

Climate Change Indicators

Provides guidance on compiling climate change indicators from ocean accounts, addressing the nexus between ocean ecosystems and global climate systems.

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OUTCOME

This Circular provides guidance on compiling climate change indicators from ocean accounts, addressing the nexus between ocean ecosystems and global climate systems. Upon completing this Circular, readers will understand how to derive indicators for blue carbon sequestration and stocks from ecosystem accounts, compile ocean acidification indicators from condition accounts, calculate emission intensity indicators by ocean-related economic sector, and develop climate risk and adaptation indicators relevant to coastal and marine systems. The guidance integrates the carbon accounting frameworks of the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) with the air emissions accounting of the SEEA Central Framework (SEEA CF), supporting the Sustainable Development Goals (SDG 13: Climate Action and SDG 14: Life Below Water), nationally determined contributions (NDCs) under the Paris Agreement, Kunming-Montreal Global Biodiversity Framework Target 8 on minimising the impact of climate change on biodiversity, and the greenhouse gas disclosure requirements of sustainability standards including IFRS S2.

The indicators compiled through this Circular support four principal policy applications: (i) NDC tracking for ocean sectors – enabling countries to quantify the contribution of blue carbon ecosystems and offshore renewable energy to national climate commitments, and to assess the emission intensity of ocean-dependent industries relative to economy-wide targets; (ii) blue carbon accounting for REDD+ and related mechanisms – providing the physical flow and stock data required for carbon credit verification and monitoring of ecosystem-based mitigation projects; (iii) IFRS S2 corporate climate disclosure – supplying the sectoral emission intensity benchmarks and physical risk metrics that ocean-dependent companies require for Scope 1, 2, and 3 emissions reporting and transition risk assessment; and (iv) climate resilience planning – informing adaptation investments through indicators of coastal vulnerability, ecosystem-based adaptation deployment, and the protective services provided by marine ecosystems under climate scenarios.

This Circular builds on the aggregate indicator methodology in [TG-2.1 Aggregate Biophysical Indicators](#), the asset accounting framework established in [TG-3.1 Asset Accounts](#), and the residual flows accounting detailed in [TG-3.4 Flows from Economy to Environment](#). It enables the policy integration addressed in [TG-1.4 OA and Sustainable Ocean Planning](#).

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ABOUT THIS CIRCULAR

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¶1 ⓘ Framework Position

¶2 TG-2.8 is a member of the Section 2 indicators family, which provides guidance on deriving policy-relevant statistics from the physical and monetary accounts compiled in Sections 3 and 4. Within that family, this Circular addresses the climate change dimension of ocean accounting: it compiles blue carbon, acidification, emission intensity, and climate risk indicators that are distinct from – but complementary to – the aggregate biophysical indicators in **TG-2.1 Aggregate Biophysical Indicators** and the disaster risk indicators in **TG-2.9 Disaster Risk Indicators**. Compilers should read TG-2.1 before this Circular for the general methodology of deriving normalised indicators from ecosystem condition accounts.

1. Outcome

¶1 This Circular provides guidance on compiling climate change indicators from ocean accounts, addressing the nexus between ocean ecosystems and global climate systems. Upon completing this Circular, readers will understand how to derive indicators for blue carbon sequestration and stocks from ecosystem accounts, compile ocean acidification indicators from condition accounts, calculate emission intensity indicators by ocean-related economic sector, and develop climate risk and adaptation indicators relevant to coastal and marine systems. The guidance integrates the carbon accounting frameworks of the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA)¹ with the air emissions accounting of the SEEA Central Framework (SEEA CF)², supporting the Sustainable Development Goals (SDG 13: Climate Action and SDG 14: Life Below Water)³, nationally determined contributions (NDCs) under the Paris Agreement⁴, Kunming-Montreal Global Biodiversity Framework Target 8 on minimising the impact of climate change on biodiversity⁵, and the greenhouse gas disclosure requirements of sustainability standards including IFRS S2⁶.

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** – for the conceptual framework and key components of Ocean Accounts
- ¶3 **TG-0.2 Overview of Relevant Statistical Standards** – for the methodological foundations provided by SNA 2025, SEEA CF, and SEEA EA
- ¶4 **TG-2.1 Aggregate Biophysical Indicators** – for the general methodology of deriving normalised indicators and composite indices from ecosystem condition accounts

- ¶5 **TG-3.4 Flows from Economy to Environment** – for the framework of air emissions accounts and attribution of residual flows to economic sectors

3. Guidance Material

¶1 Oceans are central to the global climate system, absorbing more than 90 per cent of excess heat and about 25 per cent of anthropogenic carbon dioxide emissions⁷. Marine ecosystems provide climate mitigation services through carbon sequestration. The same ecosystems experience climate-driven changes including warming, acidification, and altered circulation patterns. Ocean accounts provide a systematic framework for measuring these ocean-climate interactions, enabling compilation of indicators that track both the climate services provided by marine ecosystems and the climate pressures affecting them.

¶2 This Circular compiles blue carbon, acidification, emission intensity, and climate risk indicators from ocean accounts, spanning five thematic areas described in the sections below.

3.1 Ocean-Climate Indicator Framework

¶1 This framework distinguishes between indicators that measure the role of oceans in climate regulation (mitigation-related) and indicators that measure climate impacts on ocean systems (vulnerability and adaptation-related). Figure 2.8.1 illustrates how the ocean-climate system anchors three complementary reporting pathways – mitigation, vulnerability, and emission intensity – and maps the indicators in each to their downstream international reporting obligations.

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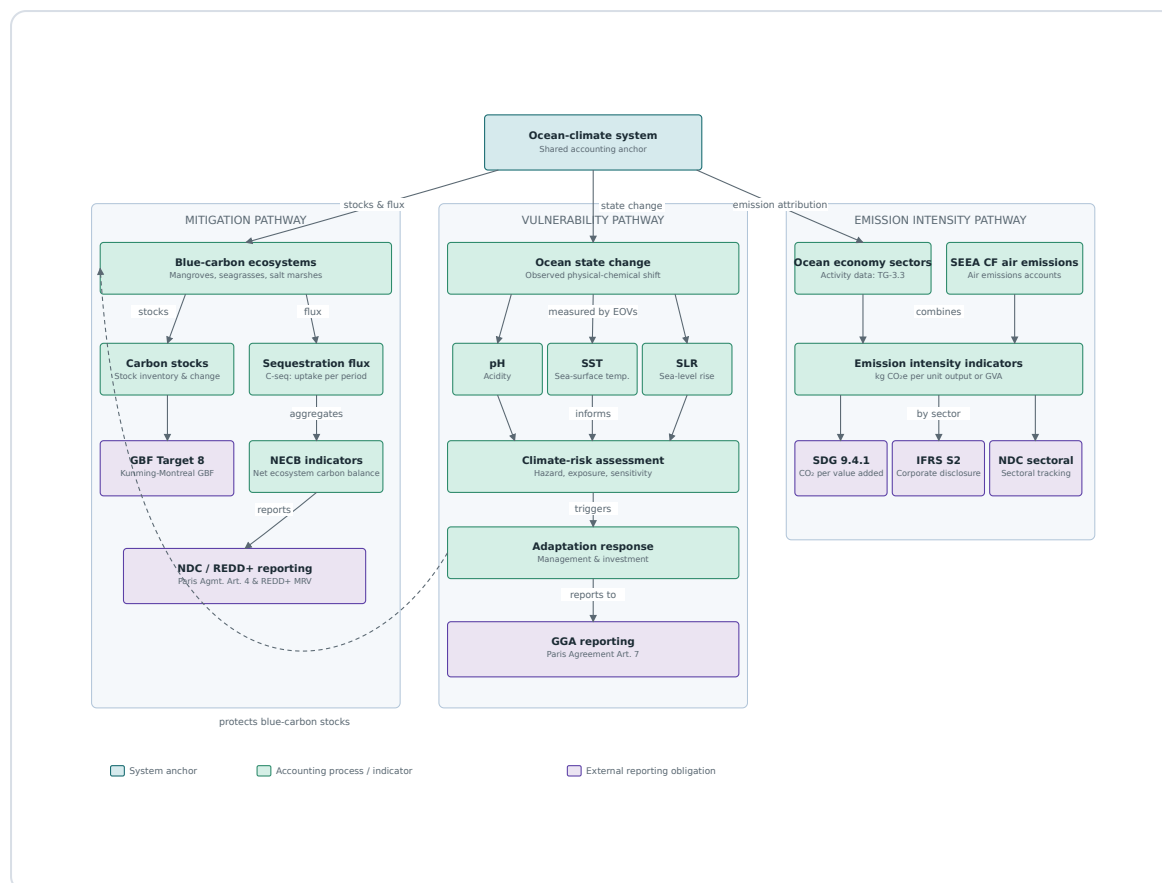


Figure 2.8.1 The ocean-climate framework links mitigation, vulnerability, and emission-intensity pathways from accounts to indicators. Vulnerability pathway uses pH, SST, and sea-level rise EOVs; intensity pathway combines TG-3.3 activity with SEEA CF air emissions.

