions are bilateral and disclosure is uneven, the involvement of a financial regulator, as in Egypt, can materially improve credibility. Oversight, in this view, is not an administrative afterthought but a condition for investors and trading partners to trust the price, and convergence on market-conduct standards is a plausible area for regional cooperation *(medium to high confidence).*

5.3.5 Key challenges and risks

Four challenges recur across the Mediterranean carbon-trading landscape: transparency, market volatility, environmental integrity, and administrative or political-economy capacity. The first three apply across compliance and voluntary markets; the fourth weighs most heavily on southern and eastern Mediterranean countries.

5.3.5.1 Transparency

Carbon markets rely on trust that emissions, allowances, credits and transfers are recorded accurately. Where data are not public, methodologies are unclear, or registries are incomplete, a market can still function administratively while losing credibility in assessment. The risk is greatest in voluntary markets, where buyers may rely on labels that obscure project-level uncertainty, and in Article 6.2 cooperation, where some transaction information may be treated as confidential. For countries seeking climate finance, transparency is also a competitiveness asset, since credible data reduces perceived risk for investors and trading partners *(high confidence).*

Transparency operates at several layers. In compliance markets, it is comparatively strong by design: the EU publishes verified installation-level emissions and provides visibility into transactions through its registry, and several Mediterranean members disclose how auction revenues are spent, thereby supporting legitimacy by showing how proceeds are recycled (European Commission 2025b). In crediting systems, it must also reach the methodological level, since the credibility of a credit depends on transparent baselines and assumptions; the Mediterranean blue carbon methodologies are instructive because they were subject to scientific review and public consultation, which reduces the risk of accusations of creative accounting (LIFE Blue Natura 2022). A practical regional step would be a common template for reporting carbon-credit transfers and corresponding adjustments, improving comparability for domestic stakeholders and international partners alike *(medium confidence).*

5.3.5.2 Market volatility

Carbon prices move with energy prices, economic activity, policy announcements and expectations about future stringency. Volatility can weaken investment signals when firms are uncertain whether prices will stay high enough to justify low-carbon investment. The EU Market Stability Reserve was designed in part to address surpluses and instability. Still, younger markets lack comparable tools, and small systems such as Montenegro's face additional risk because limited liquidity amplifies price movements. Carbon taxes, price corridors or hybrid instruments may suit some economies better than a thin stand-alone ETS *(medium to high confidence).*

5.3.5.3 Environmental integrity

Integrity is the decisive constraint for voluntary and Article 6 markets. A credit that is non-additional, over-credited, impermanent, leaked, or double-counted does not carry the climate value of a real reduction. This is not marginal: systematic evidence finds that fewer than 16% of issued credits across a considerable sample correspond to real reductions, with no statistically significant effect for renewable-energy or improved-forest-management projects (Probst et al. 2024). Mediterranean blue carbon adds complexity because coastal ecosystems store carbon in ways that are valuable but sensitive to disturbance and measurement uncertainty. Conservative baselines, long monitoring periods, buffer pools, reversal rules and restrictions on offsetting claims are therefore necessary for credible use *(high confidence).*

Three integrity failures deserve specific attention in the regional context. Additionality is contested wherever the credited activity would have proceeded anyway: as renewables become cost-competitive across the basin, renewable-energy credits in upper-middle-income settings are increasingly difficult to defend as additional, which is consistent with the finding of no significant reductions from wind-power crediting (Probst et al. 2024). Permanence is especially fragile for land and coastal carbon in a region exposed to intensifying drought and wildfire, where a single extreme fire season can reverse the sequestration credited to afforestation or restoration projects; durable use therefore requires buffer pools, long-term monitoring, and conservative crediting (IUCN 2025; Macreadie et al. 2019). Leakage arises when constraints in one place displace emitting activity elsewhere, whether through industrial relocation or, in land-use projects, the shifting of degrading pressure to an unprotected area; jurisdictional approaches that cover larger areas reduce this risk. Because all three failures are more projected to occur precisely in the project types most available to Mediterranean developers, the assessment maintains a conservative confidence level for offset-based mitigation claims *(high confidence* in the existence of these risks*).*

5.3.5.4 Administrative and political-economy constraints

Carbon trading requires more than legislation: emissions data, accredited verifiers, registries, enforcement capacity, financial supervision, legal clarity, sectoral benchmarks and dispute resolution. These are demanding for countries facing fiscal pressure or conflict-related fragmentation. Political-economy constraints are substantial where fuel subsidies, hydrocarbon rents, energy-intensive employment or state-owned enterprises shape policy, which helps explain why several countries remain cautious despite indirect CBAM exposure *(medium to high confidence).*

Energy subsidies deserve particular emphasis because they interact directly with carbon pricing. In several southern and eastern Mediterranean economies, consumer energy prices are held below cost through subsidies that effectively impose a negative carbon price, working against any explicit carbon charge and straining public budgets; the global stocktaking of carbon pricing notes that the expansion of pricing in middle-income economies is closely tied to subsidy reform and to the search for revenue (World Bank 2026). Introducing a carbon price without addressing these subsidies would send contradictory signals, while reform is politically sensitive where affordable energy is part of the social contract. For parts of the region, the sequencing of subsidy reform, social protection and carbon pricing matters as much as the choice of market instrument, and carbon-market readiness cannot be judged in isolation from the broader fiscal and energy-pricing context *(medium confidence).*

Table 5.17 | Governance risks and implications for Mediterranean carbon markets. Source: assessment based on European Commission 2025a, ICAP 2025a, ICVCM 2024, Probst et al. 2024, UNFCCC 2025a, World Bank 2026.

Risk	Mechanism	Assessment implication	Confidence
Weak MRV	Inaccurate emissions data or incompatible methodologies	Undermines compliance, CBAM recognition and credit quality	*High*
Over-allocation	Excess allowances or loose intensity benchmarks	Depresses the carbon price and delays abatement	*High*
Thin markets	Few participants and low liquidity	Raises price volatility and market-power risk	*Medium-high*
Low-integrity credits	Weak additionality, baseline inflation, leakage or reversal	Creates accounting reductions without equivalent atmospheric benefit	*High*
Regressive pass-through	Carbon costs passed to vulnerable households or small firms	Requires revenue recycling and targeted social support	*Medium-high*
Unequal capacity	Limited technical, fiscal or institutional capacity in partner countries	Can turn carbon trading and CBAM into asymmetric compliance burdens	*Medium*

5.3.6 Interaction with EU mechanisms: EU ETS, CBAM and transport coverage

The EU ETS affects the Mediterranean through direct regulation, market prices, revenue flows and policy diffusion. Member states participate fully, while neighbouring economies treat its design as a reference for domestic reform. The 2023 revision strengthened the cap and extended coverage to maritime transport, which matters because shipping is concentrated around the basin's ports, tourism corridors, and trade routes, and because port-city air quality overlaps with mitigation efforts. The inclusion of shipping creates incentives for fuel efficiency, operational improvements, and low-carbon fuels, though outcomes depend on fuel availability, port infrastructure, and international maritime rules (European Commission 2025a; European Parliament and Council 2023a).

