Ocean-based CLIMATE ACTION

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Ocean-Based Climate Action

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Foreword

The China–Europe Frontier Forum on "Progress in Ocean Science and Technology" (POST) was held in Shanghai and on line on 20-21 October 2020 in the framework of the imminent launch of the UN decade of Ocean Science for Sustainable Development (2021-2030).

The POST Frontier Forum was attended by about 300 participants. Thirteen invited speakers made presentations during three sessions on: the Earth System and the future ocean in a changing climate; progress in ocean sciences and technology; and ocean sustainable development.

The POST Frontier Forum was intended to enhance collaborations between China and Europe, and identified the following frontier topics for China-Europe action, which includes contributions on:

- Ocean based solutions for climate change mitigation and adaptation that offer a policy-relevant framework for decision and action;
- The global coastal ocean to make it sustainable for the well-being of human societies;
- The "Digital Twin of the Ocean" as component of the "Digital Earth" initiatives, which would contribute to enhance the understanding of the role of the ocean in the changing climate.

The present report deals with "Ocean-based climate action". Co-lead by Jean-Pierre Gattuso (EurASc) and Nianzhi Jiao (CAS), a working group gathered the efforts of 16 lead and contributing authors (9 from Europe and 9 from China).

It aims to be a landmark on the preparation on the POST Frontier Forum n°2 to be held in Europe and on-line.

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Abstract

As a consequence of anthropogenic perturbations the global ocean is warming, acidifying, losing oxygen and sea ice, and sea level is rising. While drastic reduction of the emission of greenhouse gases is urgently needed, which includes ocean energy substitution for fossil energy, we show that the ocean offers numerous opportunities to reduce the causes and consequences of climate change, globally and locally. A wide range of ocean-based measures to enhance societal climate adaptation are currently implemented worldwide to deal either with coastal risks or changes in ocean resources. Ocean-related measures should not be considered as a substitute for climate mitigation on land or non ocean-based adaptation measures, which must be strongly pursued for the benefit of the atmosphere, the ocean, and socio-ecological systems worldwide.

1. Introduction

The global ocean is warming, acidifying and losing oxygen and sea ice, and sea level is rising. As a result, keystone species and ecosystems such as warm-water coral reefs, seagrass meadows and kelp forests face high to very high risks even under low carbon dioxide (CO2) emissions (Bindoff et al., 2019). Moreover, unless comprehensive and intense adaptation efforts are undertaken, low-lying coastal settlements will face moderate to high sea-level rise risks by the end of the century, even under full and timely implementation of the Paris Agreement, with nearly all the world's regions are projected to experience an increase in coastal flooding throughout the 21st century (IPCC, 2021). This calls for a dramatic scaling up of efforts towards ambitious mitigation and adaptation.

The ocean offers opportunities to reduce the causes and consequences of climate change, globally and locally, as shown by The Ocean Solutions Initiative (Gattuso et al., 2018) and other recent reports (Jiao et al., 2011, Hoegh-Guldberg et al., 2019; Because the Ocean 2019; von Schuckmann et al., 2020). However, countries have poorly used ocean-based measures for tackling climate change and its impacts, in their Nationally Determined Contributions (NDCs; Gallo et al. 2017) under the Paris Agreement. Opportunities for countries to adopt more ocean-inclusive mitigation and adaptation strategies, include the first UNFCCC Global Stocktake in 2023, the UN 2030 Sustainable Development Goals, and the UN Ocean Decade for Sustainable Development (Ryabinin et al., 2019)

In this report we assess 19 ocean-based measures to support climate policies and the revision of NDCs in the areas of mitigation and adaptation (Fig. 1). The categories considered are closely based on Gattuso et al. (2018) and Magnan et al. (2018). The US National Academies of Sciences, Engineering, and Medicine (2019, 2021a,b) produced three reports which are at least partly relevant to the ocean.