Source: TG-2.8 draft v7; Paris Agreement Articles 4 and 7; Kunming-Montreal GBF Target 8 (2022); SEEA CF (air emissions accounts); SEEA EA Chapter 13 (carbon stock accounts).

Adapted from: IOC-GOOS Essential Ocean Variables specification sheets; IPCC SROCC Chapter 5 (oceans and coastal ecosystems).

Indicator categories

¶1 Climate change indicators derived from ocean accounts can be organised into the four principal categories summarised in Table 3.1.1 below⁸.

Category	Description
Carbon flux indicators	Measuring the exchange of carbon between the atmosphere and ocean ecosystems, including sequestration by blue carbon ecosystems (mangroves, seagrasses, salt marshes) and carbon uptake by open ocean systems.
Carbon stock indicators	Measuring the standing stock of carbon held in marine and coastal ecosystems, representing the climate mitigation capacity that would be released if ecosystems were degraded.
Ocean state indicators	Measuring physical and chemical changes in ocean conditions attributable to climate change, including temperature, pH, dissolved oxygen, and sea level.
Emission attribution indicators	Measuring the greenhouse gas emissions associated with ocean-related economic activities, supporting analysis of emission intensity and transition pathways.

¶2 This four-category structure does not separately distinguish adaptation effectiveness indicators from ocean state indicators. Whilst the UNFCCC Global Goal on Adaptation (GGA) framework is developing dedicated metrics for adaptation effectiveness, the indicators in this Circular that relate to adaptation outcomes, such as nature-based solution deployment and coastal protection services (Section 3.5), are compiled from the same condition and extent accounts as the ocean

state indicators. As the GGA indicator framework matures, compilers may disaggregate adaptation effectiveness as a distinct reporting category whilst maintaining the underlying accounting structure described here.

Ocean-climate indicator-account alignment table

Outputs and use cases

¶1 Table 1a maps each major indicator type to its unit of measure, the account it populates, its downstream reporting framework, the typical institutional recipient, and a key caveat. This table is intended as a navigation aid for multi-agency compilation teams to prevent misrouting of outputs across reporting frameworks.

¶2 **Table 1a: Outputs and Use Cases**

Indicator	Unit	Account Type	Reporting Framework	Institutional Recipient	Key Caveat
Annual carbon sequestration rate	tCO ₂ e/ha/yr	Physical flow – service supply	Paris Agreement; REDD+	Ministry of Environment / UNFCCC focal point	SEEA EA service flow; not a direct GHG inventory removal
Total ecosystem carbon stock	tC/ha	Carbon stock account	GBF Target 8	NSO / biodiversity ministry	Physical units; monetary valuation requires shadow price (see Section 3.2)
Carbon stock change	tC/yr	Carbon stock account	GBF Target 8; REDD+ verification	NSO / REDD+ national authority	Distinct from inventory removals; pool-specific emission factors required for inventory use
Ocean pH	pH units	Condition account	SDG 14.3.1	NSO / IOC-UNESCO focal point	Satellite-derived estimates are provisional; in situ preferred for SDG reporting
Aragonite saturation state	omega-a	Condition account	SDG 14.3.1 (supplementary)	NSO / oceanographic agency	Requires full carbonate system measurement
GHG emission intensity by ocean sector	kg CO ₂ e per tonne output or per 1,000 currency units GVA	Air emissions / supply-use hybrid	SDG 9.4.1; NDC sectoral tracking	NSO / climate ministry	Scope 1 only from SEEA CF; Scope 2 and 3 require supplementary modelling ⁹
Sea level rise exposure	ha exposed	Extent / condition account	GGA (in development)	Disaster risk / coastal planning agency	Scenario-dependent; align with national sea level projections

Indicator	Unit	Account Type	Reporting Framework	Institutional Recipient	Key Caveat
Marine heatwave frequency	days/yr	Condition account	GGA (in development)	NSO / meteorological service	Heatwave definition must follow agreed climatological threshold
NbS deployment area	ha	Extent account	GBF Target 8; GGA (in development)	NSO / biodiversity ministry	Track gross restoration; deduct losses for net assessment

Links to international frameworks

¶1 Ocean-climate indicators support multiple international monitoring and reporting frameworks. SDG indicator 14.3.1 directly addresses ocean acidification¹⁰; SDG 13 indicators on climate action are supported by emission intensity data and climate risk assessments derived from ocean accounts. National GHG inventories include emissions and removals from coastal wetlands under the AFOLU sector, using IPCC Wetlands Supplement methodologies¹¹, and many countries now reference ocean-based mitigation and adaptation measures in their NDCs¹². GBF Target 8 calls on parties to minimise the impact of climate change and ocean acidification on biodiversity through nature-based solutions⁵, and the TNFD framework identifies climate-nature linkages as a priority area, with explicit attention to blue carbon ecosystems¹³.

Spatial and temporal considerations

¶1 Ocean-climate indicators require careful attention to spatial and temporal boundaries:

- ¶2 **Spatial scope:** Indicators should align with the marine spatial framework established in **TG-0.1 General Introduction**, distinguishing between coastal waters, the Exclusive Economic Zone (EEZ), and where relevant, high seas areas and seabed beyond national jurisdiction
- ¶3 **Temporal resolution:** Climate-relevant indicators may require annual or multi-year compilation periods, with attention to interannual variability in carbon fluxes and oceanographic conditions
- ¶4 **Reference conditions:** Changes in ocean state should be assessed against appropriate baselines, acknowledging that pre-industrial reference conditions may not be directly observable and must be estimated from historical data or models. The approach to reference conditions should follow the general methodology described in **TG-2.1** Section 3.4.2

3.2 Blue Carbon Indicators

¶1 Blue carbon refers to the carbon captured and stored by coastal and marine ecosystems, particularly mangroves, tidal salt marshes, and seagrass meadows¹⁴. These ecosystems are exceptionally efficient carbon sinks, sequestering carbon at rates two to four times greater than terrestrial forests per unit area and storing carbon in sediments for millennia under undisturbed conditions¹⁵. Ocean accounts provide the framework for measuring blue carbon stocks and flows, enabling compilation of indicators for climate mitigation policy and carbon market mechanisms.

¶2 The blue carbon indicators in this section are closely related to the ecosystem service measurements in **TG-6.2 Mangrove and Coastal Wetland Accounting**, which addresses blue carbon services in detail. In particular, TG-6.2 Section 3.3 (Blue Carbon Services) describes the service measurement approaches from which several indicators below are derived. The carbon sequestration rate indicator corresponds to the regulating service flow recorded in ecosystem service supply tables; the carbon stock indicator corresponds to the carbon stock account in the asset balance sheet; and the carbon retention indicator corresponds to the ongoing service of maintaining exist-

ing stocks. Compilers should consult TG-6.2 for the detailed accounting methodology underlying these indicators.

Carbon sequestration indicators

¶1 Carbon sequestration indicators measure the rate at which blue carbon ecosystems remove carbon dioxide from the atmosphere and transfer it to long-term storage. Key indicators include:

¶2 **Annual carbon sequestration rate** (tonnes CO₂ equivalent per hectare per year): The net carbon uptake (net ecosystem carbon balance, NECB) by blue carbon ecosystems, recorded as a regulating service flow.