5.3.6.1 CBAM as a driver of carbon accounting and pricing diffusion

CBAM is the most important external driver of carbon market development across the basin. After a transitional reporting phase from 2023 to 2025, the definitive regime began on 1 January 2026, initially covering cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. A 2025 simplification refined the calendar and burden: certificate sales open in February 2027, the first annual declaration and surrender for 2026 imports fall due on 30 September 2027, the quarterly holding requirement was reduced from 80% to 50% of embedded emissions, and a 50-tonne de minimis threshold exempts an estimated 90% of importers while still covering around 99% of embedded emissions (European Commission 2025b; European Parliament and Council 2023c). Because CBAM allows recognition of a carbon price that is effectively paid in the country of origin, it creates an incentive for exporting countries to introduce domestic pricing rather than cede adjustment to the EU mechanism.

This incentive is visible in policy debates in Egypt, Tunisia, and Türkiye. The effect should be assessed mainly as an MRV and industrial-policy driver rather than a guarantee of near-term abatement: exporters of cement, fertilisers, steel or aluminium will increasingly need verified product-level data, and governments will need registries, verifiers and sectoral benchmarks. Whether emissions fall depends on whether firms use the information and price signal to invest in cleaner processes, efficiency, renewable electricity, fuel switching or low-carbon hydrogen *(high confidence for carbon-accounting effects; medium confidence for mitigation effects).*

The magnitude of exposure can be estimated for specific economies. A peer-reviewed input-output assessment for Morocco, whose exports are dominated by phosphate-based fertilisers and which sends most of its goods to the EU, places the CBAM carbon bill at roughly USD 20 to 34 million per year for Moroccan exporters in the initial phase, and finds that the country could offset much of this by introducing a domestic ETS or carbon tax or by accelerating decarbonisation, thereby retaining the revenue at home (Morchid et al. 2024). The Moroccan case captures the wider point: the mechanism transmits a measurable financial signal to exposed exporters, and whether that signal leads to mitigation or simply a transfer depends on the domestic policy response and access to finance *(medium confidence).*

The equity debate around CBAM is central. Studies argue that exposure is geographically and sectorally uneven and may create development risks for lower- and middle-income partners. For Mediterranean partners, the question is whether CBAM requirements come with technical assistance and decarbonisation finance: a cooperative approach would exert pressure to accelerate upgrading and MRV, while a non-cooperative one would raise compliance costs and political resistance (Eicke et al. 2021; Magacho et al. 2024) *(medium confidence).*

5.3.6.2 EU ETS expansion to shipping and aviation

The extension of the EU ETS to maritime transport is directly relevant, as the basin is a major shipping corridor. Large ships calling at EU ports are covered regardless of flag, with phased surrender obligations that extend pricing to routes connecting EU and non-EU ports and strengthen incentives for fuel efficiency, alternative fuels, shore-side electricity, and port decarbonisation; route shifts and uneven effects across coastal economies are possible. Aviation coverage affects tourism-dependent economies, improving the relative economics of efficiency and sustainable fuels, though short-run options remain constrained by technology, fuel availability and demand *(medium confidence for shipping; medium to low confidence for near-term aviation reductions).*

The design of maritime coverage clarifies how this signal reaches the Mediterranean trade. The obligation applies to ships of 5,000 gross tonnes or more calling at EU and EEA ports, irrespective of flag. It is phased in so that companies surrender allowances for 40% of verified emissions in respect of 2024, 70% in respect of 2025 and the full amount thereafter, with methane and nitrous oxide added to carbon dioxide from 2026 (European Parliament and Council 2023a; European Commission 2025b). Crucially for the region, voyages between two EU or EEA ports are fully covered. In contrast, voyages between an EU port and a non-EU port are covered at half their emissions, so trade between the northern shore and southern or eastern Mediterranean ports is partially priced. This creates a direct incentive for non-EU ports and operators around the basin to invest in efficiency, cleaner fuels and shore power if they wish to remain competitive on EU-facing routes, and it extends the reach of EU carbon pricing into maritime activity that no southern or eastern Mediterranean carbon market currently addresses *(medium confidence).*

Linkage practice is also evolving in ways that inform the regional assessment. Beyond the long-standing EU-Swiss link, the EU and the United Kingdom announced in 2025 their intention to link their respective systems, thereby reducing friction and extending the effective price domain (ICAP 2025a). The relevance for the Mediterranean is indirect but instructive: linkage remains contingent on comparable ambition and compatible MRV, registries and enforcement, precisely the bar that emerging basin systems would need to meet before deeper integration becomes credible.

5.3.6.3 Climate clubs, regional cooperation and knowledge transfer

Carbon pricing creates competitiveness concerns where only some countries impose carbon costs, which is the rationale for club approaches that link credible climate policy to benefits such as market access, technical assistance or reduced trade friction; the economic literature suggests clubs can curb free-riding where participation incentives are real, although implementation is politically difficult (Nordhaus 2015). A full Mediterranean carbon club is unlikely in the short term. More plausible is functional cooperation on MRV, product-carbon accounting, credit quality, verifier accreditation and registry interoperability. A concrete institutional step is the Regional Activity Centre on Climate Change, whose mandate was adopted under the Barcelona Convention at its 24th Conference of the Parties in Cairo in December 2025 and which is hosted in Ankara, providing an anchor for regional coordination and knowledge transfer (UNEP/MAP

2025). EU institutions, the Energy Community, the World Bank Partnership for Market Implementation, ICAP, and bilateral Article 6 partners can most credibly support readiness when this is framed as capacity building and industrial transition rather than the export of regulatory burdens *(medium to high confidence).*

Knowledge transfer is, in practice, the most actionable near-term opportunity. Readiness support has already shaped the regional landscape: the World Bank Partnership for Market Implementation has backed ETS design, registry development and Article 6 readiness in Türkiye, and EU and bilateral programmes have supported MRV and CBAM preparedness in Morocco, Tunisia and elsewhere (ICAP 2025c; World Bank 2026). For the southern and eastern Mediterranean, the most useful areas of cooperation concern product-level MRV in CBAM-exposed sectors, registry design, Article 6 authorisation, credit-quality assessment, and finance for low-carbon industrial investment. Cooperation of this kind transmits governance standards, since procurement criteria emphasising high additionality and sustainable-development co-benefits, as in established Article 6 partnerships, are adopted by host countries through authorisation and monitoring requirements. Framed this way, the regional agenda is less about building a single market than about raising the quality and comparability of the institutions on which any future integration would depend *(medium to high confidence).*

5.3.7 Opportunities and constraints for regional integration

Integration should be read pragmatically. Full linkage of all Mediterranean carbon markets is unlikely in the short term because countries differ in income, industrial structure, energy systems, administrative capacity and political priorities. Formal ETS linkage requires comparable ambition, robust MRV, compatible registries, legal recognition of units and confidence that one system will not undermine another. The EU-Swiss linkage shows that linkage is possible, but only with a high degree of regulatory compatibility, making immediate basin-wide linkage unrealistic where compliance markets do not yet operate *(high confidence).*