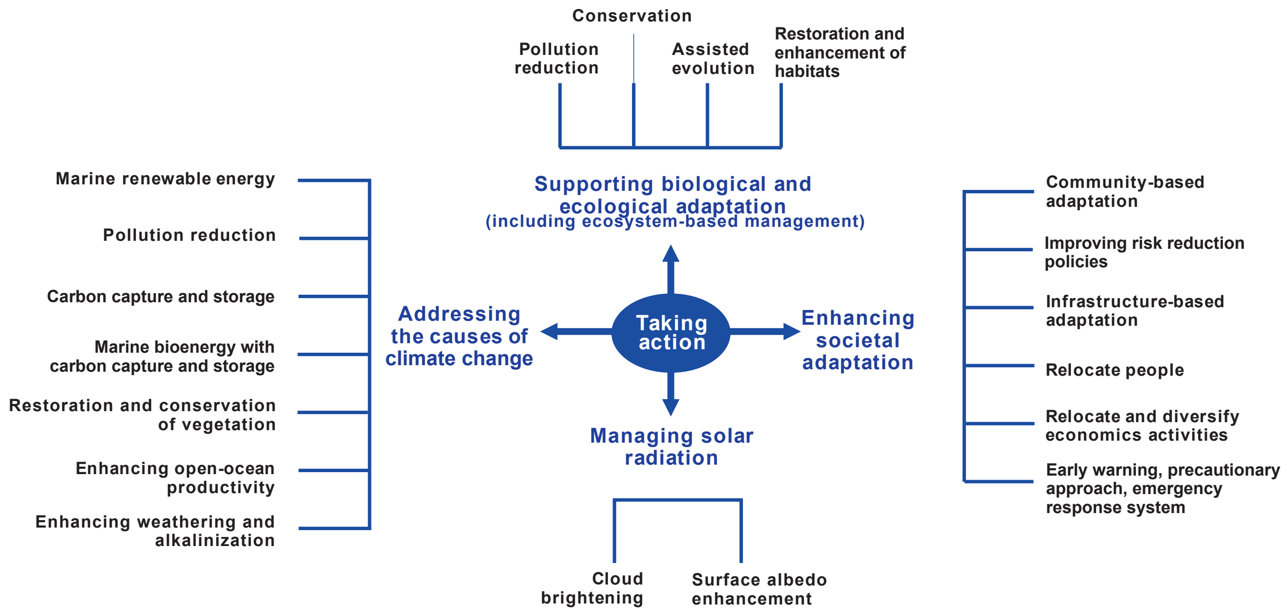

Figure 1. Overview of the main ocean-based measures for climate action.
Modified from Gattuso et al. (2018) and Abram et al. (2019).

2. Ocean-based measures

2.1. Addressing the causes of climate change

Renewable energy. Ocean energy substitution for fossil energy. The focus is on the extraction of physical (and potentially chemical) energy from or over the marine environment that is relatively rapidly replenished from natural sources, including from offshore wind. Hydrogen generation from seawater or by algae is not covered here; despite recent technical advances, such approaches are still very much at early stages of development.

Restoration and conservation of vegetation. (hereafter "Vegetation") Restoration and conservation of coastal vegetation to enhance CO_2 uptake and avoid further emissions. Vegetation refers to the implementation of the solution at the global scale (e.g. restoring all the human-induced degraded salt marshes, mangroves and seagrass habitats of the planet). Vegetation (l) refers to the ongoing implementation of the solution at the local scale (< ~100 km^2). Seaweed cultivation can also contribute to reduced emissions if the biomass is either stored in the deep sea, or used to manufacture lasting products, or used in bioenergy with carbon capture and storage (BECCS).

Enhancing Open Ocean Productivity. (hereafter "Fertilization") is the enhancement of ocean productivity by adding nutrients. The focus here is on i) the open ocean; ii) primary production by phytoplankton (and hence carbon uptake); and iii) the use of iron as the added (micro)nutrient.

