The oceans' silent sentinel:

how ocean observation data power marine climate change mitigation

ECONOMIST IMPACT

World Ocean Initiative

Ocean data value : reference note

Assessing the economic value of ocean observation data for marine-centred climate-change mitigation

About the research

Economist Impact's World Ocean Initiative has undertaken a unique and vital research programme to estimate the economic value of ocean observation data (OOD) streams to marine-centred climate-change mitigation activities globally. It demonstrates the benefits that would accrue if public, private, academic and philanthropic initiatives could more effectively unleash the potential of OOD through greater data accessibility and usability, talent development, and public-private partnerships.

By taking a first step towards improving our understanding of the economic linkages that inform and drive the blue economy, we hope to bolster the case for improved and expanded ocean observations, climate-change mitigation efforts, and research on the economic value of data for the blue economy.

Please note that this research was independently conducted by Economist Impact and commissioned by:

- Fisheries and Oceans Canada / Peches et océans Canada
- Fugro
- National Oceanic and Atmospheric Administration
- Ocean Frontier Institute at Dalhousie University
- Syndicate 708

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Context

Our oceans produce half of the Earth's oxygen, absorb 25% of its CO2 emissions, and trap 90% of its excess heat, acting as a crucial carbon sink.[1] Research suggests that ocean-based climate solutions could reduce the emissions gap[2] by up to 21% on a 1.5°C path. This rises to an impressive 25% on a 2°C trajectory by 2050.[3] Emerging marine industries, like offshore wind and carbon removal, offer substantial mitigation potential, economic benefits and employment opportunities. Ocean observations are vital for marine climate solutions, offering foundational and continuous information. They provide baselines, support operations, offer real-time monitoring and are required to assess climate practice efficacy.

Governments, academia and the private industry have spent billions of dollars on ocean observation data (OOD) collection over the past 30 years,[4] [5] capturing information on activity as diverse as changes in seafloor geology and plankton population dynamics, as well as shipping lane traffic and sea levels. The type of OOD, volume of data and regularity at which these data are collected have all increased dramatically.

Despite the many organisations, partnerships and programmes—both public and private—working with ocean data, and platforms that have stimulated the exchange of historical, contemporaneous and real-time data, the full economic potential of these data are not yet being leveraged. Only a small fraction of the data collected reaches those who could benefit most. Without these data flows, efforts to track climate change and the impacts of climate-change mitigation activities will be hindered.

OOD are already bringing about significant benefits, in both current and theoretical uses, for marine-centred climate-change mitigation, but these linkages remain largely unmeasured. For example, ocean observations are critical for understanding the pace and extent of climate change, which enables science-driven mitigation efforts. With ocean temperature data, we can better predict weather patterns, which supports sustainable fishing and aquaculture activities. Seafloor measurements are necessary for developing marine energy and many blue carbon projects. The list is already long, but the full potential of OOD is still being unravelled.

Scope

While efforts are still ongoing to fully understand the *mechanisms* by which OOD support marine-centred climate-change mitigation, this research initiative aims to estimate the dollar value of OOD pertaining to marine-centred climate-change mitigation.

The selection of industries in the blue economy, defined as the sustainable use of ocean resources for economic growth, improved livelihoods and jobs while preserving the health of the ocean ecosystem,

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[1] United Nations. (n.d.). *The ocean – the world's greatest ally against climate change | United Nations*. https://www.un.org/en/climatechange/science/climate-issues/ocean#:~:text=The%20ocean%20generates%2050%20percent,the%20impacts%20of%20climate%20change

[2] The emissions gaps is the difference between the emissions expected if current trends and policies continue and emissions consistent with limiting the global temperature increase

[3] Hoegh-Guldberg, O. (n.d.). *Turning the tide: Ocean-Based solutions could close the emission gap by 21%*. World Resources Institute. https://www.wri.org/insights/turning-tide-ocean-based-solutions-could-close-emission-gap-21

[4] Public and private sectors to advance ocean observing. (2023, July 11). Intergovernmental Oceanographic Commission. https://www.ioc.unesco.org/en/articles/public-and-private-sectors-advance-ocean-observing

[5] The United States Government invests $3.9 million for Ocean Enterprise engagement. (2023, September 28). UNESCO. https://www.unesco.org/en/articles/united-states-government-invests-39-million-ocean-enterprise-engagement

drew heavily on prior work by the OECD[6] regarding the future of the ocean economy. That list was further constrained to industries that are heavily involved with marine-centred climate-change mitigation, including:

- The decarbonisation of existing activities within marine ecosystems such as marine transport and food systems.
- New marine activities that contribute to global decarbonisation such as marine energy (including offshore wind, wave energy, tidal energy, ocean current energy and osmotic energy) or marine carbon dioxide removal (MCDR), including new blue carbon projects.
- The maintenance of existing activities, ecosystems or resources that promote decarbonisation such as marine habitat preservation activities (blue carbon)

Table 1: Industries in scope

• Blue carbon projects (eg, marine habitat preservation activities)
• MCDR
  ○ Microalgal cultivation and sequestration
  ○ Ocean alkalinisation
  ○ Electrochemical CO2 stripping
• Ocean renewable energy (excluding offshore wind)
• Offshore wind
• Shipping

Source: Economist Impact (2023).

We define OOD as the systematic collection of ocean data, which typically features these three main characteristics: data describe physical properties (including the ocean-atmosphere layer); data are observed regularly to track changing conditions—although a one-time reading would be preferable in some situations, due to constraints such as ocean depth; and the data have global relevance. Ocean observations are thus distinguishable from other types of ocean-related data, such as measuring marine life or habitats or human activities.

The definition was explicitly left broad so as to include multiple areas of study and data types (eg, bathymetric, geophysical, geotechnical, physical oceanographic, chemical oceanographic and biological oceanographic). It means that multiple sources of data collection and generation are also included:

- In situ: generated from observations or measurements conducted within or upon the ocean.
- Remotely sensed: eg, via satellites, airplane observations, high frequency radar and shore observations.
- Subsurface/seabed: via sensors and samplers that continuously gather data from the seabed, deep sea and/or water column.

OOD stream examples are included below. However, estimates assess these in aggregate rather than as individual products or collections of products.

- Argo floats (including BGC Argo): free-drifting floats that measure temperature and salinity
- Gliders: autonomous underwater vehicles
- Moorings (eg, OceanSITES): collection devices anchored to the sea floor with a wire

[6] OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris. https://doi.org/10.1787/9789264251724-en.