A staged pathway is more plausible. The first stage is common MRV improvement, especially in power, cement, fertilisers, steel, aluminium, electricity and hydrogen. The second is registry development and verifier accreditation. The third is coordination on Article 6 authorisation and corresponding adjustments. The fourth is limited mutual recognition of high-integrity credits or sectoral pilots, with broader ETS linkage credible only thereafter. This sequencing matches the current evidence: several countries are building data and crediting infrastructure, while only the EU cluster has a mature compliance market. It also leaves room for differentiated responsibilities, allowing capacity-constrained countries to begin with MRV, registries, and high-integrity crediting before economy-wide pricing, with support from EU technical assistance and the transparent use of carbon revenues *(medium confidence).*

The binding constraints are political economy and sovereignty. Pricing affects energy prices, industrial costs and public revenues, so governments are cautious about ceding design control, and linking to a stronger external system can be read as importing rules made elsewhere. Conversely, the EU is unlikely to link with systems perceived as weaker, since that could dilute prices or credibility. These concerns are not merely political: a linked system is only as strong as participants' confidence in each other's caps, registries and enforcement. Integration, in short, is more credible as technical convergence than as near-term market linkage, with *medium confidence* that staged convergence will deepen over five to ten years and *low confidence* that full regional linkage will emerge soon.

This staged reading has two advantages for an assessment. It avoids overstating political feasibility, and it concentrates attention on the features that most affect environmental integrity and trade compatibility, namely data, verification and credit quality, rather than headline announcements. It also accommodates differentiated responsibilities: lower-income or capacity-constrained countries can begin with MRV, registries, and high-integrity crediting before adopting economy-wide pricing, while EU members support the transition through technical assistance, investment, and the transparent use of carbon-related revenues. The constraints remain real, since countries differ in energy systems, fiscal structures, and political priorities; some rely heavily on hydrocarbon production or subsidies, and competition to supply cheap credit could weaken standards if integrity rules are diluted. These are reasons to treat integration as a gradual institutional process rather than a single market-building project *(medium confidence).*

The carbon-budget context sharpens the stakes of this sequencing. With the region's remaining budget for the 2°C goal projected to be exhausted around 2035 and required reductions of roughly 6% per year between 2030 and 2050, the value of carbon-market cooperation lies less in eventual linkage than in how quickly it can raise the credibility of measurement, the coverage of pricing and the integrity of credits across exposed sectors (Román et al. 2025). On that test, the most useful near-term contributions are common MRV in CBAM-relevant industries, interoperable registries and verifier accreditation, and clear Article 6 authorisation rules, all of which can proceed without waiting for full market integration.

A pragmatic near-term agenda, therefore, has four elements that can advance in parallel and are supported by the evidence. The first is harmonising product-level MRV in cement, fertilisers, steel, aluminium, electricity and hydrogen, so that Mediterranean exporters can demonstrate actual rather than default emissions under CBAM (European Commission 2025b). The second is developing interoperable registries and a common pool of accredited verifiers, lowering the transaction costs that fragment small markets. The third is strengthening Article 6 governance, including transparent authorisation, corresponding adjustments and benefit-sharing, so that internationally transferred mitigation is credible and equitable (UNFCCC 2025a, 2025b). The fourth is converging on high-integrity credit standards, anchored in the Core Carbon Principles, to protect the climate value of voluntary and blue carbon credits (ICVCM 2024). None of these requires a single regional market; each is within the reach of current institutional capacity with external support, and together they would leave the region better placed for whatever deeper cooperation later proves feasible *(medium confidence).*

Box 5.3 Assessment indicators for the second Global Stocktake cycle

- Coverage: the share of regional emissions covered by binding caps or equivalent prices, which signals whether markets reach major sources rather than niche activities.
- MRV quality: the quality and public availability of facility-level and product-level data, especially in CBAM-exposed sectors, which determines comparability and credibility
- Revenue and finance use: whether auction revenues, tax proceeds and Article 6 or voluntary-market finance support real decarbonisation, social protection and industrial upgrading.
- Credit integrity: additionality, conservative baselines, registry traceability, corresponding adjustments and rules for reversals and leakage, which distinguish real mitigation from weak offset claims.

These indicators are more informative than the number of announced initiatives because they focus on implementation and observed outcomes (ICVCM 2024; UNFCCC 2023; World Bank 2026).

Table 5.18 | Carbon-market indicators for assessment and follow-up. Source: assessment based on European Commission 2025b, ICVCM 2024, UNFCCC 2023 and 2025a, World Bank 2026.

Indicator	*Operational measure*	*Assessment use*	*Confidence*
Coverage	Share of emissions or installations under a binding ETS, carbon tax or equivalent pricing rule	Shows whether markets address major emitting sectors	*High*
MRV quality	Verified facility-level and product-level emissions, accredited verifiers and public reporting	Determines comparability, CBAM readiness and credibility	*High*
Revenue and finance use	Auction revenues, tax proceeds, Article 6 and voluntary-market finance allocated to mitigation and just transition	Links instruments to implementation capacity and legitimacy	*Medium-high*
Credit integrity	Additionality, conservative baselines, permanence, leakage control, registry traceability and corresponding adjustments	Distinguishes real mitigation from weak offset claims	*High*
Distributional safeguards	Targeted household support, worker transition, local benefit sharing and consultation	Indicates whether trading is politically and socially durable	*Medium*

5.3.8 Conclusion

Carbon trading is now part of the Mediterranean mitigation landscape, but maturity and effectiveness vary sharply. The EU ETS is the only mechanism with a long implementation record and strong evidence of emissions reductions in covered sectors, and it provides the regional benchmark for cap setting, MRV, compliance and revenue generation. Montenegro and Türkiye illustrate EU-aligned convergence outside the EU, although their systems are best assessed as institutional development rather than proven abatement. Egypt, Morocco, and Tunisia show a third pathway based on carbon accounting, voluntary markets, Article 6 and sectoral readiness, with potential benefits for finance and trade adaptation but limited evidence so far on emissions outcomes.

The evidence supports three conclusions. Carbon markets can contribute to mitigation when caps bind, MRV is credible, compliance is enforced, and revenues are used transparently. They are not automatically effective: weak caps, over-allocation, low-integrity credits, poor transparency and regressive pass-through can undermine both mitigation and legitimacy. And regional cooperation is most plausible through staged convergence rather than immediate full linkage, with MRV, registries, verifier accreditation, credit integrity and product-level accounting as the practical foundations.

For the second Global Stocktake cycle, the relevant question is not how many initiatives the region announces. It is about whether covered emissions decline, whether industrial exporters produce verified product-level data, whether revenues and credit finance support real decarbonisation and a just transition, and whether voluntary and Article 6 credits avoid double-counting and over-crediting. On these criteria, the record is mixed: strong and measurable within the EU ETS, promising but unproven in emerging systems, and conditional in voluntary and blue carbon markets. Set against a regional carbon budget projected to run out around 2035, this differentiated reading argues for treating carbon trading as a useful instrument within a broader portfolio of direct sectoral mitigation, public investment, regulation, and social safeguards, rather than as a substitute for them.