Alkalinization is the addition of natural or man-made alkalinity, including intentional dissolution of calcium carbonate or other minerals such as olivine to enhance CO_2 removal and/or carbon storage, this may be particularly beneficial for areas with hypoxia and acidification.

Hybrid methods correspond to measures involving both land and ocean components. These methods include: i) Marine-fueled bioenergy with carbon capture and storage (marine BECCS); ii) marine- or land-fueled biomass energy + accelerated weathering of limestone; iii) marine or land renewable energy based negative emissions electricity/H_2 with ocean alkalinity production; iv) soil or ocean storage of marine organic carbon and biochar; v) burial of land crop waste in ocean sediment; and vi) subsurface ocean or under sea floor storage of land-based direct air capture (DAC) or CO_2 generated by BECCS. Other methods initially considered but not included in this analysis are: i) abiotic seawater extraction and use/storage of CO_2; and ii) Increasing marine consumption of and/or reducing marine emissions of other GHGs such as CH_4, N_2O, etc.

2.2. Supporting biological and ecological adaptation

Pollution reduction corresponds to the reduction of marine and land-based pollution, including non-CO_2 drivers of ocean acidification (e.g. nitrogen, phosphorus and organic carbon from agricultural, industrial, urban and domestic sources causing eutrophication).

Restoring hydrology is about the maintenance and restoration of hydrological regime and delivery of water and sediment from watersheds to the coastal marine environment.

Eliminating over-exploitation of living resources (including vegetation and fish stocks) and over-extraction of nonliving resources (e.g., sand, minerals) through management measures.

Protection of marine habitats and ecosystems through spatial measures including marine protected areas and notake reserves.

Assisted evolution is the human intervention to accelerate the rate of naturally occurring evolutionary processes. The purpose of assisted evolution is to change certain characteristics of an organism; for example, the resistance of corals and bivalves to stress such as elevated temperature and lower pH. Synthetic biology, which involves genome editing using natural or synthetic genes, is not considered because, to our knowledge, its feasibility has not been evaluated on marine species other than in the aquaculture industry.

Relocation and reef restoration. Relocation refers to introduction of species, ecosystems and habitats where they were not historically present, but current and future climatic conditions are expected to allow them to exist. Restoration refers to the enhancement of degraded habitats and ecosystems, and the creation of new habitats. Only coral and oyster reefs are considered here, as vegetated ecosystems (mangroves, salt marshes and seagrass habitats) are already considered in the "Restoration and conservation of vegetation" measure above.

2.3. Solar radiation management

Solar radiation management (or modification) refers to the intentional modification of the Earth's shortwave radiative budget with the aim of reducing warming. Two approaches have been described in connection with the ocean.

Marine cloud brightening involves the spraying of seawater into the lower atmosphere to enhance the production, longevity and brightness of stratocumulus clouds. This approach is also called marine sky brightening because sea spray climate engineering is sometimes as efficient in clear-sky conditions as in cloudy-sky conditions.

Albedo enhancement. Increase surface ocean albedo by producing long-lived ocean foam or by artificially increasing sea-ice cover in polar regions. Only the former is considered here.

2.4. Enhancing societal adaptation

A wide range of ocean-based measures to enhance societal climate adaptation are currently implemented worldwide to deal either with coastal risks (including shoreline erosion and temporary flooding; Oppenheimer et al. 2019) or changes in ocean resources (e.g. in fish stocks at the coast and in the open ocean; Bindoff et al. 2019). Various categorizations exist to package such a diversity —for example with respect to coastal risks (protect, advance with ground elevation, accommodate, and retreat; Nicholls 2018, Oppenheimer et al. 2019)— and to provide decision-makers and practitioners with simplified guidance to develop adaptation strategies at various scales. Here we describe six measures: (a) ***Community-based adaptation***; (b) ***Improving risk reduction policies***; (c) ***Infrastructure-based adaptation***; (d) ***Relocate people***; (e) ***Relocate and diversify economic activities***; and (f) ***Early warning, precautionary approach, emergency response system***.