¶3 The SEEA EA framework for ecosystem services recognises carbon sequestration as a regulating service, recording the net ecosystem carbon balance as the measure of service supply¹⁶. For ocean accounting, this service flow should be recorded by ecosystem type and spatial unit, enabling attribution to specific marine areas and ecosystem assets.

¶4 **Carbon balance concepts – NECB, NEP, and NBP.** The target concept for the sequestration rate formula above is the net ecosystem carbon balance (NECB) – the quantity recorded as a regulating service flow in SEEA EA physical flow accounts (paragraphs 6.110–6.113). Compilers should distinguish NECB from two related but non-equivalent concepts. Net ecosystem production (NEP) excludes lateral carbon export losses (dissolved organic carbon, particulate organic carbon transported to adjacent systems), and will overestimate NECB where lateral exports are significant. Net biome production (NBP) additionally deducts carbon losses from disturbance events (fire, pest outbreaks, harvesting); NBP is the appropriate concept for landscape-scale GHG inventory reporting but is more restrictive than the SEEA EA service flow concept.

¶5 When applying Tier 1 IPCC default sequestration rates from the 2013 Wetlands Supplement, compilers should consult the relevant methodology chapter (particularly Section 2.3 for generic wetland concepts and Chapter 4 for coastal wetlands) to confirm which carbon balance concept the default rates represent, and adjust if necessary. Study designs underlying the defaults vary: some approximate NECB through long-term sediment accumulation measurements, whilst others measure NEP or NBP. Applying a NECB formula to input data derived from NBP studies will produce a systematic underestimate.

¶6 **Ecosystem-specific sequestration rates:** Compilation should distinguish sequestration by ecosystem type, recognising substantial variation in rates:

- ¶7 Mangroves: 6–8 tonnes CO₂ per hectare per year
- ¶8 Salt marshes: 5–8 tonnes CO₂ per hectare per year
- ¶9 Seagrass meadows: 1.5–3 tonnes CO₂ per hectare per year¹⁷

¶10 These indicative ranges represent net ecosystem carbon balance (NECB) estimates, consistent with long-term sediment carbon accumulation rates. They should not be compared to gross primary production values without first subtracting respiration and export terms as specified in the formula above.¹⁸

¶11 These rates vary substantially with ecosystem condition, latitude, and local environmental conditions, and should be derived from local measurements or regionally calibrated estimates where available. Uncertainty in sequestration rate estimates is substantial, and compilers should document it following the guidance in the 2013 IPCC Wetlands Supplement¹¹. Uncertainty quantification is particularly important when estimates are used for carbon credit verification or national inventory reporting, where the confidence interval directly affects the credibility of reported removals.

¶12 **National blue carbon sequestration:** The aggregate carbon sequestration across all blue carbon ecosystems within national marine areas, expressed in tonnes CO₂ equivalent per year. This indicator supports national climate reporting and assessment of nature-based solutions to climate change.

¶13 ① Relationship to National GHG Inventory Reporting

¶14 Blue carbon sequestration compiled as a SEEA EA regulating service flow and coastal wetland removals reported in the national GHG inventory (IPCC AFOLU sector) are related but distinct estimates produced by different processes.

¶15 **Conceptual mapping.** The SEEA EA service flow account records the net ecosystem carbon balance (NECB) as a physical flow in tonnes of carbon per accounting period. The IPCC inventory, by contrast, requires activity data (land area by management category) plus emission factors (from the 2013 Wetlands Supplement, Tier 1–3) to produce a removals estimate in CO₂-equivalent tonnes. These inputs are not interchangeable: physical stock totals from ocean accounts cannot be directly submitted to the inventory without conversion using the appropriate activity-data and emission-factor framework.

¶16 **Use of the two estimates.** How the account estimate and the inventory estimate are reconciled, which of them governs for crediting, and how the compiling agencies coordinate are decision-use questions outside the scope of this Circular.

Spatial boundary protocol for submerged habitat stocks

¶1 Compilers assembling carbon stock totals for submerged blue carbon ecosystems – particularly seagrass meadows, which are frequently located on the continental shelf beyond national land registries – should apply the following spatial boundary rules.

¶2 The **Exclusive Economic Zone (EEZ) boundary** governs inclusion of submerged habitat stocks in the national account. Coastal State sovereign rights over natural resources in the EEZ are established under UNCLOS Part V (Articles 55–75)¹⁹, providing the legal basis for including stocks in submerged lands throughout the EEZ, even where those areas are not registered in national land cadastres.

¶3 Where maritime boundaries are subject to **overlapping claims or joint jurisdiction**, compilers should note the relevant spatial units as disputed in the compilation metadata and document the boundary assumptions applied. The treatment of stocks in disputed areas should follow any applicable bilateral or multilateral agreement; where no such agreement exists, compilers should disclose the boundary assumption and avoid making unilateral allocation decisions in the published accounts.

¶4 For remote sensing approaches to mapping submerged habitats in outer EEZ contexts, including areas not covered by coastal mapping surveys, see **TG-4.1 Remote Sensing**. For small island developing states (SIDS) with large EEZs relative to land area, submerged seagrass stocks may represent the majority of national blue carbon assets; applying adequate remote sensing coverage is particularly important in these contexts.

Carbon stock indicators

¶1 Carbon stock indicators measure the accumulated carbon held in blue carbon ecosystem pools, representing both the climate mitigation asset and the emission liability if ecosystems are degraded.

¶2 **Total ecosystem carbon stock** (tonnes carbon per hectare): The carbon stored across all pools within the ecosystem, comprising:

- ¶3 Aboveground biomass (trees, shrubs, vegetation)
- ¶4 Belowground biomass (roots)
- ¶5 Dead organic matter (litter, dead wood)
- ¶6 Soil organic carbon (the largest pool, often extending metres deep in coastal sediments)

¶7 The SEEA EA carbon stock account provides the accounting structure for recording these stocks by ecosystem type and tracking changes between accounting periods²⁰. Table 13.3 of SEEA EA presents the structure of carbon stock accounts, disaggregating stocks into geocarbon, biocarbon, carbon in the economy, carbon in the oceans, and carbon in the atmosphere.

¶8 **Ecosystem carbon stock by type:** Carbon stocks should be compiled separately for each blue carbon ecosystem type, recognising substantial variation:

- ¶9 Mangroves: approximately 1,000–1,500 tonnes carbon per hectare (including deep sediments)
- ¶10 Salt marshes: approximately 200–400 tonnes carbon per hectare
- ¶11 Seagrass meadows: approximately 100–300 tonnes carbon per hectare²¹

¶12 **Carbon stock change indicators:** Changes in ecosystem carbon stocks between accounting periods provide indicators of net carbon accumulation or release:

- ¶13 Increase in carbon stocks (positive) indicates net carbon removal from atmosphere
- ¶14 Decrease in carbon stocks (negative) indicates net carbon emission to atmosphere

¶15 Stock changes may result from ecosystem extent changes (conversion, restoration), condition changes (degradation, improvement), or natural dynamics. The SEEA EA framework for ecosystem condition accounts enables tracking of the drivers of stock change. When blue carbon ecosystems are converted or degraded, not all stored carbon is released immediately. Decay rates vary by pool: aboveground biomass may decompose within years, whilst deep sediment carbon may remain stable for decades or longer depending on the nature of the disturbance. Compilers should apply pool-specific emission factors that reflect these differential release rates, drawing on the guidance in Chapter 4 of the IPCC 2013 Wetlands Supplement²² and, where available, locally calibrated emission factors. This distinction is particularly important for policy analyses comparing the climate impact of different types of ecosystem degradation.