Two implications follow for how the chapter presents carbon markets. First, the evidence hierarchy should be respected: *high confidence* attaches to the direction of EU ETS effects on covered emissions*, medium confidence* to innovation and investment effects, medium to *low confidence* to emerging systems whose design is still developing, and *low to medium confidence* to the mitigation equivalence of voluntary and blue carbon credits. Reporting that flattens these distinctions would overstate what is known. Second, the regional value of carbon markets in the near term lies less in trading volumes than in the institutions they build, namely measurement, verification, registries and credit-quality rules, which are the foundations for both domestic mitigation and any future cooperation. Assessed on that basis, carbon trading is a developing and uneven instrument in the Mediterranean: established and effective in one cluster, institutionally promising in others, and dependent everywhere on integrity, transparency and the credible use of revenue.

5.4 Co-benefits and trade-offs

Key messages

- Integrated adaptation–mitigation strategies are essential in the Mediterranean, where accelerating warming, water scarcity, and ecosystem degradation demand solutions that simultaneously reduce emissions and strengthen resilience *(high confidence).*
- Multiple sectors already offer strong synergies, from agroecological practices that boost soil carbon and climate-resilient production, to floating photovoltaics that save water while generating clean energy, to urban interventions that reduce heat stress and energy demand *(medium confidence).*
- Strategic planning must balance short-term deployable actions with long-term structural transformations, while managing trade-offs such as land competition, biodiversity impacts, and the risk that some adaptation measures (e.g. irrigation, desalination) may increase emissions if not powered by renewables or managed carefully *(medium confidence).*

Aim: Identifies synergies and trade-offs between adaptation and mitigation strategies, emphasising integrated solutions with multiple benefits without producing more GHGs.

5.4.1 Joint adaptation-mitigation strategies and synergies

Key messages

- Integrated strategies deliver multiple dividends: reduced emissions, lower exposure to heat and floods, and stronger ecosystem services *(medium confidence).*
- High-potential synergies include building retrofits and urban greening, FPV on reservoirs, agroecology, and blue carbon restoration *(medium confidence).*
- Implementation requires coordination across sectors so that adaptation measures do not increase emissions through energy-intensive water and cooling solutions. *(high confidence)*
- Regional cooperation to enhance regional synergies.

Addressing climate change in the Mediterranean increasingly requires integrated strategies that deliver both adaptation and mitigation outcomes. This is essential in a region simultaneously confronting accelerated warming, water scarcity, sea-level rise, and ecosystem degradation.

Several technological and nature-based options already deployed in the Mediterranean provide clear examples of these synergies. Coastal wetland and seagrass restoration, for instance, strengthens shoreline protection against storm surges and saltwater intrusion while serving as highly effective blue-carbon sinks that store substantial amounts of organic carbon.

Another example of a joining adaptation-mitigation is nature-based solutions: agroecological practices. Agroecology is increasingly recognised as a powerful dual adaptation–mitigation strategy for Mediterranean agricultural landscapes. Practices such as agroforestry, crop diversification, intercropping, soil organic and reduced tillage strengthen ecosystem resilience to drought, heatwaves, and soil erosion. At the same time, these practices increase soil carbon sequestration, enhance biodiversity, and reduce the need for energy-intensive fertilisers and irrigation, leading to significant mitigation co-benefits. Recent scenario analyses show that agroecological landscapes in Mediterranean rural areas can shift from net emitters to net carbon sinks while improving water retention and reducing land degradation (Brandolini et al. 2025). Agroecology also supports climate-resilient rural economies by stabilising yields under extreme climate conditions and reducing dependence on external inputs, further strengthening long-term adaptive capacity.

Similarly, the deployment of floating photovoltaic (FPV) systems on reservoirs reduces evaporation losses, which are crucial under intensifying drought cycles, while simultaneously generating clean electricity and lowering emissions (Ilgen 2024; Santos et al. 2022; Farrar 2022).

Urban interventions offer additional dual benefits. Green roofs, urban vegetation, and permeable surfaces reduce heat stress and improve stormwater management while decreasing energy demand for cooling, an important co-benefit in Mediterranean cities with high summer temperatures (Vassiliades et al. 2024). In the built environment, deep renovation and building-integrated PV (BIPV) improve thermal resilience to heatwaves while contributing to long-term emission reductions (Manso-Burgos et al. 2023). Similarly, sustainable mobility technologies such as electrified public transport and cycling networks enhance air quality, reduce urban heat due to lower vehicle concentration, and cut greenhouse gas emissions (Sifuentes-Muñoz et al. 2025).

From a planning standpoint, joint adaptation–mitigation strategies require a short-term focus on deployable, high-impact measures such as energy-efficient retrofits, urban cooling solutions, and water-saving FPV combined with long-term structural transformations, including restored coastal ecosystems, resilient land management, and integrated renewable-energy systems (Brandolini et al. 2025; ECCO 2024). Trade-offs, however, remain important: renewable-energy infrastructures must avoid sensitive ecological areas, and adaptation measures such as desalination must be powered by

Despite the potential for SOC sequestration to counteract crop- and livestock-related GHG emissions, climate change (increased temperature and decreased soil water content) will increase SOC mineralisation and reduce plant biomass production (i.e. lower carbon input). Irrigation and best management practices are necessary. However, increased irrigation may lead to increased emissions elsewhere in the system (Aguilera et al. 2021).

5.4.2 Possible conflicts with food production and biodiversity

Key messages

- Drought-intensified Mediterranean conditions increase competition for land and water, with land-intensive mitigation options such as afforestation of non-forest shrublands, monoculture plantations and dedicated bioenergy and BECCS associated with higher risks for food production, biodiversity and hydrological systems.
- While many land-based mitigation options entail trade-offs with food production and biodiversity, lower-conflict options include dietary and food-system shifts, agroecology and regenerative practices, native reforestation on historically forested land, agroforestry and silvopastoral systems, and small-scale wetland and riparian restoration. These approaches are associated with co-benefits such as improved soil moisture, enhanced biodiversity, yield stability, and reduced fire susceptibility.
- Land competition arising from renewable-energy deployment varies across technologies, with agrivoltaics and floating PV commonly described as land-sparing approaches, while ground-mounted PV in high-value or sensitive landscapes is more often associated with localised food- and biodiversity-related pressures.
- Dietary patterns are an important driver of land and water demand, with plant-rich Mediterranean-style diets consistently associated with lower land footprints, reduced water use and lower agricultural emissions than current regional consumption trends.
- Maritime traffic.

5.4.2.1 Mediterranean constraints that amplify conflicts

Mitigation measures in the Mediterranean, i.e., renewable-energy siting (PV, wind onshore or offshore), afforestation and reforestation, soil-carbon enhancement via agroecology and regenerative practices, agroforestry or silvopastoral systems, wetland/riparian restoration, and bioenergy/BECCS, can reduce emissions and build resilience. Dietary shifts toward more plant-rich Mediterranean diets can also ease pressure on land and water. However, in a climate hotspot marked by warming of ~1.5 °C above the pre-industrial era and more frequent and intense droughts, such measures may also compete for scarce land and water and drive trade-offs with food production and biodiversity if poorly designed (IPCC 2022a; Toreti et al. 2024).