One of the main conclusions from scientific literature and experience gained through practice is that the relevance of any of these (categories of) measures in terms of their potential to reduce climate-related risk, highly depends on the specificities of the context and conditions under which they are implemented (e.g., institutional leadership, social acceptability, affordability, legal frameworks, etc.; Duvat et al. 2020, Magnan and Duvat 2020, Magnan et al. 2020). As a result, policy clustering is complicated for societal adaptation measures as characteristics (effectiveness, feasibility, co-benefits, disbenefits, governability, etc.) necessarily vary from one context to another. One measure could provide a solution in one case but a maladaptation in another (i.e. when vulnerability to climate change is insidiously exacerbated instead of being reduced), for example over time or if it implies negative collateral effects on neighboring or economically/socially connected systems. Some general lessons can however be highlighted distinguishing between: measures that do not raise major concern whatever the context of implementation; measures for which climate relevance cannot be decided *a priori*; and measures for which we still lack experience.

A first set of measures, comprising (a) and (b) described above, have low disbenefits (i.e., associated adverse impacts and other undesirable consequences, including opportunity costs), have a more or less direct but proven influence on climate risk reduction, and do not face strong barriers in terms of their governability. *Community-based adaptation* addresses a major concern raised in the scientific literature: the need to engage local people and communities in both the design and implementation of adaptation-related responses. This is important for three reasons. First, because these people usually play a central role in implementation (e.g., when raising risk-awareness); second, because they are the ultimate beneficiaries of any adaptation measure; and third, because social acceptability is a critical criteria to decide the feasibility of any adaptation-related measure. *Improving risk reduction policies* (e.g. limit new buildings in risk-prone areas at the coast) or shifting toward less fish-dependent consumption patterns and markets can be considered relatively low regret[1] in that they contribute to reduce exposure to climate events and/or pressure to climate-sensitive natural resources. It is however important to note that despite these categories apparently being low regret, they are not cost-free and require well-informed planning and effective coordination over a wide range of stakeholders, scales and timeframes.

For a second set of measures, comprising (c) to (f), whether or not they contribute to adaptation or maladaptation, will intrinsically depend on the geographical, policy and societal context of their implementation. While seawalls and other *Infrastructure-based adaptation* can protect against sea level rise in densely populated coasts, they can be counterproductive to natural environments (e.g. sand-dune systems, mangroves and coral reefs) as they tend to undermine ecosystems' natural

[1] The term "low regret'" is used to show that there are costs as well as benefits for these actions. However, on balance the benefits are considered greater, and therefore many of these measures could also be considered as "no regret".

adjustments to ocean changes, inland migration, and buffering function against storm surges. In the former case, Infrastructure-based adaptation describes a decisive, unavoidable climate solution, while in the latter it carries a high risk of maladaptation. The benefits of *Relocating people* are also context-dependent: if planned and at a local-scale (e.g. within an island), such relocation can help save lives, and it is therefore decisive (Magnan and Duvat 2020); but if unplanned or forced, relocation can generate multiple and ramifying detrimental effects on both the displaced people and host communities, and therefore must be considered risky and maladaptive (Haasnoot et al. 2021). The same caution applies to *Relocating and diversifying economic activities*, which can either secure local jobs and economies, or generate the opposite effect. *Early warning*, *precautionary approach, emergency response system* is another illustration of adaptation measures that can play a decisive role as a vehicle for maladaptation over time. It is clear that early warning systems (e.g. tsunamis superimposed on sea-level rise) are a critical tool to alert decision-makers and populations in case of the occurrence of potentially damaging extreme events such as tropical cyclones or ocean heat waves. In the same way, developing cyclone shelters for example is a way to provide secure places to people in the case of high impacts, particularly useful in low-lying countries. These measures could however have counterproductive effects if not accompanied with a series of measures including awareness campaigns and sustainable funding. It has been shown for example in Bangladesh that when too frequent, precautionary early warnings about cyclones that finally do not hurt the area can lead to lowering the trust people have in alerts, and therefore a decrease in local communities' preparedness to extreme events. Similarly, the development of cyclone shelters in areas affected by intense cyclones but of low occurrence (e.g., Tuamotu atolls in French