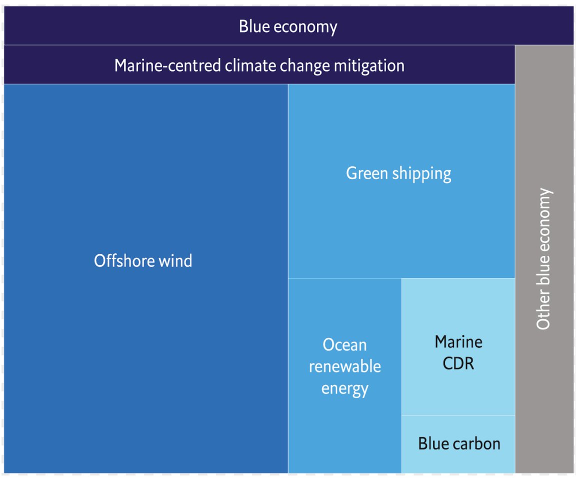
- Regular cruise tracks (eg, GO-SHIP): ship-based hydrographic surveys
- Satellite observations (Copernicus, etc.): ocean monitoring from satellites
- High-frequency radar: used to measure ocean surface currents in near real time
- Sea level gauges: also called tide gauges, these are often placed on piers and used to measure sea level trends

Research process

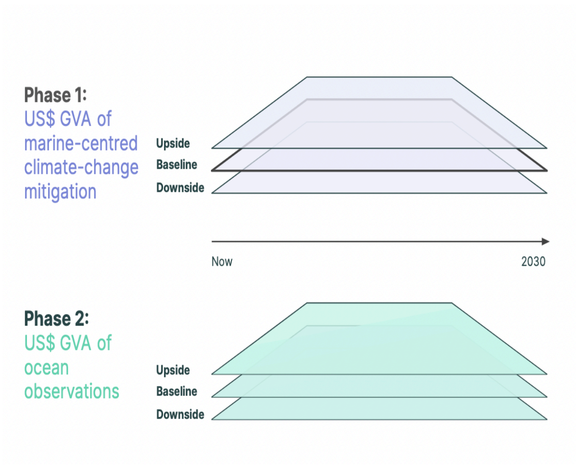
The first stage of research began with an in-depth literature review to explore the latest concepts, debates, metrics and sources of evidence regarding the blue economy and OOD. These findings were critical for establishing the conceptual framework (see Figure 1), which, for the purpose of estimation efforts, was used to constrain the scope (described above) and guide the valuation approach (detailed below).

Figure 1: Conceptual framework

Scope



Valuation approach



Source: Economist Impact (2023).
Note: scope hierarchy displays the conceptual relationship between industries, marine-centred climate-change mitigation activities and the larger blue economy. Size is not to scale for legibility purposes.

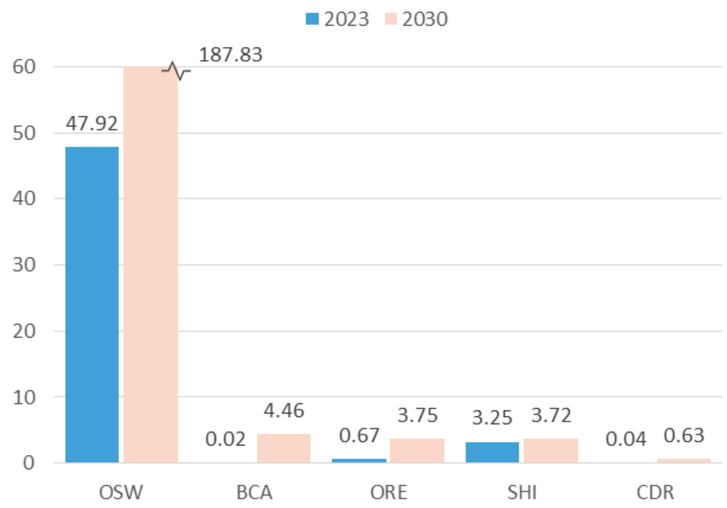
This process was supplemented with one-on-one expert consultations to solicit feedback and recommendations on the conceptual framework.

Core research was conducted in two parts, corresponding to the conceptual framework shown in Figure 1. Detailed sources and methods used for each stage are included in each industry section below.

- In the first stage of estimates, research began with a bottom-up quantitative analysis of the global value-added(GVA) of marine-centred climate-change mitigation activities within ocean industries, including a forecast of this value until 2030 (Table 2). In addition to the baseline forecasts, upside and downside estimates for each industry considered uncertainties and alternative scenarios for key drivers (Annex 1).

- The second stage involved the valuation of OOD, which was defined as the proportion of first-stage estimates that are existentially dependent upon OOD (Table 3). The value of this ratio was estimated independently across each industry. An extensive stakeholder consultation exercise was used to establish preliminary estimates, using an informal online survey. Those preliminary estimates were then stress-tested through additional expert consultations. Relative growth over the forecast period and scenarios (described below) were then applied consistently across industries, unless otherwise noted below.

Figure 2: Industry-specific value-added in 2023 and 2030, baseline scenario (US$ bn)



Source: Economist Impact modelled estimates (2023).
Note: OSW: offshore wind; BCA: blue carbon; ORE: ocean renewable energy (excluding offshore wind); SHI: shipping (passenger and cargo); CDR: marine carbon dioxide removal. Axis break for 2030 value for offshore wind.

Scenarios

In creating the scenario forecasts for each industry, we relied on a set of core assumptions regarding the baseline, downside and upside scenarios that impose consistency across estimates and are important for context. These are summarised in Figure 3 below.

Figure 3: Core assumptions across scenarios

	Downside scenario	Baseline scenario	Upside scenario
Net zero commitments	Historical growth in commitments, few targets met	Historical growth in commitments, most targets met	Increasing growth in commitments, most targets met
CDR supply/demand	0-low	Moderate	High
Policy support and investment for OOD	Low	Medium	High
Policy support and investment for marine-centred climate-change mitigation	Medium	Medium	High

Source: Economist Impact modelled estimates (2023).

The upside scenario considers the presence of robust carbon markets, denoted as carbon GVA in the table provided. Carbon market activities are integrated into all scenarios concerning blue carbon and MCDR. However, due to the specialised nature of the shipping sector, we have opted not to analyse its carbon market dynamics. For more information on carbon market pricing and estimates, please refer to Annex 2. For industry-specific values, please refer to the industry estimates below.