Carbon retention services

¶1 Beyond annual sequestration, blue carbon ecosystems provide carbon retention services by maintaining existing carbon stocks that would otherwise be released to the atmosphere²³. This service concept recognises that:

- ¶2 Ecosystems with high carbon stocks (such as old-growth mangroves) provide high retention value even if their current sequestration is low due to equilibrium conditions
- ¶3 Degradation or conversion of carbon-rich ecosystems results in substantial emissions
- ¶4 The retention service is an ongoing service flow, distinct from the one-time sequestration that accumulated the stock

¶5 SEEA EA provides guidance on valuing carbon retention services using the annuity approach, which spreads the value of the carbon stock across expected future periods²⁴. This approach sends appropriate policy signals regarding the importance of conserving existing blue carbon stocks.

¶6 ⓘ **Carbon price assumption for retention service valuation**

¶7 Monetary valuation of carbon retention services using the annuity approach (SEEA EA Annex A12.1) requires a shadow price or social cost of carbon as a key parameter. Published estimates of the social cost of carbon span a wide range – from approximately USD 15 to over USD 400 per tonne CO₂ depending on discount rate, damage function, and equity weighting – and NSOs are unlikely to have a nationally agreed value established for statistical purposes.

¶8 Compilers should apply the following hierarchy:

1. ¶9 **National or ETS price:** Where the country has adopted a formal carbon price (emissions trading scheme or carbon tax), use this price as the primary assumption for comparability with national policy valuations.
2. ¶10 **Stern-Stiglitz benchmark:** Where no national price exists, use the High-Level Commission on Carbon Prices benchmark of USD 40–80 per tonne CO₂ by 2020, rising to USD 50–100 per tonne CO₂ by 2030 (in 2015 USD terms), as an internationally recognised reference value.²⁵
3. ¶11 **Sensitivity range:** Regardless of the price chosen, report the monetary valuation result alongside an explicit sensitivity range – at minimum, results using the lower and upper bounds of the adopted price range. This is essential for reproducibility and cross-country comparability.
4. ¶12 **Physical stock as primary indicator:** Consider reporting the physical stock estimate (tonnes carbon per hectare) as the primary indicator, with the monetary valuation as a supplementary figure. The physical stock is methodologically unambiguous; the monetary value is a policy construct that depends on contested parameters.

Data sources and compilation

¶1 Blue carbon indicators require integration of multiple data sources, as summarised in Table 3.2.1 below.

Data Source	Description
Extent data	Remote sensing products for mangrove, salt marsh, and seagrass distribution, including the Global Mangrove Watch ²⁶ for standardised mangrove extent mapping and the Allen Coral Atlas for reef-associated habitat mapping. Detailed methodology for remote sensing-based extent compilation is provided in TG-4.1 Remote Sensing .
Carbon density estimates	From field sampling, literature synthesis, or ecosystem models.
Flux measurements	From eddy covariance towers, sediment cores, or modelled estimates.
Stock-change detection	From repeated extent mapping and condition assessment.

¶2 The IPCC Guidelines for National Greenhouse Gas Inventories and the 2013 Wetlands Supplement provide Tier 1 default values for carbon stocks and sequestration rates that can be applied where local data are unavailable²⁷. These global datasets are particularly important for countries with limited national monitoring capacity, providing a baseline from which national estimates can be progressively refined as local data become available.

3.3 Ocean Acidification Indicators

¶1 Ocean acidification reduces seawater pH through absorption of anthropogenic carbon dioxide, with significant ecological and economic consequences²⁸. The SEEA EA framework for ecosystem condition accounts provides the structure for recording pH and related carbonate chemistry variables as condition indicators, supporting compilation of ocean acidification indicators for climate monitoring and policy.

pH-based indicators

¶1 **Mean surface ocean pH:** The average pH of surface ocean waters within the accounting area, measured at representative sampling stations. SDG indicator 14.3.1 specifies this measurement approach, requiring pH data from an agreed suite of representative sampling stations²⁹.

¶2 **pH change from reference period:** The change in mean pH relative to a baseline period (typically pre-industrial or a specified reference decade). Given the logarithmic pH scale, a decrease of

0.1 pH units represents approximately a 26 per cent increase in hydrogen ion concentration.

¶3 **Aragonite saturation state:** The saturation state of calcium carbonate minerals, particularly aragonite, which is essential for shell-forming organisms including corals, molluscs, and some plankton³⁰. Aragonite saturation (ω_a) below 1.0 indicates undersaturation and corrosive conditions for calcifying organisms.

¶4 **Seasonal pH variability:** The range and timing of pH variation within the accounting period, important for understanding biological exposure to acidification stress.

¶5 Measurement precision and accuracy are central considerations for pH-based indicators. Spectrophotometric pH measurements typically achieve precision of plus or minus 0.001 pH units, whilst electrode-based measurements may be an order of magnitude less precise. The Global Ocean Acidification Observing Network (GOA-ON) best practices guide³¹ provides detailed quality assurance guidance for acidification observations, including requirements for certified reference materials, inter-laboratory comparisons, and metadata documentation. Compilers should document the measurement methods and associated uncertainty for all pH-based indicators to support comparability across stations and time periods.

Data adequacy for national reporting

¶1 Before using pH observations for national SDG 14.3.1 or ocean account reporting, compilers should assess whether their observing network meets adequacy criteria for the intended use.

¶2 **GOA-ON coverage recommendations.** The GOA-ON Requirements and Governance Plan³¹ provides station coverage recommendations distinguishing **coastal** representativeness (sufficient stations to capture nearshore gradients driven by upwelling, river inputs, and biological activity) from **open ocean** representativeness (sufficient spatial coverage within the EEZ to characterise offshore conditions). Countries should consult Section 3 of the GOA-ON Requirements document for specific guidance applicable to their oceanographic context.

¶3 **Sparse network protocol.** Countries with fewer stations than the applicable GOA-ON threshold must: (a) Report the pH indicator with a coverage caveat specifying the share of the EEZ represented by in situ observations. (b) Disclose their reliance on global gridded products – such as SOCAT v2024 (surface ocean CO₂ atlas) or GLODAPv2 (interior ocean carbon data) – to supplement the sparse national network, including the version of the product used and the spatial cells applied.

¶4 **Satellite-derived estimates.** Satellite-based pH estimation algorithms offer spatial coverage for data-scarce countries but carry substantially higher uncertainty than in situ spectrophotometric measurement (typically ± 0.1 – 0.3 pH units for current algorithms versus ± 0.001 for in situ). Before using satellite-derived pH estimates for SDG 14.3.1 reporting, compilers should consult the IOC-UNESCO custodian agency guidance on acceptable data sources for this indicator. Where satellite estimates are used, compilers must: (a) Disclose the algorithm used and its root-mean-square error (RMSE) against available in situ validation data. (b) Report the uncertainty of the satellite-derived estimate alongside the indicator value. (c) Classify the satellite-based estimate as **provisional** in the national ocean accounts metadata, with a documented plan for progressive validation improvement as in situ capacity develops.

¶5 Satellite estimates are appropriate as provisional data for spatial pattern analysis and for countries with no in situ capacity. They should not be treated as equivalent to in situ measurements for SDG reporting unless the IOC-UNESCO custodian agency has issued guidance confirming their acceptability.³²

Spatial distribution indicators

¶1 Ocean acidification varies substantially with location, creating spatial patterns that are important for ecosystem impact assessment:

- ¶2 **Coastal vs. open ocean:** Coastal waters may experience more extreme pH variation due to upwelling, river inputs, and biological activity
- ¶3 **Depth gradients:** pH generally decreases with depth, with acidification effects most pronounced in deeper waters
- ¶4 **Regional patterns:** Some regions (high latitudes, upwelling zones) experience accelerated acidification

¶5 Condition accounts should record pH and acidification indicators at appropriate spatial resolution to capture these patterns.

Ecosystem impact indicators

¶1 The ecological significance of acidification depends on the sensitivity of resident organisms and ecosystems. Mapping these impacts to the SEEA EA ecosystem condition typology strengthens integration with broader condition accounting:

¶2 **Coral calcification impact:** Reduced calcification rates in reef-building corals, measurable through growth rates, skeletal density, and reef accretion rates. Within the SEEA EA condition typology, this maps to the “ecosystem structural state” characteristic, reflecting changes in the physical structure of the reef ecosystem. This indicator links to the coral reef condition assessment in **TG-6.1 Coral Reef Accounts**.