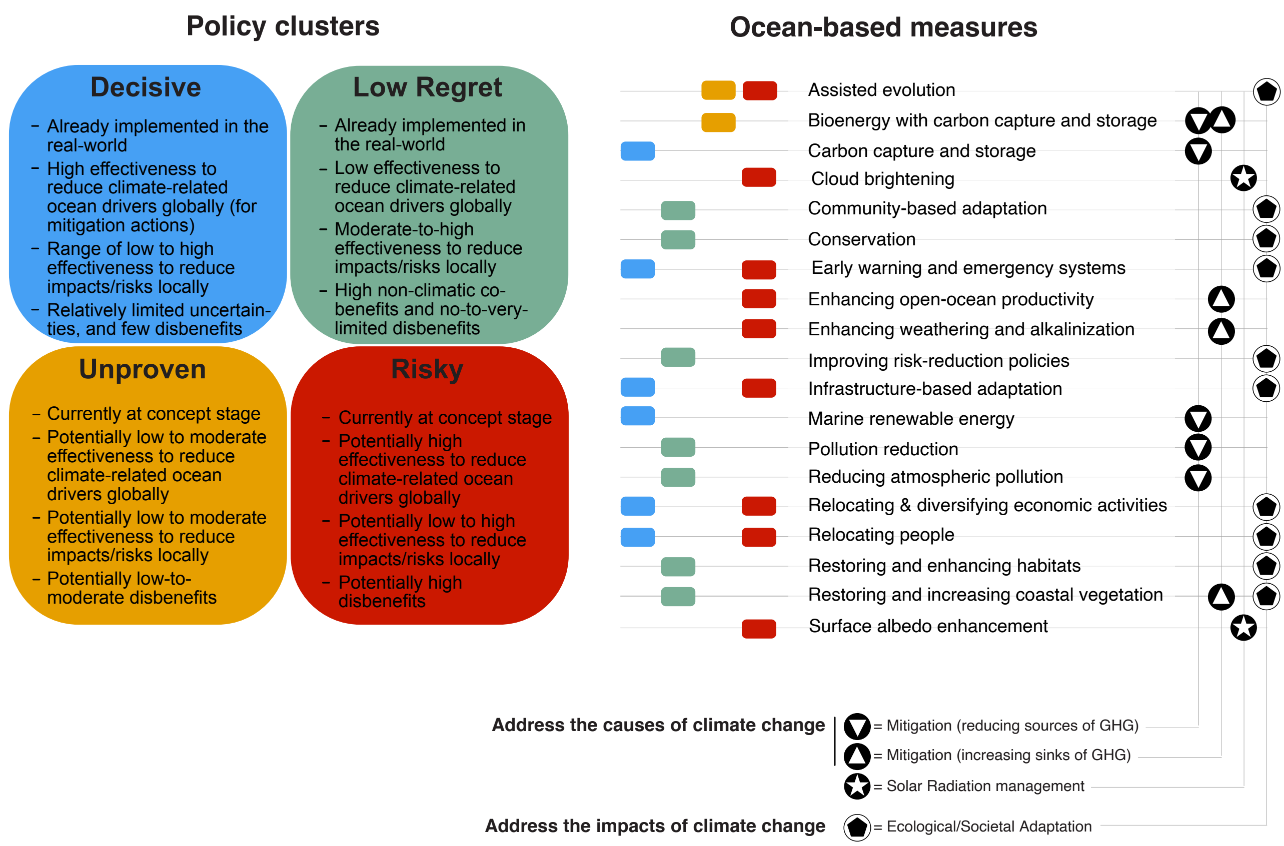

Figure 2. Policy clusters of the main ocean-based measures for climate action. Modified from Gattuso et al. (2019).