Table 2: Detailed value-added forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Offshore wind									
Baseline	47.92	58.25	70.80	86.06	104.60	127.14	154.53	187.83	21.5%
Downside	47.92	53.72	60.22	67.51	75.68	84.83	95.10	106.60	12.1%
Upside	53.03	63.59	76.60	94.11	116.31	144.25	179.20	222.86	22.8%
Core GVA	47.92	59.67	74.31	92.53	115.23	143.48	178.67	222.49	24.5%
Carbon GVA	5.11	3.91	2.29	1.57	1.08	0.76	0.53	0.37	-31.40%
of which: Marine CDR									
Baseline	0.04	0.06	0.08	0.11	0.17	0.26	0.41	0.63	48.3%
Downside	0.04	0.02	0.04	0.06	0.11	0.19	0.32	0.54	45.0%
Upside	0.04	0.06	0.09	0.16	0.28	0.55	0.93	1.11	60.8%
of which: Ocean renewable energy (excluding offshore wind; wave energy, tidal energy)									
Baseline	0.67	0.85	1.09	1.40	1.79	2.29	2.93	3.75	27.9%
Downside	0.67	0.75	0.84	0.94	1.06	1.19	1.34	1.50	12.2%
Upside	0.72	0.93	1.20	1.57	2.08	2.75	3.64	7.94	40.9%
Core GVA	0.67	0.88	1.17	1.56	2.06	2.74	3.63	7.93	42.5%
Carbon GVA	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01	-24.69%
of which: Shipping (passenger and cargo)									
Baseline	3.25	3.31	3.37	3.44	3.51	3.58	3.65	3.72	1.9%
Downside	3.25	3.28	3.31	3.34	3.37	3.40	3.43	3.47	0.9%
Upside	3.25	3.34	3.44	3.54	3.64	3.75	3.86	3.97	2.9%
of which: Blue carbon									
Baseline	0.02	0.04	0.08	0.19	0.39	0.90	1.96	4.46	116.5%
Downside	0.02	0.03	0.07	0.13	0.25	0.49	0.95	1.83	90.6%
Upside	0.02	0.05	0.12	0.33	0.86	2.26	5.93	15.57	158.8%

Source: Economist Impact modelled estimates (2023).

Table 3: Detailed valuation of OOD forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added, dependent on ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Offshore wind									
Baseline	32.16	41.38	53.25	68.52	88.16	113.45	145.98	187.83	28.7%
Downside	32.16	38.17	45.29	53.75	63.79	75.70	89.83	106.60	18.7%
Upside	35.59	45.17	57.61	74.93	98.03	128.71	169.28	222.86	30.0%
of which: Marine CDR									
Baseline	0.02	0.03	0.05	0.08	0.12	0.20	0.32	0.53	59.7%
Downside	0.02	0.01	0.02	0.04	0.06	0.11	0.19	0.33	49.3%
Upside	0.02	0.04	0.06	0.11	0.22	0.46	0.86	1.11	77.5%
of which: Ocean renewable energy (excluding offshore wind; wave energy, tidal energy)									
Baseline	0.52	0.69	0.91	1.21	1.60	2.13	2.83	3.75	32.6%
Downside	0.52	0.60	0.70	0.82	0.95	1.11	1.29	1.50	16.3%
Upside	0.56	0.75	1.00	1.36	1.86	2.55	3.51	7.94	46.1%
of which: Shipping (passenger and cargo)									
Baseline	1.30	1.41	1.52	1.64	1.77	1.92	2.07	2.24	8.1%
Downside	1.30	1.33	1.36	1.40	1.43	1.46	1.50	1.53	2.4%
Upside	1.30	1.46	1.63	1.83	2.05	2.29	2.56	2.87	12.0%
of which: Blue carbon									
Baseline	0.01	0.03	0.07	0.16	0.36	0.84	1.90	4.46	139.0%
Downside	0.01	0.03	0.06	0.11	0.23	0.46	0.91	1.83	110.5%
Upside	0.01	0.04	0.11	0.29	0.78	2.11	5.73	15.57	185.8%

Source: Economist Impact modelled estimates (2023).

Industry-specific estimates

Offshore wind

As one of the most dominant forms of ocean renewable energy at present, 100% of the GVA of offshore wind contributes to climate-change mitigation. A starting point for GVA was taken from OECD estimates.[7] A slight downward adjustment to current and forecasted estimates was applied due to the pandemic, bringing growth in line with latest industry performance and forecast reports from the IEA.[8]

Key drivers considered in the 2030 estimates included current GVA, installed capacity and energy output. Current geographic spread and country specific targets[9] were also reviewed to make appropriate adjustments to capacity investment numbers. A key assumption is that countries will achieve their short-term offshore wind deployment targets as installation costs continually decline.

Scenario forecasts

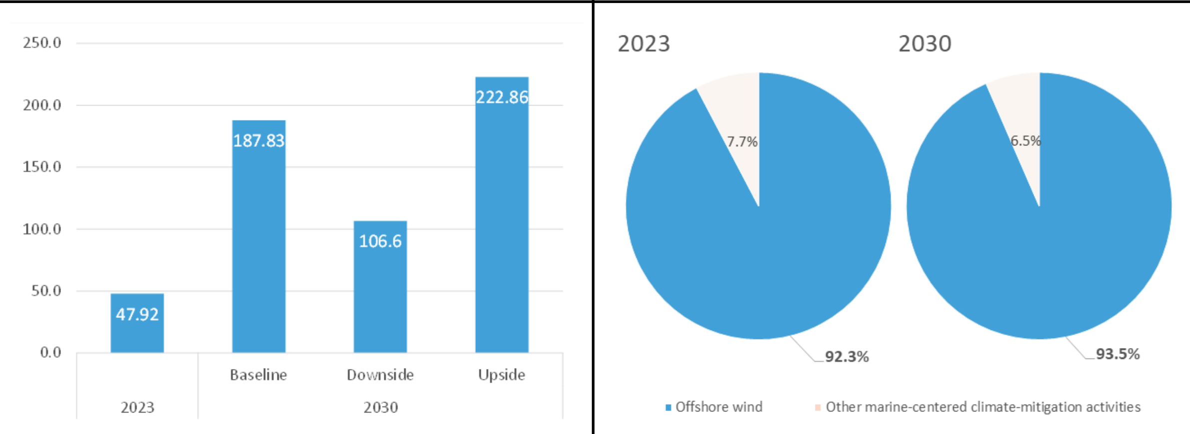
Forecast estimates consider the historical relationships between total industry GVA, capacity investment as well as estimates and commitments[10] [11] [12] regarding net zero scenario emissions in the sector. Power generation data were used to calculate the carbon footprint of the industry to determine GVA through carbon market trade.[13] Data on annual direct CO2 emissions avoided per kilowatt of electricity generated, compared with other non-renewable sources (eg, coal), were used to estimate the total carbon footprint of the industry.[14]