¶3 **Shellfish production impact:** Effects on commercially important molluscs and crustaceans, potentially measurable through aquaculture production data or wild stock assessments. This maps to the “species-based characteristics” of ecosystem condition, specifically the abundance and productivity of calcifying species.

¶4 **Pteropod shell condition:** Pteropods (swimming snails) are sentinel organisms for acidification, with shell dissolution providing an early warning indicator of ecosystem stress. Within the condition typology, pteropod shell condition serves as a “species-based characteristic” indicator of the chemical dimension of ecosystem condition.

Data sources and compilation

¶3 Ocean acidification indicators require specialised oceanographic measurements:

- ¶4 **Fixed monitoring stations:** Time-series stations with continuous or regular pH measurement
- ¶5 **Research vessel surveys:** Periodic hydrographic surveys with carbonate chemistry analysis
- ¶6 **Autonomous platforms:** Profiling floats, gliders, and moorings with pH sensors
- ¶7 **Satellite-derived estimates:** Algorithms relating sea surface temperature and other observable variables to pH (see data adequacy section above for fitness-for-purpose criteria)

¶8 The Global Ocean Acidification Observing Network (GOA-ON) provides coordination and data access for acidification monitoring that can support national compilation³¹.

3.4 Emission Intensity Indicators

¶1 Emission intensity indicators link greenhouse gas emissions to economic activity, enabling assessment of the carbon footprint of ocean-related industries and tracking of decarbonisation progress. These indicators combine the air emissions accounts of the SEEA CF with the economic activity data described in **TG-3.3 Economic Activity Relevant to the Ocean**. The SEEA CF air emissions account methodology attributes emissions to the economic unit responsible for the direct release, which corresponds to Scope 1 emissions in the GHG Protocol terminology³³. The SNA 2025 reinforces this treatment through its framework for recording residual flows from the economy to the environment, providing the national accounting basis for emission attribution³⁴.

Compilation procedure for ocean sector emission intensity

¶1 The derivation of emission intensity indicators from ocean accounts follows a structured procedure:

¶2 **Step 1: Extract emissions data by industry** – From the air emissions account compiled under **TG-3.4 Flows from Economy to Environment**, identify the rows corresponding to ocean-related industries (fishing, aquaculture, maritime shipping, offshore energy, coastal tourism) using the ISIC concordance from **TG-3.3** Table 2. Record the tonnes of CO₂-equivalent emissions attributed to each industry for the accounting period.

¶3 **Step 2: Extract activity data by industry** – From the ocean economy supply and use tables compiled under TG-3.3, extract the corresponding denominators: tonnes of production (for fishing and aquaculture), tonne-kilometres of freight (for shipping), units of energy produced (for off-shore energy), or visitor-days (for coastal tourism). Alternatively, use gross value added (GVA) in monetary units as a common denominator across industries.

¶4 **Step 2a: Verify temporal alignment** – Confirm that the emissions data from Step 1 and the activity data from Step 2 refer to the same reference year. National air emissions accounts are often published two to three years after the reference year, whilst fisheries landings data and aquaculture production figures may follow different reporting cycles (harvest year versus calendar year). Where a data lag prevents alignment, the compiler must either (a) interpolate the lagged series using a documented methodology and record the interpolation approach in the indicator metadata, or (b) publish the indicator with a metadata mismatch flag in accordance with the quality disclosure framework in **TG-0.7 Quality Assurance**, specifying which data element relates to a different year and the direction of likely bias. Where fuel prices have fallen and fleet size is stable, lagged emissions data are likely to overstate current-year intensity (upward bias); where fleet expansion is ongoing, they may understate it (downward bias). Compilers should document the relevant trend direction in the indicator metadata. Silently mixing reference years is not acceptable.³⁵

¶5 **Step 3: Calculate intensity ratios** – Divide the emissions (Step 1) by the activity measure (Step 2) to derive the emission intensity for each industry. Express the result in appropriate units: kg CO₂e per tonne of fish landed, g CO₂e per tonne-kilometre, kg CO₂e per unit of energy, or kg CO₂e per visitor-day. For GVA-based intensity, express as kg CO₂e per thousand currency units of value added.

¶6 **Step 4: Disaggregate by sub-industry where feasible** – Where data permit, disaggregate intensity indicators by gear type (for fishing), vessel class (for shipping), fuel type (for offshore energy), or tourism segment (for coastal tourism). This disaggregation enables more targeted policy analysis and identification of transition opportunities.

¶7 **Step 5: Compile time series** – Repeat Steps 1–4 for successive accounting periods to construct a time series showing trends in emission intensity. Declining intensity over time indicates relative decoupling of emissions from economic activity, a key indicator of progress toward climate targets.

¶8 **Step 6: Document data sources and assumptions** – For each indicator, record the data sources for both the numerator (emissions) and denominator (activity), document any estimation methods or proxies used, and note any discontinuities in the time series due to methodological changes. This documentation is essential for quality assurance per **TG-0.7 Quality Assurance**.

Industry emission intensity

¶1 **GHG emissions per unit of output** (kg CO₂ equivalent per unit of production or value added): The greenhouse gas intensity of specific ocean-related industries, enabling comparison across sectors and tracking over time. Table 2 maps the ocean industries referenced in this section to ISIC Rev.4 codes, following the classification established in **TG-3.3** Section 3.3.

¶2 **Table 2: Ocean Industry Emission Intensity – ISIC Rev.4 Mapping**

Ocean Industry	ISIC Rev.4	Indicator Unit	Note
Marine fishing	0311, 0312	kg CO ₂ e per tonne of landed catch	
Aquaculture	0321, 0322	kg CO ₂ e per tonne of production	
Maritime shipping	5011, 5012	g CO ₂ e per tonne-kilometre	
Offshore energy (fossil)	0610, 0620	kg CO ₂ e per unit of energy produced	
Offshore energy (renewable)	3510 (partial) ³⁶	kg CO ₂ e per unit of energy produced	Identification of the offshore renewable subset requires supplementary data from energy statistics or licensing records
Coastal tourism	5510, 9319 (partial)	kg CO ₂ e per visi- tor-day	

¶3 Table 3.4.1 below summarises industry-specific considerations for emission intensity indicators.

Industry	Considerations
Fishing industry	Emissions per tonne of landed catch or per unit of fish biomass provisioning service. Fuel combustion is the primary emission source, with intensity varying substantially by gear type and target species. For detailed guidance on fisheries accounting, see TG-6.7 Fisheries Accounting: Integrating Stock Assessment .
Aquaculture	Emissions per tonne of production, including both direct emissions (fuel, heating) and embedded emissions in feed and other inputs.
Maritime shipping	Emissions per tonne-kilometre of freight or per passenger-kilometre, following IMO methodologies ³⁷ .
Offshore energy	Emissions per unit of energy produced, distinguishing between fossil fuel extraction and renewable energy generation. For detailed guidance, see TG-6.9 Offshore Energy .
Coastal tourism	Emissions per visitor-day or per unit of tourism expenditure.

¶4 SDG indicator 9.4.1 (CO₂ emission per unit of value added) provides the general methodology for industry emission intensity that can be applied to ocean sectors³⁸.

Scope 1, 2, and 3 emissions

¶1 Following the IFRS S2 framework for climate disclosure, emission intensity indicators should distinguish between the scopes summarised in Table 3.4.2 below.³⁹

Scope	Description
Scope 1	Direct emissions from owned or controlled sources (e.g., vessel fuel combustion, facility operations).
Scope 2	Indirect emissions from purchased electricity, steam, heating, and cooling.
Scope 3	All other indirect emissions in the value chain, including upstream (fuel production, equipment manufacture) and downstream (product use, end-of-life treatment).