The Mediterranean’s constrained biophysical context, with chronic water scarcity, strong warming signals, and persistent agricultural and hydrological drought, means that mitigation actions that expand land or water footprints readily heighten conflicts with agriculture and ecosystems. Recent evidence from Spain, Portugal, Morocco, Algeria and Italy (2023–2024) shows low reservoirs, vegetation stress, early yield losses and widespread water-use restrictions (Toreti et al. 2024), underscoring the diminishing room for additional land- or water-intensive mitigation. UNEP’s GEO-7 assessment (UNEP 2025) highlights the interconnected pressures of climate change, biodiversity loss, land degradation and pollution. It warns against maladaptation, including ‘double allocation’ of land for energy or carbon sequestration at the expense of food and ecosystems. WEFE-nexus analyses similarly stress the need for water-first planning to avoid reinforcing trade-offs (Drobinski et al. 2025).

5.4.2.2 Measure-by-measure assessment

5.4.2.2.1 Renewable energy siting: ground-mount PV, agrivoltaics and onshore wind (succinct version)

Studies analysing renewable-energy deployment in Mediterranean landscapes identify substantial variation in land requirements and ecological outcomes among different solar and wind technologies. Ground-mounted photovoltaic (PV) installations exhibit relatively high land-use intensity, with empirical assessments showing that the area needed per unit of electricity produced can exceed that of many other low-carbon technologies, raising concerns about habitat conversion and potential competition with croplands in regions with limited available land (Lovering et al. 2022; Bolinger and Bolinger 2022). Reported impacts include localised vegetation removal, soil disturbance, and changes in habitat structure, which can affect species sensitive to land-cover modification.

In contrast, agrivoltaic systems, where crops and solar panels are co-located, appear in the literature as a means of reducing land-use conflicts by maintaining agricultural production beneath or between elevated solar structures. Mediterranean pilot studies report stable or moderately increased yields for certain crops under partial shading, alongside improved microclimate conditions during heat stress, although outcomes depend strongly on panel geometry, crop type, and irrigation context (Walston et al. 2022; Trommsdorff et al. 2025). These studies indicate that agrivoltaics generally involve lower habitat disturbance than ground-mounted PV, while still expanding solar capacity.

Floating PV (FPV) on reservoirs has been examined as another land-sparing option. Potential co-benefits have been observed, such as reduced evaporation and improved panel performance due to cooling. Still, there is also a need to evaluate site-specific ecological interactions, including possible effects on aquatic ecosystems and reservoir operations (Almeida et al. 2022). FPV installations are increasingly being tested in Mediterranean water bodies, where space constraints or land competition are prominent, and countries across the Basin have been identified as having high FPV potential, for example, Morocco, Portugal, Tunisia, Egypt, Syria, and Türkiye (Almeida et al. 2022).

For onshore wind, turbines have a relatively small direct land footprint, with most surrounding areas remaining available for grazing or low-intensity agriculture (Rnjak et al., 2023). While collision risk for some bird and bat species does occur, particularly during late-summer and autumn migration periods, empirical evidence from southern Europe indicates that impacts vary strongly by species, local topography and turbine configuration (Salguero et al., 2023). Crucially, when viewed relative to other forms of infrastructure, onshore wind represents a much smaller source of wildlife mortality. An assessment in the USA showed that power lines kill millions of birds annually (Loss et al. 2014), while the only direct field comparison using harmonised methods found that power line fatalities per hectare were three times higher than those from nearby wind turbines in the same landscape (Brenninkmeijer and Klop 2017). Against this wider context, the relative contribution of onshore wind to bird and bat mortality is small, particularly compared with power-line impacts, provided that wind farms are sited and operated with appropriate ecological safeguards. Moreover, painting one blade of a turbine black has been found to increase visibility and reduce bird fatalities by more than 70% (May et al. 2020).

Renewable energy deployment offers very high mitigation potential by displacing fossil fuel-based electricity. Lifecycle emissions from solar and wind power are typically in the range of 10–50 gCO_2e per kWh, compared to approximately 400–1000 g CO_2eq kWh^{-1} for fossil fuel-based generation, implying avoided emissions of approximately 400–900 g CO_2eq per kWh^{-1} generated (IPCC 2022). At the system level, this translates into substantial mitigation impacts, with installations at the gigawatt scale capable of avoiding several megatonnes of CO_2 annually, depending on the carbon intensity of the displaced energy mix.

These mitigation benefits, however, are associated with land-use and ecological trade-offs that are highly context dependent. Ground-mounted solar and, to a lesser extent, onshore wind may compete with agriculture and biodiversity in land-constrained or high-value landscapes, particularly in Mediterranean regions characterised by water scarcity, habitat sensitivity, and multifunctional land use.

Overall, evidence indicates that renewable energy technologies span a spectrum of land-use interactions, from higher-impact installations (e.g. ground-mounted PV) to lower-conflict or co-location approaches such as agrivoltaics and floating PV. This diversity highlights the importance of spatial planning and system design in determining whether the deployment of renewables primarily leads to land competition or generates synergies with food production and ecosystem services (IPCC 2022; Walston et al. 2022; Lovering et al. 2022).

5.4.2.2.2 Dietary change and food-system shifts

Recent assessments examining the environmental footprint of dietary patterns in Mediterranean countries show a clear distinction between traditional plant-rich Mediterranean diets and current consumption trends, which in many cases feature substantially higher intakes of meat and dairy (Castaldi et al. 2022; Tepper et al. 2022). Analyses based on life-cycle and footprint metrics consistently report that dietary patterns with lower ruminant-meat consumption (e.g. beef, lamb) tend to exhibit reduced land requirements, lower water footprints, and lower associated GHG emissions, with several studies identifying dietary change as one of the most influential demand-side levers affecting land competition in the region (Vanham et al. 2021). At the EU scale, modelling studies indicate that shifts toward more plant-rich diets, when combined with agroecological production systems, can maintain overall calorie exports without cropland expansion, while reducing pressure on grasslands and lowering reliance on feed imports (Schiavo et al. 2023). Conversely, scenarios assuming unchanged dietary patterns tend to show higher competition for cropland and increased dependence on imported feed and food commodities.

Across the Mediterranean, the implications of dietary change therefore appear closely linked to regional land-use dynamics, influencing the demand for grazing areas, feed crops, and irrigated agriculture. The literature broadly identifies dietary shifts as a factor that can modulate pressure on land and water resources, although outcomes depend on baseline consumption patterns, cultural preferences, and the structure of agricultural sectors in individual countries (Castaldi et al. 2022; Tepper et al. 2022).

Demand-side measures such as dietary shifts have high mitigation potential at the system level, with transitions toward plant-based diets estimated to reduce food-system greenhouse gas emissions by approximately 20-50%, and by around 3-8 Gt CO_2-equivalent per year globally under ambitious dietary change scenarios (Clark et al. 2020; IPCC 2022).

5.4.2.2.3 Afforestation and reforestation (A and R)

The outcomes of afforestation and reforestation in the Mediterranean vary widely with ecosystem type, water availability and historical land cover. Establishing tree cover on cropland or productive rangeland can reduce food-producing area and, in several Mediterranean catchments, has been linked to lower water yield due to increased evapotranspiration under drought-prone conditions (Nadal-Romero et al. 2023). Most importantly, it has been demonstrated that native forest restoration tends to provide stronger biodiversity, soil and water benefits than plantation-based afforestation, particularly in dry regions (Hua et al. 2022).