[7] OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris, https://doi.org/10.1787/9789264251724-en.
[8] IEA (2019), Offshore Wind Outlook 2019, IEA, Paris https://www.iea.org/reports/offshore-wind-outlook-2019, License: CC BY 4.0
[9] IRENA (2019), Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper), International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/-/media/files/irena/agency/publication/2019/oct/irena_future_of_wind_2019.pdf
[10] Ibid
[11] Global Wind Energy Council (2022). New global alliance taps into offshore wind's enormous potential. Global Wind Energy Council. https://gwec.net/new-global-alliance-taps-into-offshore-wind-enormous-potential/#:~:text=A%20new%20multi%2Dstakeholder%20alliance,to%20380%20GW%20in%202030
[12] Fugro(2023). How offshore wind is evolving to achieve 2050 net zero targets. Fugro. https://www.fugro.com/news/long-reads/2023/how-offshore-wind-is-evolving-to-hit-2050-net-zero-targets
[13] Eneger.gov (2022). How wind energy can help us breathe easier. Energy.gov. https://www.energy.gov/eere/wind/articles/how-wind-energy-can-help-us-breathe-easier
[14] Ibid

Figure 4: Offshore wind value-added in 2023 and 2030

By scenario, US$ bn

Relative to other marine-centred climate-change mitigation activities, baseline scenario, percent



Source: Economist Impact modelled estimates (2023).

Valuing OOD

Stakeholder consultations suggested that roughly 67% of the offshore wind industry's value would be lost without access to any OOD; across scenarios, a starting assumption of 67% in 2023 was used. All stakeholders expected an increase in the importance of OOD over the forecast period.

Table 4: Detailed offshore wind forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Offshore wind									
Baseline	47.92	58.25	70.80	86.06	104.60	127.14	154.53	187.83	21.5%
Downside	47.92	53.72	60.22	67.51	75.68	84.83	95.10	106.60	12.1%
Upside	53.03	63.59	76.60	94.11	116.31	144.25	179.20	222.86	22.8%
Value of ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Offshore wind									
Baseline	32.16	41.38	53.25	68.52	88.16	113.45	145.98	187.83	28.7%
Downside	32.16	38.17	45.29	53.75	63.79	75.70	89.83	106.60	18.7%
Upside	35.59	45.17	57.61	74.93	98.03	128.71	169.28	222.86	30.0%

Source: Economist Impact modelled estimates (2023).

MCDR

MCDR is the most nascent industry considered. Three technologies, described in more detail below, were included in this industry's larger aggregate.

For each technology, GVA is solely driven by the difference between revenue, ie, carbon credit sales on the voluntary market, and the costs of carbon removal—both in 2023 and across scenario forecasts. The 2023 quantity and value of CO2e sales was premised on open-source data on voluntary market dynamics.[15] The development of each technology's costs and carbon removal through 2030 were then estimated on the basis of assumptions regarding each technology's knowledge base, efficacy, scalability and total potential for carbon removal.[16] [17] [18] Finally, estimates of carbon removal were multiplied by CDR-specific voluntary market prices (see Annex 2 on carbon market estimates) across scenarios.

For such early stage technologies, it is broadly assumed that as research and development (R&D) increases, scale-up costs will decrease, encouraging market entrants and catalysing investment. The high CDR potential and well-established theoretical knowledge base of these technologies must be balanced against significant anticipated scale-up costs and few proof-of-concept projects outside of the lab today.[19] These conditions contribute to significant uncertainty in the MCDR estimates. Indeed, 100% of the industry's GVA is tied to climate-change mitigation activities.

Scenario forecasts

Algae cultivation and sequestration

The 2023 GVA includes 13,500 tonnes of CO2e sold on the voluntary market at a price of US$1,053.40 per tonne and production costs of US$125 per tonne. In the baseline scenario, carbon removal potential at scale is assumed to be 0.3 GtCO2/year, with full scale assumed possible by 2035.[20]

Ocean alkalinisation

The 2023 GVA includes 995 tonnes of CO2e sold on the voluntary market at a price of US$1,053.40 per tonne and production costs of US$160 per tonne. In the baseline scenario, carbon removal potential at scale is assumed to be 0.5 GtCO2/year, with full scale assumed possible by 2045.[21]

Electrochemical CO2 stripping

The 2023 GVA includes 62,104 tonnes of CO2e sold on the voluntary market at a price of

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[15] cdr.fyi (n.d.). https://www.cdr.fyi/

[16] National Academies of Sciences, Engineering, and Medicine. (2021). A research strategy for ocean-based carbon dioxide removal and sequestration. https://nap.nationalacademies.org/download/26278

[17] Cross, J.N., Sweeney, C., Jewett, E.B., Feely, R.A., McElhany, P., Carter, B., Stein, T., Kitch, G.D., and Gledhill, D.K., 2023. Strategy for NOAA Carbon Dioxide Removal Research: A white paper documenting a potential NOAA CDR Science Strategy as an element of NOAA's Climate Interventions Portfolio. NOAA Special Report. NOAA, Washington DC. DOI: 10.25923/gzke-8730

[18] Ocean Visions (n.d.). Ocean-Based Carbon Dioxide Removal: Road Maps. https://www2.oceanvisions.org/roadmaps/

[19] National Academies of Sciences, Engineering, and Medicine. (2021). A research strategy for ocean-based carbon dioxide removal and sequestration. https://nap.nationalacademies.org/download/26278; Cross, J.N., Sweeney, C., Jewett, E.B., Feely, R.A., McElhany, P., Carter, B., Stein, T., Kitch, G.D., and Gledhill, D.K., 2023. Strategy for NOAA Carbon Dioxide Removal Research: A white paper documenting a potential NOAA CDR Science Strategy as an element of NOAA's Climate Interventions Portfolio. NOAA Special Report. NOAA, Washington DC. DOI: 10.25923/gzke-8730

[20] See footnotes 16-19.