¶2 For ocean-related industries, Scope 3 emissions are often substantial: in aquaculture, for example, emissions from feed production may exceed direct operational emissions. However, compilers should note that the SEEA CF air emissions account methodology, which underpins the emission

data in ocean accounts, attributes emissions to the economic unit responsible for the direct release. This corresponds to Scope 1 emissions by definition. Ocean accounts based on the SEEA CF air emissions methodology directly capture Scope 1 emissions attributed by industry. Scope 2 emissions can be derived by reallocating electricity generation emissions to purchasing industries using supply-use data, whilst Scope 3 analysis requires supplementary supply chain modelling using input-output techniques as described in **TG-3.3** Section 3.4 on extended applications.

3.5 Climate Risk and Adaptation Indicators

¶1 Climate risk indicators assess the exposure and vulnerability of ocean systems and ocean-dependent economies to climate-related hazards; adaptation indicators track responses through ecosystem-based adaptation and conservation. This Circular addresses gradual, chronic climate risks (sea level rise, progressive acidification, long-term warming) whilst **TG-2.9 Disaster Risk Indicators** addresses acute event-based hazards. Where measurement approaches overlap – for example, coastal inundation mapping serving both gradual sea level rise assessment and acute storm surge modelling – compilers should ensure methodological consistency between the two indicator sets.

Physical risk indicators

¶1 Physical climate risks can be categorised following the IFRS S2 framework as either chronic (gradual, persistent changes) or acute (event-driven disruptions)⁴⁰. This distinction affects both measurement methodology and disclosure requirements.

¶2 Chronic physical risks:

¶3 **Sea level rise exposure:** The area of coastal land, infrastructure, and ecosystems exposed to projected sea level rise under various scenarios:

- ¶4 Current elevation relative to mean sea level and high tide lines
- ¶5 Projected inundation under 0.5m, 1.0m, and 2.0m rise scenarios
- ¶6 Population and infrastructure within exposed zones

¶7 **Coastal erosion rates:** The rate of shoreline change, distinguishing between:

- ¶8 Erosion (negative change, land loss)
- ¶9 Accretion (positive change, land gain)
- ¶10 Attributable to sea level rise, storm intensity, or other climate factors

¶11 Acute physical risks:

¶12 **Marine heatwave exposure:** Frequency, intensity, and duration of marine heatwave events affecting the accounting area:

- ¶13 Number of marine heatwave days per year
- ¶14 Maximum intensity (degrees above climatological mean)
- ¶15 Ecosystem impact (coral bleaching, species displacement)

¶16 **Storm and cyclone exposure:** Frequency and intensity of extreme weather events affecting coastal and marine areas, with potential attribution to climate change. Indicators in this category should be compiled in coordination with the acute hazard indicators in **TG-2.9** to ensure consistent treatment of event definitions and thresholds.

Ecosystem vulnerability indicators

¶1 **Coral bleaching indices:** The frequency and severity of coral bleaching events, linked to sea surface temperature anomalies and marine heatwaves. Repeated bleaching compromises reef resilience and recovery capacity.

¶2 **Ecosystem condition change:** Changes in ecosystem condition indicators attributable to climate factors, as recorded in condition accounts:

- ¶3 Seagrass decline from thermal stress
- ¶4 Mangrove die-off from altered hydrology
- ¶5 Species range shifts from changing temperatures

¶6 **Climate-vulnerable ecosystem extent:** The area of ecosystems identified as highly vulnerable to climate impacts, based on sensitivity and adaptive capacity assessments.

Economic risk indicators

¶1 **Climate-exposed ocean economy:** The share of ocean economic activity (value added, employment) in sectors highly exposed to climate physical risks:

- ¶2 Coastal tourism dependent on beach and reef conditions
- ¶3 Fisheries dependent on climate-sensitive stocks
- ¶4 Aquaculture in areas subject to marine heatwaves or extreme events

¶5 **Projected production impacts:** Modelled changes in ecosystem service provision (fisheries yield, coastal protection, carbon sequestration) under climate scenarios.

Adaptation indicators

¶1 **Nature-based solution deployment:** Area of ecosystem-based adaptation implemented:

- ¶2 Mangrove restoration for coastal protection
- ¶3 Seagrass restoration for carbon sequestration
- ¶4 Coral reef restoration for biodiversity and tourism

¶5 The thematic guidance in **TG-6.2 Mangrove and Coastal Wetland Accounting** provides detailed methodology for accounting for these blue carbon ecosystems and their climate adaptation services.

¶6 **Coastal protection ecosystem services:** The value of natural coastal protection provided by coastal ecosystems, representing avoided damages from storm surge and flooding. This indicator links ecosystem condition to climate adaptation benefits.

¶7 **Climate adaptation expenditure:** Climate adaptation expenditure as an ocean account indicator is currently developmental, pending formal guidance on its classification within the SEEA CF environmental protection expenditure account (EPEA) framework. The CEPA 2000 classification, which structures the EPEA, does not include climate adaptation as a standalone class; adaptation expenditure must currently be imputed from CEPA class 1 (protection of ambient air and climate) and potentially other classes, with significant methodological ambiguity in separating adaptation from mitigation and from general coastal infrastructure investment. Compilers should consult SEEA CF Chapter 4 on the EPEA and the CEPA 2000 classification for current guidance. An ocean-specific spatial filter will be required to isolate marine and coastal adaptation expenditure when EPEA compilation guidance is finalised.⁴¹

¶8 **Resilience indicators:** Rather than a composite index – which requires aggregation methodology, weighting, and normalisation approaches not yet standardised for this domain – resilience to climate hazards should be reported as separately measurable indicator components:

- ¶9 **Area under ecosystem-based coastal protection** (hectares): The extent of mangrove, salt marsh, seagrass, and reef habitat providing quantified coastal protection services, compiled from extent accounts.
- ¶10 **Number of early warning systems operational:** A count of functioning coastal and marine early warning systems (for storm surge, tsunami, and marine heatwave), compiled from national disaster risk management registries.

- ¶11 **Ecosystem integrity index:** The composite condition index for coastal and marine ecosystems, compiled using the methodology in **TG-2.1 Aggregate Biophysical Indicators** Section 3.4.3.

¶12 These components can be reported individually and benchmarked against national targets or baseline periods without requiring aggregation. A weighted composite resilience index may be introduced in a future revision of this Circular when GGA indicator guidance provides a standardised aggregation framework.⁴²

¶13 The Paris Agreement's Global Goal on Adaptation (GGA) framework is developing standardised metrics for assessing adaptation effectiveness at national and global scales⁴³. As the GGA indicator framework is progressively elaborated, compilers should monitor developments and align adaptation indicators with the emerging international framework where practicable, whilst maintaining consistency with the accounting structures described in this Circular.

3.6 Worked Example: Ocean Sector GHG Emission Intensity

¶1 This worked example demonstrates the compilation procedure for a specific emission intensity indicator: GHG emissions per unit of gross value added for the marine fishing industry. All figures are illustrative and designed to show the accounting logic; actual compilations would use observed data from national air emissions accounts and ocean economy accounts.

Scenario: National marine fishing emissions intensity

¶1 **Context.** A coastal State compiles ocean accounts including air emissions accounts for ocean industries and ocean economy supply-use tables. The compiler seeks to derive the GHG emission intensity indicator for the marine fishing industry (ISIC 0311) for use in national climate reporting and to track progress toward sectoral emission reduction targets.

¶2 **Step 1: Extract emissions data.** From the air emissions account for the accounting period (Year N), the compiler identifies the row for ISIC 0311 (Marine fishing) and records the total GHG emissions:

Industry	Emissions (tonnes CO ₂ e)
ISIC 0311 Marine fishing	450,000

¶3 The emissions figure represents Scope 1 direct emissions from vessel fuel combustion (diesel, gasoline) during fishing operations, recorded at the point of release from the vessel.

¶4 **Step 2: Extract activity data.** From the ocean economy supply-use table for Year N, the compiler extracts two activity measures:

Activity measure	Value	Unit
Landed catch	180,000	tonnes
Industry GVA	75,000,000	currency units

¶5 **Step 2a: Verify temporal alignment.** The compiler confirms that the air emissions account and the supply-use table both reference Year N. In this example, the air emissions account is published with a two-year lag; the most recently published account covers Year N-2. The compiler interpolates Year N emissions using a linear trend from Years N-4 to N-2 and records this interpolation in the indicator metadata, specifying the method and the resulting uncertainty contribution. The indicator is published with a metadata note disclosing that the emissions numerator is an interpolated estimate for Year N derived from the Year N-2 published account.