In long-established shrubland and maquis ecosystems, conversion to closed-canopy forest is associated with loss of shrubland specialist species, reductions in habitat heterogeneity and, in some cases, changes in fuel structure relevant to fire regimes (Peñuelas and Sardans 2021; Roy et al. 2024). Regional case studies from the Iberian Peninsula, Apennine or Balkan ranges, and the Levant illustrate how these effects manifest under varying drought intensities, terrain types, and vegetation histories (Hua et al. 2022; Toreti et al. 2024).

Overall, afforestation and reforestation outcomes are strongly context-dependent, with ecological and hydrological responses varying with species composition, previous land cover, and local climate conditions (Hua et al. 2022; Nadal-Romero et al. 2023). These interventions generally offer relatively high mitigation potential, with carbon sequestration rates typically in the range of approximately 2–6 t CO_2 per hectare per year, depending on species, climate, and management. This range is consistent with recent global analyses of forest regrowth, which identify substantial carbon uptake from reforestation and natural regeneration across a wide range of biomes (Cook-Patton et al. 2020; IPCC 2022).

However, the realisation of these mitigation benefits is contingent on land-use context. When implemented at scale on non-forested land, afforestation and reforestation can generate trade-offs with food production, biodiversity, and water availability, particularly in Mediterranean systems characterised by drought-prone conditions and long-established open ecosystems. As a result, native forest restoration and regeneration on historically forested land are generally associated with lower conflict and higher co-benefits than large-scale plantation-based approaches.

5.4.2.2.4 Agroecology

Agroecological and regenerative approaches in Mediterranean farming systems have been shown to improve soil moisture retention, soil carbon, and crop stability, particularly under high climatic variability. Practices such as reduced tillage, cover crops, organic amendments, and diversified rotations are frequently associated with improvements in soil structure and water-holding capacity, which can help buffer crops against seasonal drought (Hrameche et al. 2024; Pelman et al. 2024).

Biodiversity benefits are also reported, with field-margin vegetation, hedgerows, and reduced chemical inputs supporting a wider range of plant and invertebrate communities, although yield responses vary depending on local soils, crop types, and management histories (Santos et al. 2022; Altieri et al. 2025). Evidence from Mediterranean foothills and dryland systems indicates that these approaches can reduce erosion and improve soil function on sloping or degraded terrain, while maintaining or modestly enhancing productivity in many cases (Hrameche et al. 2024).

Across the region, the literature underscores that outcomes remain strongly context-dependent, shaped by water availability, crop choice, and the degree of existing land degradation. Nonetheless, agroecological and regenerative practices consistently appear in the literature as lower-conflict, land-based mitigation options compared with more land- or water-intensive alternatives (IPCC 2022b; Pelman et al. 2024).

Consistent with this characterisation, agroecological and regenerative practices are typically associated with moderate but robust mitigation potential, primarily through soil carbon sequestration. Per-hectare sequestration rates are generally modest and highly variable, with empirical studies in Mediterranean and comparable systems commonly reporting values on the order of a few tenths of a tonne of CO_2-equivalent per hectare per year. This is consistent with recent high-resolution global analyses of agricultural soil carbon dynamics, which identify significant but limited sequestration potential relative to other land-based mitigation options (Sanderman et al. 2017; Bossio et al. 2020).

Despite relatively modest per-hectare mitigation rates, these practices provide important co-benefits for soil health, water retention, and resilience, making them a key component of low-conflict mitigation portfolios in Mediterranean landscapes.

5.4.2.2.5 Agroforestry or silvopastoral systems

Agroforestry and silvopastoral systems in Mediterranean regions are often associated with improved soil structure, microclimate buffering, and higher landscape biodiversity, significantly due to increased structural heterogeneity and perennial vegetation cover (Santos et al. 2022; Tsiakiris et al. 2024). Studies from traditional systems such as the Dehesa or montado in south-west Iberia report co-occurring carbon storage, forage production and species-rich understories when tree density and grazing pressure are balanced.

Evidence from North African drylands shows that integrating native shrubs, such as Atriplex, can enhance forage biomass and water infiltration while maintaining agricultural use of surrounding land (El Mzouri et al. 2025). Across the region, outcomes appear sensitive to species choice, tree spacing, and grazing management, with research generally indicating that these systems represent lower-conflict mitigation options compared with more land- or water-intensive interventions (Tsiakiris et al. 2024).

Agroforestry and silvopastoral systems are also associated with meaningful mitigation potential through both biomass and soil carbon sequestration. Reported carbon sequestration rates vary widely depending on system type and climatic conditions, with global estimates typically on the order of 0.3–2 t C per hectare per year, equivalent to approximately 1–7 t CO_2 per hectare per year. However, lower values are generally observed in Mediterranean and low-density silvopastoral systems (Zomer et al. 2016).

5.4.2.2.6 Wetland and riparian restoration

Studies examining Mediterranean wetland and riparian restoration describe benefits for water regulation, flood moderation, water quality, and habitat provision, especially in landscapes experiencing seasonal hydrological stress (Creed et al. 2022; MedWet 2022). Re-wetting or reconnecting floodplains can contribute to downstream irrigation stability and support species-rich wetland assemblages, although in some cases this involves reductions in local arable areas.

Examples from the Po–Adriatic and Northern Adriatic regions highlight the role of riparian mosaics in reducing peak flows and improving hydrological reliability for high-value crops (MedWet 2022; Giovannini et al. 2025). In coastal lagoon systems of the Maghreb and Iberia, wetland buffers have been reported to reduce salinity intrusion and enhance the resilience of adjacent farmland. Overall, wetland and riparian restoration is a context-dependent but frequently low-conflict mitigation option within Mediterranean hydrological regimes (Creed et al. 2022).

Wetland and riparian restoration can also provide substantial mitigation benefits through both carbon sequestration and the avoidance of emissions from degraded or drainted systems. Reported mitigation magnitudes vary widely depending on hydrological conditions and prior land use, with studies indicating typical fluxes of approximately 1-5 t CO_2eq ha^{-1} yr^{-1} for mineral wetlands and riparian systems, and substantially higher values (often exceeding 5-20 t CO_2eq ha^{-1} yr^{-1}) for re-wetted organic soils and peatland systems (Günther et al. 2020).

5.4.2.2.7 Bioenergy crops or BECCS

Dedicated bioenergy crops and BECCS are among the most land- and water-intensive mitigation options, with implications that are particularly pronounced in drought-prone Mediterranean systems. Large areas are typically required to produce energy from biomass, often exceeding land requirements of other renewables, and can lead to habitat conversion and increased water demand where irrigation is involved (EASAC 2022; IPCC 2022a).

Modelling work indicates that biodiversity impacts tend to be greatest where extensive land-use change accompanies bioenergy expansion, especially when semi-natural vegetation or grazing land is replaced (Hirata et al. 2024; Smith et al. 2024). The hydrological dimension is particularly relevant in the region: recent drought analyses in the Maghreb and Iberian Peninsula report prolonged low reservoir levels and vegetation stress during 2022–2024, conditions under which additional water-demanding biomass cultivation may intensify existing pressures on agriculture and ecosystems (JRC 2023; JRC 2024).