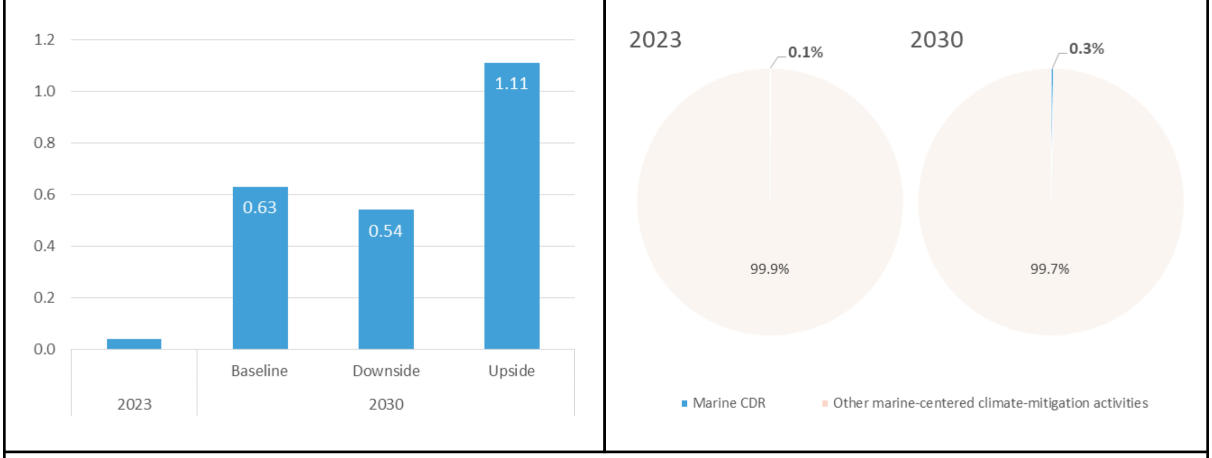
[21] See footnotes 16-19.

US$1,053.40 per tonne and production costs of US$600 per tonne. In the baseline scenario, carbon removal potential at scale is assumed to be 0.5 GtCO2/year, with full scale assumed possible by 2045.[22]

Figure 5: MCDR value-added in 2023 and 2030

By scenario, US$ bn

Relative to other marine-centred climate-change mitigation activities, percent



Source: Economist Impact modelled estimates (2023).

Valuing OOD

Stakeholder consultations suggested that roughly 48-77% of the MCDR industry's relevant value (ie, that which is tied to climate-change mitigation activities) would be lost without access to any OOD; across scenarios, a starting assumption of 56% in 2023 was used. All stakeholders expected an increase in the importance of OOD over the forecast period, quickly approaching the 100% upper-bound.

[22] See footnotes 16-19.

Table 5: Detailed MCDR forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Marine CDR									
Baseline	0.04	0.06	0.08	0.11	0.17	0.26	0.41	0.63	48.3%
Downside	0.04	0.02	0.04	0.06	0.11	0.19	0.32	0.54	45.0%
Upside	0.04	0.06	0.09	0.16	0.28	0.55	0.93	1.11	60.8%
Value of ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Marine CDR									
Baseline	0.02	0.03	0.05	0.08	0.12	0.20	0.32	0.53	59.7%
Downside	0.02	0.01	0.02	0.04	0.06	0.11	0.19	0.33	49.3%
Upside	0.02	0.04	0.06	0.11	0.22	0.46	0.86	1.11	77.5%

Source: Economist Impact modelled estimates (2023).

Ocean renewable energy (excluding offshore wind)

The ocean renewable energy estimates comprise wave and tidal energy. These technologies are the most mature relative to other ocean power technologies.[23] Given the nature of this industry, we assume that 100% of the GVA contributes to climate-change mitigation.

Due to limited data availability, revenue per terawatt of power generated was used as a proxy for the GVA. IEA records on power generation were taken as a starting point along with multiple additional sources of market research analysis.[24 25 26] Current geographic spread and country investment plans[27] were studied to make appropriate adjustments to power generation estimates. A key assumption is that revenue per terawatt of electricity generated remains constant until 2030.

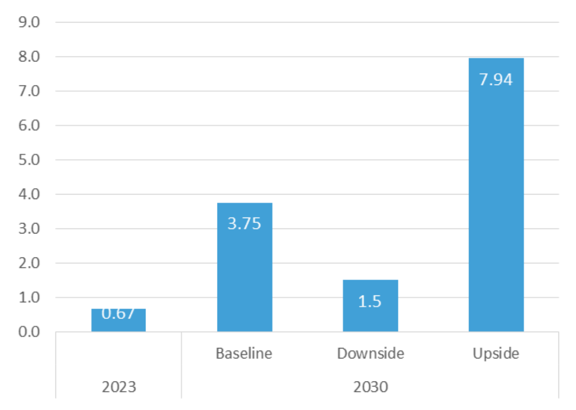
[23] European Commission. (2022). *The EU Blue Economy Report. 2022.* Publications Office of the European Union. Luxembourg. https://op.europa.eu/en/publication-detail/-/publication/156eecbd-d7eb-11ec-a95f-01aa75ed71a1
[24] IEA (2020), Ocean power generation in the Sustainable Development Scenario, 2000-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/ocean-power-generation-in-the-sustainable-development-scenario-2000-2030, IEA. Licence: CC BY 4.0
[25] Habibic, A., & Habibic, A. (2023). Global wave and tidal energy market poised to reach $10 bln by 2031, report shows. Offshore Energy. https://www.offshore-energy.biz/global-wave-and-tidal-energy-market-poised-to-reach-10-bln-by-2031-report-shows
[26] Wave and Tidal Energy Market Size, Share, Growth & Forecast 2028. (2022). https://www.fortunebusinessinsights.com/industry-reports/wave-and-tidal-energy-market-100584
[27] Tapping the ocean's large renewable energy sources. (2022). *impact.economist.com*. https://impact.economist.com/ocean/sustainable-ocean-economy/tapping-the-oceans-large-renewable-energy-sources

Scenario forecasts

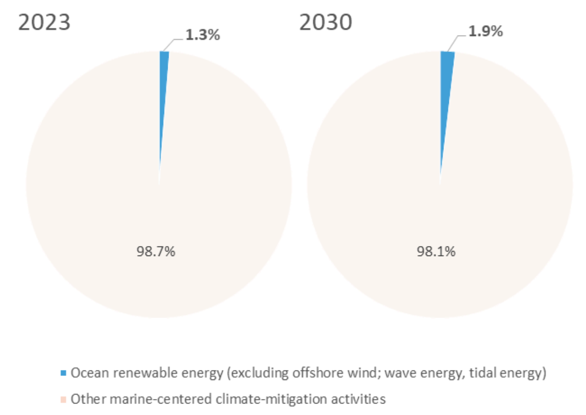
Forecast estimates consider the historical trends in total power generation and investment in capacity deployment, as well as estimates and commitments regarding net zero scenario emissions in the sector.[28] Power generation data, similar to offshore wind, were used to calculate the carbon footprint of the industry to determine the GVA through carbon market trade.[29]

Figure 6: Ocean renewable energy value-added in 2023 and 2030

By scenario, US$ bn



Relative to other marine-centred climate-change mitigation activities, percent



Source: Economist Impact modelled estimates (2023).

Valuing OOD

Stakeholder consultations suggested that roughly 78% of the ocean energy industry's value would be lost without access to any OOD; across scenarios, a starting assumption of 78% in 2023 was used. All stakeholders expected an increase in the importance of OOD over the forecast period.