Polynesia, Pacific) can be perceived by local populations as useless investments conflicting with more urgent needs (e.g. support to improve roads and houses, or to educational and economic activities), and therefore been disregarded as a risk prevention option. Making shelters a place for daily life activities, even if not focussed on reducing climate risk (e.g., social and traditional activities), is often critical to sustain the relevance of this measure as an adaptation solution.

3. Policy clusters of ocean-based action

Ocean-based measures to enhance both global mitigation and local coastal adaptation can be clustered into overarching policy-relevant clusters (Fig. 2). Two clustering exercises were recently performed based on key features according to their state of implementation, effectiveness to reduce climate-related ocean drivers globally, effectiveness to reduce impacts/risks locally, and potential co-benefits and disbenefits. Gattuso et al. (2019) grouped 18 ocean-related measures into four policy-relevant categories: Decisive, Low Regret, Unproven and Risky. Another clustering (Gattuso et al., 2021) grouped a subset of 12 measures into three clusters (Decisive, Low Regret, Concept Stage). We use here the more complete groupings of Gattuso et al. (2019).

Decisive measures address the causes of climate change: Marine renewable energy and Carbon Capture and Storage (CCS). Marine renewable energy has the theoretical potential to meet all global electricity requirements, although requiring further infrastructure development. Whilst some local adverse impacts are inevitable, these can be minimized. Importantly, CCS is a Decisive measure only if implemented in a way which avoids significant leakage. When ocean-based CCS is deployed for enhanced oil recovery, that application negates its climate mitigation benefits. Four societal adaptation measures can also be considered Decisive (Infrastructure-based adaptation, Relocating and diversifying economic activities, Relocating people, and early warning and emergency systems), but can also be Risky depending on the context within which they are implemented, as discussed below.

Low Regret measures provide both climatic and non-climatic benefits, with few disbenefits (associated adverse impacts and other undesirable consequences, including opportunity costs). For example, *Conservation* measures can protect carbon-rich coastal ecosystems from direct human disturbance and loss, and play an important role in limiting local climate impacts. Similarly, *Restoring and enhancing coastal vegetation* supports ecological adaptation whilst providing storm protection, contributing to food security, and enhancing biodiversity. It can also increase carbon uptake, at levels that may be locally and/or nationally significant. Nevertheless, because of the limited total area for restoring such blue carbon ecosystems, this action can only make a very small contribution to climate mitigation at the global scale (Bindoff et al., 2019). Pollution reduction in coastal waters removes contaminants and excess nutrients that impair ecosystem function, thereby supporting ecosystem-based adaptation (Jiao et al., 2011). Reduced pollution from shipping can also, to a limited degree, address the causes of climate change. The societal measures *Community-based adaptation* and *Improving risk reduction policies* are also considered as Low Regret, providing self-evident benefits. However, these actions are not cost-free, requiring well-informed planning and effective coordination over a wide range of spatial and temporal scales. It is critical to note that, in many contexts, Low Regret measures will only be effective under the lowest levels of warming (Bindoff et al., 2019).

Unproven measures are illustrated by *Marine bioenergy with carbon capture and storage*, and some forms of *Assisted evolution*. The former would use macroalgae (seaweed) or cultivated microalgae as the biomass source for bioenergy. Such measures have potential but their practicality and cost-effectiveness for climatic benefits have yet to be demonstrated. Assisted evolution envisages alterations to species and genetics; the feasibility of such actions is uncertain, and they are also considered Risky.