¶6 **Step 3: Calculate intensity ratios.** The compiler calculates two intensity indicators:

¶7 (a) **Emissions per tonne of landed catch:**

$450,000 \text{ tonnes CO}_2\text{e} / 180,000 \text{ tonnes catch} = 2.5 \text{ tonnes CO}_2\text{e per tonne of catch}$

¶8 (b) **Emissions per unit of GVA:**

$450,000 \text{ tonnes CO}_2\text{e} / 75,000,000 \text{ currency units} = 0.006 \text{ tonnes CO}_2\text{e per currency unit} =$
 $6,000 \text{ kg CO}_2\text{e per thousand currency units of GVA}$

¶9 **Step 4: Disaggregate by gear type (optional).** Where data permit, the compiler disaggregates the intensity indicator by fishing method. Using supplementary data from the fisheries management authority on fleet composition and catch by gear type:

Gear type	Emissions (tonnes CO ₂ e)	Catch (tonnes)	Intensity (kg CO ₂ e/tonne)
Bottom trawl	180,000	45,000	4,000
Purse seine	120,000	90,000	1,333
Longline	90,000	30,000	3,000
Other	60,000	15,000	4,000
Total	450,000	180,000	2,500

¶10 This disaggregation reveals that purse seine fishing has substantially lower emission intensity (1,333 kg CO₂e per tonne) compared to bottom trawl (4,000 kg CO₂e per tonne), informing policy discussions on transitioning to lower-emission fishing methods.

¶11 **Step 5: Compile time series.** The compiler repeats the calculation for Years N-4 through N to construct a five-year time series:

Year	Emissions (tonnes CO ₂ e)	Catch (tonnes)	Intensity (kg CO ₂ e/tonne)
N-4	500,000	170,000	2,941
N-3	480,000	175,000	2,743
N-2	470,000	178,000	2,640
N-1	460,000	179,000	2,570
N	450,000	180,000	2,500

¶12 The time series demonstrates declining emission intensity over the five-year period (from 2,941 to 2,500 kg CO₂e per tonne), a 15 per cent reduction. This indicates relative decoupling of emissions from fishing production, potentially driven by fleet modernisation, fuel efficiency improvements, or shifts in gear composition.

¶13 **Step 6: Document and report.** The compiler documents:

- ¶14 **Data sources:** Air emissions account (national statistics office), ocean economy accounts (marine agency), fleet composition (fisheries authority)
- ¶15 **Coverage:** Emissions data cover Scope 1 direct emissions only; Scope 2 and 3 are not included
- ¶16 **Exclusions:** Small-scale and subsistence fishing are excluded due to data limitations (estimated to represent 10 per cent of national catch)
- ¶17 **Coverage gap treatment:** The excluded 10 per cent of catch is a quantifiable subset. In accordance with UNFCCC Enhanced Transparency Framework (ETF) completeness requirements, compilers must either (a) apply a Tier 1 emission factor to the estimated excluded catch (total national catch = 180,000 / 0.9 = 200,000 tonnes; excluded catch = 200,000 × 0.1 = 20,000 tonnes) to produce a complete indicator, or (b) report the indicator as a partial estimate explic-

itly covering 90 per cent of national catch and flag this as an incompleteness in the national reporting tables. For NDC sectoral analysis – as used in this example – the UNFCCC ETF Modalities, Procedures, and Guidelines (Annex III) require estimation of excluded categories even at Tier I; omitting them without estimation would constitute a material incompleteness.⁴⁴

- ¶18 **Uncertainty:** Emissions data have an estimated uncertainty of plus or minus 8 per cent based on fuel consumption survey error
- ¶19 **Policy use:** Indicator feeds into NDC sectoral analysis. The emissions behind it are fuel combustion, which the national GHG inventory reports in the Energy sector (category 1.A.4.c.iii, fishing), not in AFOLU⁴⁵

¶20 The indicator is published in the national climate reporting tables and the ocean accounts publication, with time series enabling trend analysis and assessment against national emission reduction targets.

Case illustration: Offshore renewable energy emission intensity (ISIC 3510)

¶1 The compilation of emission intensity for offshore renewable energy generation presents additional steps due to the need to disaggregate offshore wind and wave/tidal capacity from broader electricity generation data. The following illustration demonstrates the approach for offshore wind.

¶2 **Step A: Identify offshore wind capacity from licensing records.** The compiler obtains the national offshore wind licensing registry from the energy regulator. The registry lists each licensed offshore wind farm, its rated capacity (MW), commissioning date, and spatial coordinates. Active farms in the accounting year total 850 MW of installed capacity.

¶3 **Step B: Calculate capacity factor-adjusted generation.** Apply the national or technology-specific capacity factor (in this example, 38 per cent, consistent with regional offshore wind performance) to derive annual energy output:

$$850 \text{ MW} \times 8,760 \text{ hours} \times 0.38 \text{ capacity factor} = 2,828 \text{ GWh} = 10.18 \text{ PJ}$$

¶4 **Step C: Apply emission factor for direct operations.** Offshore wind farms produce minimal Scope 1 emissions during operation – primarily from maintenance vessels and facility backup generators. Apply an operations-phase emission factor (in this example, 2.5 kg CO₂e per MWh from maintenance vessel fuel, sourced from plant operator reports):

$$2,828,000 \text{ MWh} \times 2.5 \text{ kg CO}_2\text{e/MWh} = 7,070 \text{ tonnes CO}_2\text{e (Scope 1)}$$

¶5 **Step D: Calculate Scope 1 intensity.** Divide Scope 1 emissions by energy output:

$$7,070 \text{ tonnes CO}_2\text{e} / 2,828,000 \text{ MWh} = 0.0025 \text{ tonnes CO}_2\text{e/MWh} = 2.5 \text{ kg CO}_2\text{e/MWh}$$

¶6 **Step E: Report lifecycle intensity as supplementary metric.** Because direct operational emissions for offshore renewables are near-zero, the Scope 1 intensity indicator alone does not convey the full climate relevance of the sector. Compilers should additionally report the lifecycle (Scope 3) carbon intensity using published lifecycle assessment estimates for offshore wind (typically 7–15 g CO₂e/kWh including manufacturing, installation, and decommissioning). This supplementary metric should be clearly labelled as a lifecycle estimate derived from external LCA literature, not from the ocean accounts air emissions account.⁴⁶

¶7 **Step F: Handle non-disaggregable residual.** Where a share of ISIC 3510 production cannot be attributed to offshore renewables through licensing records (e.g., unlicensed small installations,

shared grid connections), the compiler should document the unattributable share and report the offshore renewable intensity as covering the licensed portion only (ISIC classification: Table 2, footnote ³⁶).