[28] IEA (2020), Ocean power generation in the Sustainable Development Scenario, 2000-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/ocean-power-generation-in-the-sustainable-development-scenario-2000-2030, IEA. Licence: CC BY 4.0
[29] Smoot, G. (n.d.). What is the carbon footprint of tidal energy and wave energy? A Life-Cycle Assessment. Impactful Ninja. https://impactful.ninja/the-carbon-footprint-of-tidal-energy-and-wave-energy/

Table 6: Detailed ocean renewable energy forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Ocean renewable energy (excluding offshore wind; wave energy, tidal energy)									
Baseline	0.67	0.85	1.09	1.40	1.79	2.29	2.93	3.75	27.9%
Downside	0.67	0.75	0.84	0.94	1.06	1.19	1.34	1.50	12.2%
Upside	0.72	0.93	1.20	1.57	2.08	2.75	3.64	7.94	40.9%
Value of ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Ocean renewable energy (excluding offshore wind; wave energy, tidal energy)									
Baseline	0.52	0.69	0.91	1.21	1.60	2.13	2.83	3.75	32.6%
Downside	0.52	0.60	0.70	0.82	0.95	1.11	1.29	1.50	16.3%
Upside	0.56	0.75	1.00	1.36	1.86	2.55	3.51	7.94	46.1%

Source: Economist Impact modelled estimates (2023).

(Green) Shipping

A starting point for GVA was taken from OECD estimates.[30] A slight downward adjustment to current and forecasted growth was applied due to the pandemic, bringing growth in line with the latest maritime shipping industry performance and forecast reports from the UN Conference on Trade and Development.[31]

The proportion of industry GVA tied to climate-change mitigation activities was estimated as the value of investment in decarbonisation, defined as the sum of corporate R&D in the shipping industry[32] plus official development assistance in sustainable ocean economy for water transport.[33] A key assumption is that the entirety of corporate R&D in this sector contributes to decarbonisation.

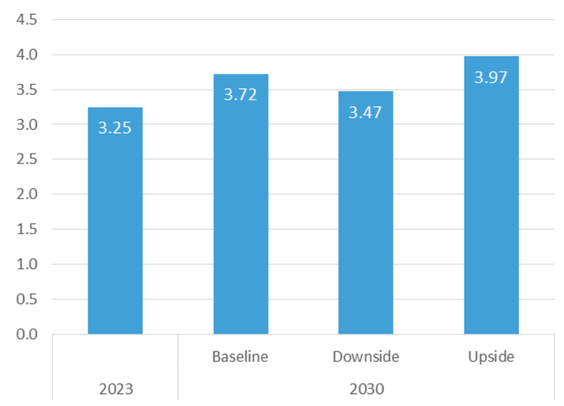
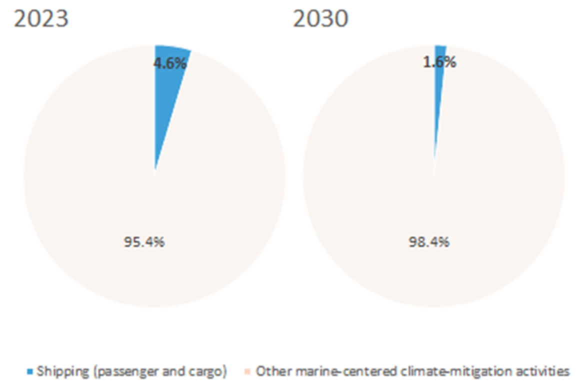
Scenario forecasts

Forecast estimates consider the historical relationships between total industry GVA, CO2 emissions

[30] OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris. https://doi.org/10.1787/9789264251724-en.
[31] UNCTAD (2022). Review of Maritime Transportation 2022. https://unctad.org/system/files/official-document/rmt2022_en.pdf
[32] IEA, Global corporate R&D spending of selected sectors, 2007-2019, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-corporate-r-and-d-spending-of-selected-sectors-2007-2019-2, IEA. Licence: CC BY 4.0
[33] OECD (n.d.), Data Platform on Development Finance for the Sustainable Ocean Economy, OECD Publishing, Paris. https://oecd-main.shinyapps.io/ocean/

and decarbonisation investment as well as estimates[34] and commitments[35] regarding net zero scenario emissions in the sector.

Figure 7: Shipping value-added in 2023 and 2030

By scenario, US$ bn	Relative to other marine-centred climate-change mitigation activities, percent
	

Source: Economist Impact modelled estimates (2023).

Valuing OOD

Stakeholder consultations suggested that roughly 15-33% of the shipping industry's relevant value (ie, revenue that is tied to climate-change mitigation activities) would be lost without access to any OOD; across scenarios, a starting assumption of 29% in 2023 was used. All stakeholders expected an increase in the importance of OOD over the forecast period.

[34] IEA, CO2 emissions from international shipping in the Net Zero Scenario, 2000-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/co2-emissions-from-international-shipping-in-the-net-zero-scenario-2000-2030-2, IEA. Licence: CC BY 4.0

[35] International Maritime Organization (IMO) (2018).“Resolution MEPC.304(72).”Initial IMOStrategy on Reduction of GHG Emissions from Ships.
https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

Table 7: Detailed shipping forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Shipping (passenger and cargo)									
Baseline	3.25	3.31	3.37	3.44	3.51	3.58	3.65	3.72	1.9%
Downside	3.25	3.28	3.31	3.34	3.37	3.40	3.43	3.47	0.9%
Upside	3.25	3.34	3.44	3.54	3.64	3.75	3.86	3.97	2.9%
Value of ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Shipping (passenger and cargo)									
Baseline	1.30	1.41	1.52	1.64	1.77	1.92	2.07	2.24	8.1%
Downside	1.30	1.33	1.36	1.40	1.43	1.46	1.50	1.53	2.4%
Upside	1.30	1.46	1.63	1.83	2.05	2.29	2.56	2.87	12.0%

Source: Economist Impact modelled estimates (2023).

Blue carbon

Given the nature of the industry, we assume that 100% of the GVA of blue carbon contributes to the climate-change mitigation industry. The 2023 quantity and value of CO2e sales was premised on estimates regarding hectares under blue carbon treatment[36] and voluntary market dynamics.[37] The carbon sequestration potential of blue carbon ecosystems was estimated to determine GVA through participation in carbon market trade.[38]

Current investments in marine nature-based solutions[39] and the current area of blue carbon ecosystems[40] were used to verify the aforementioned GVA per hectare under treatment ratio.