Risky measures are mostly defined based on their potentially high disbenefits: *Enhancing open-ocean productivity* through ocean fertilization; *Enhancing weathering and alkalinization*, by adding CO_2-absorbing materials to the ocean; and the solar radiation management techniques of Marine cloud brightening and Surface albedo enhancement, neither of which would ameliorate ocean acidification. Whilst all these actions have a very large theoretical potential to address climate change globally, only the first one has been tested in the field, with limited success. Risky measures may also have unintended adverse consequences and some are short-lived, implying a long-term commitment. Much more attention needs to be given to their international governance and public acceptability before they can be considered for implementation as climate policy responses.

Some societal adaptation measures cannot be classified in a single policy cluster because their effectiveness critically depends on the environmental and societal contexts of their implementation (Fig. 2). While seawalls and other infrastructure-based adaptation can protect against sea level rise in densely populated coasts, they can be counterproductive to natural environments (e.g. sand-dune systems, mangroves and coral reefs) as they tend to undermine ecosystems' natural adjustments to ocean changes, inland migration, and future ability to provide coastal protection. In the former case, *Infrastructure-based adaptation* is Decisive while in the latter it is Risky. The benefits of *Relocating people* are also context-dependent: if planned and at a local-scale (e.g. within an island), such relocation can help save lives, and it is therefore Decisive; but if unplanned or forced, relocation can generate multiple and ramifying detrimental effects on both the displaced people and host communities, and it is therefore Risky. The same caution applies to *Relocating and diversifying economic activities*, which can either secure local jobs and economies, or generate the opposite effect; and to *Early warning and emergency systems* (see above).

4. Ongoing and future activities

Several programmes, projects and other activities are currently on-going or planned. First, some of the measures described above are rapidly being implemented. Significant progress is being made on deployment of capacity of marine renewable energy, which was deemed decisive in previous assessments. For example, China built more offshore wind capacity in 2021 than the rest of the world in the last 5 years[2]. Its 26 GW now accounts for half of the world's 54 GW total.

Relevant research projects planned or on-going include Ocean Carbon Negative Emissions (ONCE; Jiao at al., 2020) and harvesting energy from waves (Wang, 2017) in China, Ocean-based Negative Emission Technologies (OceanNETs; www.oceannets.eu) and Marine carbon sinks in decarbonisation pathways (CDRmare; https://cdrmare.de/en/) in Europe. It should also be mentioned that the United Nations has proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030) to support efforts to reverse the cycle of decline in ocean health and gather ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in creating improved conditions for sustainable development of the Ocean (Ryabinin et al., 2019).

[2] https://www.carbonbrief.org/china-briefing-27-january-2022-surge-in-offshore-wind-xis-new-speech-ieas-report

5. Conclusion

It is now clear that the ocean is a key driver of Earth's climate system and a critical element in the response to rising greenhouse gas. It moderates global warming by absorbing more than 90% of the excess heat and about a quarter of anthropogenic carbon emissions. Ocean-based actions could provide major benefits to society but it is critical that their implementation is sustainable, and that they do not add further stress to the already severe consequences of ocean warming, acidification, deoxygenation and sea level rise. Ocean-related measures should not be considered as a substitute for climate mitigation on land or non ocean-based adaptation measures, which must also be strongly pursued for the benefit of the atmosphere, the ocean and socio-ecological systems worldwide. Ocean-based climate action should prioritise Decisive and Low Regret measures, improve knowledge on the Unproven measures, and very cautiously weigh the Risky ones.

It has been argued that defining a "gross marine product" index — a measure of the oceans' natural capital — would be invaluable for achieving the goals of SDG 14 (Lu et al., 2016; Sumaila et al., 2021). It would also highlight the benefits of ocean-climate action.

International discussions and ocean governance are essential, even if slow going. There are, however, reasons for hope. For example, the ocean, climate and biodiversity policy agendas, which have been siloed for decades are now slowly converging as part of the the Ocean and Climate Change Dialogue, decided at COP25 and launched in December 2020. This forum of the UNFCCC could be a key vehicle to address ocean-related mitigation and adaptation (Dobush et al., 2021).

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