The environmental impacts of bioenergy systems also depend strongly on the mode of production. Large-scale dedicated bioenergy crops are frequently established as monocultures and may require substantial inputs of fertilisers, irrigation, and mechanisation, leading to additional greenhouse gas emissions and pressures on soils and biodiversity. These characteristics align bioenergy production in some contexts with industrial agricultural systems and may reduce net mitigation benefits when full life-cycle emissions are considered (EASAC 2022; IPCC 2022). In contrast, smaller-scale or integrated bioenergy production systems, such as on-farm biomass use for machinery or local energy supply, may reduce reliance on fossil fuels while maintaining greater landscape diversity and lower input requirements. Such approaches can provide more localised mitigation benefits with reduced land-use conflict, although their overall contribution to large-scale emissions reduction is typically more limited (IPCC 2022).

Across Mediterranean subregions, assessments consistently find that outcomes depend strongly on water availability, ecosystem type, and existing land competition, with residues and wastes appearing more compatible than dedicated biomass production in recent evaluations (JRC 2023; Hirata et al. 2024). The extent to which bioenergy contributes to mitigation depends strongly on land availability and prior land use. Evidence indicates that lower-conflict outcomes are more likely where bioenergy crops are deployed on marginal, degraded, or otherwise underutilised land, whereas cultivation on productive agricultural land or semi-natural ecosystems can intensify competition with food production, biodiversity, and water resources (IPCC 2022; EASAC 2022).

Scenario analyses indicate that many low-emissions pathways rely on large-scale deployment of BECCS in the second half of the century. This raises concerns that delayed mitigation could increase dependence on future carbon removal. If BECCS deployment does not materialise at the scale assumed, this could result in higher cumulative emissions, increased mitigation costs, and more abrupt or disruptive transitions, with associated environmental and socio-economic impacts (EASAC 2022; IPCC 2022).

5.4.2.3 Sea-space competition

Recent research on offshore wind development in the Mediterranean highlights a growing interest in floating turbine technologies, which are being considered in several parts of the basin due to deep coastal bathymetry. Studies examining the ecological dimensions of this expansion report a range of potential interactions between offshore wind infrastructure and marine ecosystems. These include the possibility of collision or disturbance risks for seabirds and bats, noise-related impacts on marine mammals during construction, and changes in benthic habitats associated with mooring and anchoring systems (Lloret et al. 2023; Danovaro et al. 2024).

Spatial analyses combining wind resource maps with species-distribution or foraging-activity data indicate that areas with favourable wind conditions can overlap with biodiversity hotspots, such as seabird foraging zones and cetacean pathways (Morant et al. 2025). Some studies also describe cases in which offshore wind project areas intersect with, or occur near, marine protected areas (MPAs), prompting discussions in the literature about the ecological sensitivities of such locations (Wawrzynkowski et al. 2024).

Table 5.19 | Land and sea competition by mitigation measure. *** = High conflict risk; ** = Moderate; * = Low

Mitigation measure	Food production	Biodiversity	Water	Wildfire risk	Sea-space	Evidence strength
Reforestation (historical forest, native, mosaic)	*	*	**	*	n/a	***High*** (Hua et al. 2022; Peñuelas and Sardans 2021)
Afforestation of non-forest shrublands/maquis (monocultures)	***	***	***	***	n/a	***High*** (Roy et al. 2024; Nadal-Romero et al. 2023)
Bioenergy crops / BECCS (dedicated land)	***	***	***	**	n/a	***High*** (IPCC 2022; EASAC 2022; Hirata et al. 2024; Smith et al. 2024)
Agroecology/regenerative (soil carbon, diverse rotations)	*	*	*	*	n/a	***High*** (Pelman et al. 2024; Hrameche et al. 2024)
Agroforestry/silvopastoral (native, planned grazing)	*	*	*	*	n/a	***Medium–High*** (Tsiakiris et al. 2024; Santos et al. 2022)
Wetland/riparian restoration (mosaics, compensation)	**	*	*	*	n/a	***Medium–High*** (Creed et al. 2022; MedWet 2022)
PV ground-mount (utility scale, standard siting)	**–*** (farmland)	**–*** (habitat conversion)	**	**	n/a	***Medium–High*** (Bolinger and Bolinger 2022; Lovering et al. 2022)
Agrivoltaics (co-located crops + PV)	*	** (site-dependent)	*	*	n/a	***Medium–High*** (Walston et al. 2022; Trommsdorff et al. 2025)
Floating PV (reservoirs)	*	** (site-dependent)	* (evaporation ↓)	*	n/a	***Medium*** (Joshi 2023; Almeida et al. 2022)
Onshore wind (dual-use landscapes)	** (grazing usually maintained)	**–*** (raptors/bats)	*	*	n/a	***Medium*** (Konczak 2024)
Offshore wind (robust MSP, avoid MPAs)	n/a	** (residual)	n/a	n/a	*	***Medium–High*** (Lloret et al. 2023; Med OCEaN 2024)
Offshore wind (weak MSP, encroaches on MPAs/hotspots)	n/a	***	n/a	n/a	***	***Medium–High*** (Lloret et al. 2023; Morant et al. 2025)

Studies examining offshore renewable energy planning in the Mediterranean emphasise that maritime spatial planning (MSP) has become a central mechanism for aligning ecological constraints with competing spatial demands as offshore wind proposals expand. MSP processes increasingly rely on biodiversity data, species-distribution modelling, mapping of fishing grounds, shipping routes, and other maritime uses to identify areas where offshore wind development presents the lowest environmental risk (Lloret et al., 2022; Avesani, 2025). MSP is therefore an important governance tool for assessing cumulative pressures from existing activities, such as fisheries, tourism, and commercial shipping, alongside planned offshore wind zones, and for structuring how ecological interactions and spatial conflicts are addressed in decision-making (Lloret et al. 2023; Med OCEaN 2024; CrossGov 2025). Table 5.19 provides a summary of the different levels of conflict risk for each mitigation measure.

5.4.3 Competition for land under different scenarios

Key messages

- In the Mediterranean, competition for land among agricultural production, biodiversity conservation and restoration, energy infrastructure (PV and wind), and land-based carbon-dioxide removal (afforestation and reforestation, agroforestry, bioenergy and BECCS) is intensifying under most pathways. *(high confidence)*
- Strategic co-location (e.g. agrivoltaics), low-conflict siting, and demand-side measures markedly reduce conflict compared with supply-heavy pathways reliant on considerable land areas for BECCS or new plantations. *(medium confidence)*
- Recurrent drought, declining snow water equivalent and soil-moisture deficits now act as binding constraints on feasible land allocation and productivity across scenarios. *(high confidence)*

Scenario outcomes diverge sharply: pathways emphasising dual-use deployment, spatial optimisation and low-consumption water use consistently exhibit the lowest land-competition risk, whereas BECCS-heavy or BAU pathways show systematic high risk across all criteria. *(medium confidence)*