Scenario forecasts

Forecast estimates include key assumptions that the costs of treatment and the price per tonne of

[36] Friessid, D. A., Howardid, J., Huxham, M., Macreadie, P. I., & Rossid, F. (2022). Capitalizing on the global financial interest in blue carbon. *PLOS Climate*, *1*(8), e0000061. https://doi.org/10.1371/JOURNAL.PCLM.0000061

[37] Martinez se la Hoz, G., Emmer, I., Bravo, F., Zabala, A., & Perpignan, E. (2023). Deep Blue: Opportunities for blue carbon finance in coastal ecosystems. *IFC*. www.ifc.org

[38] Smoot, G. (n.d.). What is the carbon footprint of tidal energy and wave energy? A Life-Cycle Assessment. Impactful Ninja. https://impactful.ninja/the-carbon-footprint-of-tidal-energy-and-wave-energy/

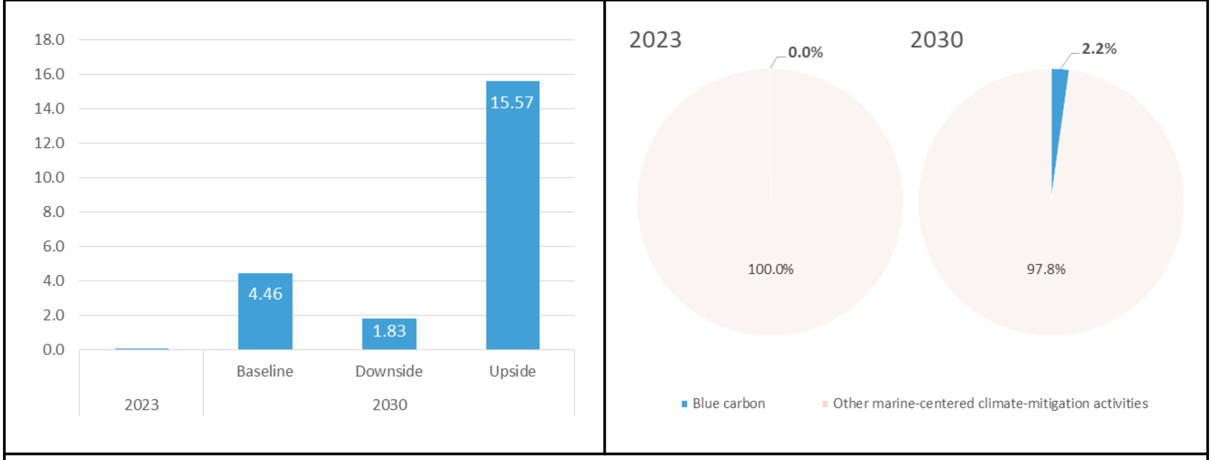
[39] United Nations Environment Programme. (2022). State of Finance for Nature. Time to act: Doubling investment by 2025 and eliminating nature-negative finance flows. Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/41333/state_finance_nature.pdf?sequence=3

[40] The Blue Carbon Initiative. (n.d.). The Blue Carbon Initiative. https://www.thebluecarboninitiative.org/#:~:text=WHERE%20IS%20IT%3F,17.7%20and%2060%20Mha%2C%20respectively

carbon sold will increase over the forecast period.[41] For all scenarios, carbon prices were set at US$30 in 2023 and US$55 in 2030. In 2023-30 the amount of hectares under treatment increased by a compound annual growth rate (CAGR) of 4.33% in the baseline scenario, 1.44% in the downside scenario and 12.99% in the upside scenario. These are roughly premised on the historical pace of blue carbon project proposals and development.[42]

Figure 8: Blue carbon value-added in 2023 and 2030

By scenario, US$ bn | Relative to other marine-centred climate-change mitigation activities, percent



Source: Economist Impact modelled estimates (2023).

Valuing OOD

Stakeholder consultations suggested that roughly 50-58% of the blue carbon industry's relevant value (ie, that which is tied to climate-change mitigation activities) would be lost without access to any OOD. Across scenarios, a starting assumption of 54% in 2023 was used. All stakeholders expected an increase in the importance of OOD over the forecast period.

[41] Martinez se la Hoz, G., Emmer, I., Bravo, F., Zabala, A., & Perpignan, E. (2023). Deep Blue: Opportunities for blue carbon finance in coastal ecosystems. *IFC*. www.ifc.org

[42] Friessid, D. A., Howardid, J., Huxham, M., Macreadie, P. I., & Rossid, F. (2022). Capitalizing on the global financial interest in blue carbon. *PLOS Climate*, *1*(8), e0000061. https://doi.org/10.1371/JOURNAL.PCLM.0000061

Table 8: Detailed blue carbon forecasts

	2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Gross value added (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	51.90	62.51	75.42	91.20	110.46	134.17	163.48	200.39	21.3%
Downside	51.90	57.80	64.48	71.98	80.47	90.10	101.14	113.94	11.9%
Upside	57.06	67.97	81.45	99.71	123.17	153.56	193.56	251.45	23.6%
of which: Blue carbon									
Baseline	0.02	0.04	0.08	0.19	0.39	0.90	1.96	4.46	116.5%
Downside	0.02	0.03	0.07	0.13	0.25	0.49	0.95	1.83	90.6%
Upside	0.02	0.05	0.12	0.33	0.86	2.26	5.93	15.57	158.8%
Value of ocean observation data (US$ bn)									
Marine-centred climate-change mitigation activities									
Baseline	34.01	43.54	55.80	71.61	92.01	118.54	153.10	198.81	28.7%
Downside	34.01	40.14	47.43	56.12	66.46	78.84	93.72	111.79	18.5%
Upside	37.48	47.46	60.41	78.52	102.94	136.12	181.94	250.35	31.2%
of which: Blue carbon									
Baseline	0.01	0.03	0.07	0.16	0.36	0.84	1.90	4.46	139.0%
Downside	0.01	0.03	0.06	0.11	0.23	0.46	0.91	1.83	110.5%
Upside	0.01	0.04	0.11	0.29	0.78	2.11	5.73	15.57	185.8%

Source: Economist Impact modelled estimates (2023).

Limitations of the research

Efforts to fully understand the mechanisms by which OOD support marine-centred climate-change mitigation are ongoing. Furthermore, future-gazing is an extremely complicated task given the nascent nature of many technologies included in this study, plethora of decarbonisation and policy scenarios, and underdeveloped state of voluntary carbon markets.

This research initiative is not underpinned by a formal model that enforces partial or general equilibrium, given that so little historical data exist. While our best efforts have been made to ground forward-looking estimates, this initiative was an exercise in future-gazing, imagination and story-telling regarding the value and potential of OOD in driving marine-centred climate-change mitigation.