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

5. References

1. ¶1 United Nations et al., *System of Environmental-Economic Accounting – Ecosystem Accounting* (New York: United Nations, 2021).
2. ¶2 United Nations et al., *System of Environmental-Economic Accounting 2012 – Central Framework* (New York: United Nations, 2014).
3. ¶3 United Nations, *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*, A/RES/71/313.
4. ¶4 United Nations (2015). *Paris Agreement*. Adopted under the United Nations Framework Convention on Climate Change. Article 4 on nationally determined contributions and Article 7 on adaptation.
5. ¶5 Kunming-Montreal Global Biodiversity Framework (2022). Decision 15/4 of the Conference of the Parties to the Convention on Biological Diversity. Target 8 on minimising the impact of climate change and ocean acidification on biodiversity.
6. ¶6 IFRS Foundation, *IFRS S2 Climate-related Disclosures* (London: IFRS Foundation, 2023).
7. ¶7 IPCC, *Special Report on the Ocean and Cryosphere in a Changing Climate* (Cambridge: Cambridge University Press, 2019), Chapter 5.
8. ¶8 See SEEA EA, Chapter 13, for guidance on thematic accounts including carbon stock accounts that provide the foundation for ocean-climate indicator compilation.
9. ¶9 IFRS S2, paragraphs 29–32, specifies requirements for greenhouse gas emissions disclosure including Scope 1, 2, and 3 emissions and cross-industry metrics.
0. ¶10 SDG indicator 14.3.1: Average marine acidity (pH) measured at agreed suite of representative sampling stations.
1. ¶11 IPCC, *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (Geneva: IPCC, 2014).
2. ¶12 As of 2024, over 70 countries reference ocean-based climate actions in their NDCs, spanning blue carbon conservation, sustainable fisheries, marine renewable energy, and coastal adaptation measures. See UNFCCC NDC Registry for current submissions.
3. ¶13 Taskforce on Nature-related Financial Disclosures, *Recommendations of the Taskforce on Nature-related Financial Disclosures* (September 2023).
4. ¶14 Nellemann, C. et al. (eds.), *Blue Carbon: The Role of Healthy Oceans in Binding Carbon* (UNEP, FAO, UNESCO-IOC, IUCN, 2009).
5. ¶15 Mcleod, E. et al., “A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO₂”, *Frontiers in Ecology and the Environment* 9, no. 10 (2011): 552–560.
6. ¶16 SEEA EA, paragraphs 6.110–6.113, describe the accounting treatment of global climate regulation services including carbon sequestration and carbon retention.
7. ¶17 Values represent indicative ranges compiled from multiple studies; local rates vary substantially with ecosystem condition and environmental factors.
8. ¶18 IPCC (2014). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*, Chapter 4, Table 4.2. Default sequestration rates are derived from long-term sediment carbon accumulation studies and approximate NECB rather than gross primary production. See also Howard, J. et al. (2014). *Coastal Blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors*. IUCN, Conservation International, IOC-UNESCO, Appendix B.
9. ¶19 United Nations Convention on the Law of the Sea (UNCLOS), Part V, Articles 55–75, on the Exclusive Economic Zone. Articles 56–57 establish coastal State sovereign rights for exploring, exploiting, conserving, and managing natural resources within the EEZ.
0. ¶20 SEEA EA, Table 13.3, presents the structure of carbon stock accounts disaggregating stocks by carbon pool type.
1. ¶21 Carbon stock estimates are indicative and include both biomass and sediment carbon pools. Sediment carbon stocks depend on sediment depth, which can extend metres below the surface in mature coastal ecosystems.
2. ¶22 IPCC (2014). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Chapter 4 provides Tier 1 emission factors for coastal wetland conversion, disaggregated by carbon pool and disturbance type.
3. ¶23 SEEA EA, paragraphs 6.110–6.113 on the measurement of carbon retention services; see also Chapter 8 on monetary valuation approaches for ecosystem services.

4. ¶24 The annuity approach to carbon service valuation is described in SEEA EA annex A12.1 and in the SEEA Valuation technical guidance.
5. ¶25 High-Level Commission on Carbon Prices (2017). *Report of the High-Level Commission on Carbon Prices*. World Bank, Washington, DC. The Commission recommended carbon prices of USD 40–80 per tonne CO₂ by 2020 and USD 50–100 by 2030 to achieve Paris Agreement goals.
6. ¶26 Bunting, P. et al. (2018). “The Global Mangrove Watch – A New 2010 Global Baseline of Mangrove Extent”, *Remote Sensing* 10, no. 10: 1669. The Global Mangrove Watch provides standardised annual mangrove extent maps from 1996 to present.
7. ¶27 IPCC, *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (Geneva: IPCC, 2014), Chapters 2–4. Note: the 2006 Guidelines Volume 4 Chapter 4 covers Forest Land; coastal wetland methodologies are in the 2013 Wetlands Supplement.
8. ¶28 Doney, S.C. et al., “Ocean Acidification: The Other CO₂ Problem”, *Annual Review of Marine Science* 1 (2009): 169–192.
9. ¶29 SDG 14.3.1 methodology notes that measurements should be taken at representative stations covering coastal and open ocean areas within national jurisdiction.
0. ¶30 The aragonite saturation state (omega-a) is calculated from dissolved inorganic carbon, total alkalinity, temperature, salinity, and pressure.
1. ¶31 Newton, J.A. et al. (2015). *Global Ocean Acidification Observing Network: Requirements and Governance Plan*. Second Edition. GOA-ON. The GOA-ON maintains a data portal, quality standards, and best practices for acidification observations.
2. ¶32 IOC-UNESCO, SDG 14.3.1 indicator metadata and methodology (maintained by the IOC-UNESCO custodian agency); Shutler, J.D. et al. (2020). “Satellites will address critical science priorities for the ocean decade.” *Frontiers in Earth Science* 8: 320; GOA-ON best practices documentation for satellite pH products.
3. ¶33 World Resources Institute and World Business Council for Sustainable Development (2004). *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. Revised Edition.
4. ¶34 United Nations et al. (2025). *System of National Accounts 2025*. Chapter 35 addresses environmental-economic accounting including residual flows from economic activity to the environment.
5. ¶35 SEEA CF, para 3.173, on reference period consistency in environmental accounts; Eurostat, *Air Emissions Accounts: Compilation Guide* (2019), Section 4.2 on temporal alignment of emissions and activity data.
6. ¶36 In ISIC Rev.4, class 3510 covers all electric power generation, transmission, and distribution. ISIC Rev.4 does not distinguish generation technology type at the 4-digit class level; the subdivision into renewable and non-renewable generation was introduced in ISIC Rev.5 (endorsed 2024). National compilers using European classifications should note that NACE Rev.2 code 35.11 (which does distinguish technology type) is an adaptation of ISIC Rev.4, not an ISIC code. Until ISIC Rev.5 is adopted, identification of the offshore renewable subset requires supplementary data from energy statistics, licensing registries, or national energy balances.
7. ¶37 IMO, *Fourth IMO Greenhouse Gas Study 2020* (London: International Maritime Organization, 2021).
8. ¶38 SDG indicator 9.4.1: CO₂ emission per unit of value added, calculated as the ratio of total CO₂ emissions from fuel combustion to total industry value added.
9. ¶39 The GHG Protocol Corporate Standard and IFRS S2 define the scope categories, with detailed guidance for Scope 3 emissions in the GHG Protocol Scope 3 Standard.
0. ¶40 IFRS S2, Appendix A, distinguishes physical risks as either “acute” (event-driven, such as cyclones and floods) or “chronic” (longer-term shifts, such as sea level rise and sustained higher temperatures). This classification follows the TCFD framework.
1. ¶41 SEEA CF, Chapter 4 (Environmental Protection Expenditure Accounts); CEPA 2000 classification of environmental protection activities. OECD DAC climate marker methodology provides an approach to adaptation expenditure tagging in development finance contexts but is not directly applicable to national accounts.
2. ¶42 TG-2.1, Section 3.3, describes the composite condition index methodology including normalisation and aggregation; SEEA EA, Chapter 7, on ecosystem condition accounts; UNFCCC GGA Glasgow-Sharm el-Sheikh work programme on adaptation indicators.
3. ¶43 The Glasgow-Sharm el-Sheikh work programme on the Global Goal on Adaptation (GGA) was established at COP26 and elaborated at COP27–COP28. The framework aims to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, with indicators under progressive development.
4. ¶44 UNFCCC, *Modalities, Procedures, and Guidelines for the Transparency Framework for Action and Support* (MPGs), Decision 18/CMA.1, Annex III, paragraph 16, on completeness requirements for GHG inventories under the Enhanced Transparency Framework. IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 1, Chapter 1, Section 1.3, on completeness as an inventory quality criterion.
5. ¶45 IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 2: Energy, Chapter 3 (Mobile Combustion), Section 3.5 (Water-borne Navigation), which covers fishing (1.A.4.c.iii).
6. ¶46 ISIC Rev.4 class 3510 notes; IEA offshore wind statistics methodology; lifecycle emission intensity estimates for offshore wind are typically in the range of 7–15 g CO₂e/kWh based on published LCA literature; IRENA (2021). *Renewable Power Generation Costs in 2020*, Annex.

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