5.4.3.1 Framing and methodological approach

Land competition in the Mediterranean arises from overlapping claims by food, feed and fibre systems, energy-sector expansion (onshore wind, ground-mount PV, agrivoltaics, floating PV), conservation and restoration to meet the Global Biodiversity Framework (GBF) 30×30 conservation target, and land-based carbon removal (afforestation and reforestation, agroforestry, bioenergy and BECCS). Mediterranean conditions intensify competition: water scarcity, recurrent drought, soil-moisture deficits and heightened fire risk constrain yields, undermine the permanence of land sinks and shape renewable-energy siting (IPCC 2022a; Toreti et al. 2024). This section evaluates how integrated scenario families redistribute land, water, and biodiversity pressures, drawing on IPCC AR6 WGII CCP4, IPCC AR6 WGIII Chapters 5, 6, and 7, and spatial-optimisation evidence (Kiesecker et al. 2024). Additional empirical studies on agrivoltaics, FPV, BECCS feasibility, land-use change, drought impacts and restoration outcomes inform the scenario narratives. Measure-level performance and risk profiles are provided in Section 5.4.2. The assessment adopts a WEFE-nexus lens to clarify how interactions among water, energy, food and ecosystem systems shape both land-competition risks and the effectiveness of mitigation options.

5.4.3.2 Scenario families

5.4.3.2.1 Scenario 1: Renewables – Spatially Optimised (REN-SO)

This pathway accelerates solar-wind deployment through rooftops, agrivoltaics (Chatzipanagi et al. 2023), brownfields, FPV and Renewables Acceleration Areas, with strong demand-side measures and limited BECCS. Land conflict remains low-to-medium, as dual-use designs reduce farmland displacement and low-conflict spatial planning limits biodiversity impacts (IPCC 2022b; Kiesecker et al. 2024). Exposure to drought is minimised by avoiding high-stress basins and favouring land-neutral or water-saving options such as FPV (Jin et al. 2023; Toreti et al. 2024).

5.4.3.2.2 Scenario 2: Bioenergy-heavy Net-Zero (BIO-NZ)

This pathway relies heavily on BECCS using dedicated energy crops, with moderate wind and solar expansion. Land and water demand are high, increasing competition with food production and biodiversity, particularly where irrigation is required or conversion of semi-natural land occurs (Briones-Hidrovo et al. 2022; IPCC 2022c). Feasibility depends on feedstock source, CCS proximity, and drought exposure; in Mediterranean basins these constraints make the pathway high-risk for land competition (IPCC 2022d; Toreti et al. 2024). Compared with AR/ER, BECCS offers lower permanence under water-limited conditions (IPCC 2022d; Melnikova et al. 2023).

5.4.3.2.3 Scenario 3: Nature-first (NAT-30×30+)

This pathway implements the 30×30 target with strict no-go rules for high-value ecosystems, extensive restoration, and strong demand-side reductions aligned with IPCC WGIII Chapter 5 (IPCC 2022b). Renewables expand primarily via rooftops, agrivoltaics, FPV and offshore wind, minimising land take and biodiversity conflict. By prioritising ecological integrity, the pathway features low land competition, with Carbon Dioxide Removal (CDR) met mainly through restoration and agroforestry rather than BECCS (Donnelly and Rodríguez-Rodríguez 2022; IPCC 2022d).

5.4.3.2.4 Scenario 4: Business as usual (BAU)

A continuation of recent patterns: rapid utility-scale PV and wind expansion on available land, mixed enforcement of protection rules, limited demand-side measures and expanding settlement pressure. Land competition is high, as ground-mount PV and wind frequently overlap with productive farmland or biodiversity-sensitive areas (IPCC 2022c). Water-stress hotspots are rarely avoided, compounding vulnerability to drought (Toreti et al. 2024). CDR is uncoordinated, with a risk of low-integrity offsets and weak permanence safeguards (IPCC 2022d).

5.4.3.2.5 Cross-scenario insights and land competition risks

Differences across the four scenario families reflect variations in land take, water exposure, biodiversity safeguards, and reliance on land-based carbon-removal measures. Scenarios emphasising dual-use renewable deployment, spatial optimisation and lower consumptive water use tend to generate fewer conflicts, whereas those expanding bioenergy or ground-mounted infrastructure in water-stressed or high-value landscapes show systematically higher risks.

More specifically, across pathways, several factors consistently determine the intensity of land competition:

- Land take and siting: Ground-mount PV and dedicated bioenergy crops exert the strongest pressures; siting in low-conflict areas can meet capacity needs with far lower impacts (Kiesecker et al. 2024).
- Water scarcity as binding constraint: Scenarios that avoid drought-stressed basins and reduce consumptive water use (agrivoltaics, FPV) minimise conflict; those that amplify water demand (BECCS) face structural feasibility limits (De Roo et al. 2021; IPCC 2022a; Chatzipanagi et al. 2023). These water constraints propagate across energy (renewables siting, BECCS feasibility), food systems (irrigation potential, crop stability) and ecosystem integrity.
- CDR strategy and permanence: Restoration-led CDR performs better than BECCS under high drought and fire probability (IPCC 2022d), with lower land-water intensity and higher permanence (IPCC 2022a; Melnikova et al. 2023). Specifically, AR/ER with strong safeguards yield more robust, long-term carbon benefits once land-use change emissions and capture efficiencies are included (Briones-Hidrovo et al., 2022; IPCC, 2022a; IPCC, 2022c; Melnikova et al., 2023).
- Biodiversity safeguarding: Integrating 30×30 constraints and no-go zones avoids irreversible trade-offs and improves multi-objective outcomes across scenarios (Donnelly and Rodríguez-Rodríguez 2022).
- FPV as land-neutral energy: FPV can reduce evaporation and land pressure but requires ecological assessment; relative to ground-mount PV, it offers clear advantages in water-limited regions (Vourdoubas 2023; Ilgen et al. 2024; Mouhaya et al. 2025)

- Demand-side measures: Scenarios incorporating efficiency and sufficiency reduce overall land pressure across food, energy and CDR systems (IPCC 2022b).

Table 5.20 provides a summary of land competition risk for the four scenario families and the five criteria used (i.e. land take 2030-2050, water use and drought sensitivity, food-system conflict, biodiversity conflict, and CDR reliance and permanence)

Table 5.20 | Scenario-level land-competition risk across four scenario families. (REN-SO, BIO-NZ, NAT-30×30+, BAU). Conflict levels: 5 = Very High, 4 = High, 3 = Medium, 2 = Low, 1 = Very Low.

Criterion	REN–SO (Renewables – Spatially Optimised)	BIO–NZ (Bioenergy-heavy Net-Zero)	NAT–30×30+ (Nature-first)	BAU (Business as usual)
Land take (2030–2050)	2	5	11	5
Water use / drought sensitivity	2	5	1	4
Food-system conflict	2	5	1	4
Biodiversity conflict	1	5	1	5
CDR reliance and permanence	2	5	1	5
Overall land-competition risk	2	5	1	5
Indicative siting strategy	Low-conflict siting; rooftops/agrivoltaics/FPV	High land-take bioenergy; CCS-dependent	Strict no-go zones; dual-use; offshore	BAU ground-mount; weak screening

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[PLACEHOLDER: the references will be completed for the second order draft]

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