Annex 1: Key drivers

Key forecast drivers

		2023	2024	2025	2026	2027	2028	2029	2030	CAGR (2023-30)
Offshore wind										
Installled capacity										
Baseline	Gigawatt (GW)	78.60	98.50	123.30	154.40	193.40	242.30	303.40	380.00	25.2%
Downside	Gigawatt (GW)	78.60	91.50	106.60	124.10	144.50	168.20	195.80	228.00	16.4%
Upside	Gigawatt (GW)	78.60	100.90	129.40	166.10	213.10	273.40	350.70	450.00	28.3%
Carbon price (RE offset, all market:	USD per metric ton CO2	87.68	85.45	85.14	85.04	85.13	87.47	88.26	89.36	0.3%
Carbon sales (upside only)	MtCO2e	58.2	45.8	26.9	18.5	12.7	8.7	6.0	4.1	-31.6%
Marine CDR										
Carbon removal volume										
Baseline										
Algae	metric tons	13,500	31,086	71,581	164,828	379,545	873,967	2,012,461	4,634,040	130.3%
Electrochemical stripping	metric tons	62,104	97,367	152,653	239,330	375,223	588,277	922,305	1,445,996	56.8%
Ocean alkalinity enhancement	metric tons	995	1,807	3,282	5,960	10,824	19,658	35,701	64,837	81.6%
Downside										.
Algae	metric tons	13,500	28,367	59,604	125,242	263,162	552,961	1,161,895	2,441,401	110.1%
Electrochemical stripping	metric tons	62,104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0%
Ocean alkalinity enhancement	metric tons	995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0%
Upside										
Algae	metric tons	13,500	44,336	145,607	478,196	1,570,473	5,157,682	16,938,649	55,629,214	228.4%
Electrochemical stripping	metric tons	62,104	109,795	194,109	343,171	606,700	1,072,599	1,896,273	3,352,467	76.8%
Ocean alkalinity enhancement	metric tons	995	2,241	5,049	11,374	25,621	57,714	130,009	292,864	125.3%
Costs										
Algae	USD per metric ton	125	117	110	103	97	91	85	80	-6.2%
Electrochemical stripping	USD per metric ton	600	492	404	331	272	223	183	150	-18.0%
Ocean alkalinity enhancement	USD per metric ton	160	150	140	131	122	114	107	100	-6.5%
Carbon price (mCDR removal, voluntary market)										
Baseline	USD per metric ton CO2	1,053	831	655	517	408	322	254	200	-21.1%
Downside	USD per metric ton CO2	1,053	880	736	615	514	430	359	300	-16.4%
Upside	USD per metric ton CO2	1,053	753	538	384	274	196	140	100	-28.6%
Ocean renewable energy (excluding offshore wind; wave energy, tidal energy)										
Power generation										
Baseline	Terawatt hour (Twh)	2.27	2.90	3.72	4.76	6.09	7.79	9.98	12.77	28.0%
Downside	Terawatt hour (Twh)	2.27	2.55	2.86	3.22	3.61	4.06	4.56	5.12	12.3%
Upside	Terawatt hour (Twh)	2.27	3.01	3.99	5.29	7.02	9.32	12.36	27.00	42.4%
Carbon price (RE offset, all market:	USD per metric ton CO2	87.68	85.45	85.14	85.04	85.13	87.47	88.26	89.36	0.3%
Carbon sales (upside only)	MtCO2e	0.65	0.51	0.30	0.21	0.15	0.10	0.07	0.09	-24.9%
Shipping (passenger and cargo)										
Emissions										
Baseline	MtCO2	658	654	649	660	656	652	647	643	-0.3%
Downside	MtCO2	706	726	747	768	790	813	836	860	2.9%
Upside	MtCO2	667	667	667	647	628	609	590	573	-2.1%
Total industry GVA	USD billions	98.50	99.60	101.40	103.20	105.10	107.00	108.90	110.90	1.7%
Blue carbon										
Blue carbon hectares under treatment										
Baseline	Million hectares (Mha)	602,095	617,362	618,762	667,807	667,807	727,296	750,996	810,007	4.3%
Downside	Million hectares (Mha)	602,095	610,782	619,595	628,535	637,604	646,804	656,136	665,603	1.4%
Upside	Million hectares (Mha)	602,095	680,282	768,622	868,433	981,206	1,108,624	1,252,587	1,415,245	13.0%

Source: Economist Impact modelled estimates (2023).

Annex 2: Carbon market estimates

Forecasting carbon market prices in voluntary markets was applied to the MCDR and blue carbon industries. Due to significant uncertainty in the future development of voluntary markets, pricing was estimated across three scenarios.

For the renewable energy industries (offshore wind and ocean renewable energy), forecasting was subject to the following assumptions:

- Across scenarios, renewable energy (RE) carbon offset credits will be quickly crowded out of voluntary markets, where the preference would be for carbon removal credits.[43]
- In the upside scenario, increased scrutiny of RE offset credits would help to improve the quality of offset credits. These would primarily be traded on regulated compliance markets, where the EU Emissions Trading System price would dominate.[44] [45]
- In the baseline and downside scenarios, backlash regarding the integrity[46] and effectiveness[47] of offset credits would lead to challenges around monetising RE offsets in any market.

The final forecasted price estimates for removal credits on the voluntary market and RE credits in compliance markets can be found in Annex 1 above.

[43] Carbon Direct. (2023). *State of the Voluntary Carbon Market*. https://insights.carbon-direct.com/hubfs/The%20State%20of%20the%20Voluntary%20Carbon%20Market.pdf; Karan Mistry, Bahar Carroll, Alex Dewar, & Amy Sims. (2023). *The Time for Carbon Removal Has Come*. BCG. https://web-assets.bcg.com/44/75/58c3126c4050b74ae75b037e9434/bcg-the-time-for-carbon-removal-has-come-sep-2023.pdf
[44] IETA, & PWC. (2023). *GHG Market Sentiment Survey 2023*. https://www.ieta.org/resources/ghg-sentiment-survey/2023-survey/
[45] World Bank. (n.d.). *Carbon Pricing Dashboard*. Retrieved November 16, 2023, from https://carbonpricingdashboard.worldbank.org/map_data
[46] Eric Roston. (2023). *New Rules for Carbon Offsets Aim to Clean Up Company Climate Claims - Bloomberg*. Bloomberg. https://www.bloomberg.com/news/articles/2023-06-28/new-rules-for-carbon-offsets-aim-to-clean-up-company-climate-claims
[47] Boyd, P. W., Bach, L., Holden, R., & Turney, C. (2023). Carbon offsets aren't helping the planet — four ways to fix them. *Nature 2023 620:7976*, *620*(7976), 947–949. https://doi.org/10.1038/d41586-023-02649-8