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POLICY BRIEF

Ocean-based measures for climate action

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Current emission reduction pledges under the 2015 Paris Agreement are insufficient to keep global temperature "well below +2°C" in 2100 relative to pre-industrial levels and to reach targets of the United Nations Sustainable Development Goals. Increased political ambition is therefore required, as well as enhanced efforts in terms of both mitigation and ecosystem and human adaptation. There is growing evidence highlighting both the role the ocean plays in mitigating anthropogenic climate change (i.e., absorption of atmospheric heat and anthropogenic carbon), and the cascading consequences on its chemistry and physics (i.e., ocean warming, acidification, deoxygenation, sea-level rise), ecosystems and ecosystem services. In such a context, a critical question arises: what are the ocean-based opportunities for climate action? In other words, what is the potential of the ocean and its ecosystems to reduce the causes of climate change and its impacts?

This document summarises the main findings of *The Ocean Solutions Initiative*[1] that assessed the potential of 13 ocean-based measures.

1. Open Access paper (with authors' affiliations): Gattuso, J.-P. *et al.* (2018). Ocean solutions to address climate change and its effects on marine ecosystems. Frontiers in Marine Science, http://bit.ly/2MVx4pm

KEY MESSAGES

Several ocean-based measures are available to reduce both climate change and its impacts on the open-ocean and coastal ecosystems, suggesting that the international community working on the ocean, from institutions to the private sector, can play a significant role in both adaptation and mitigation.

All measures have limitations and trade-offs. Despite a large theoretical potential to address the global problem, several global scale measures exhibit too many uncertainties and/or risks of negative collateral effects to be recommended for large-scale deployment. In contrast, most local measures are low-regret options but are far less effective to address the large-scale challenge.

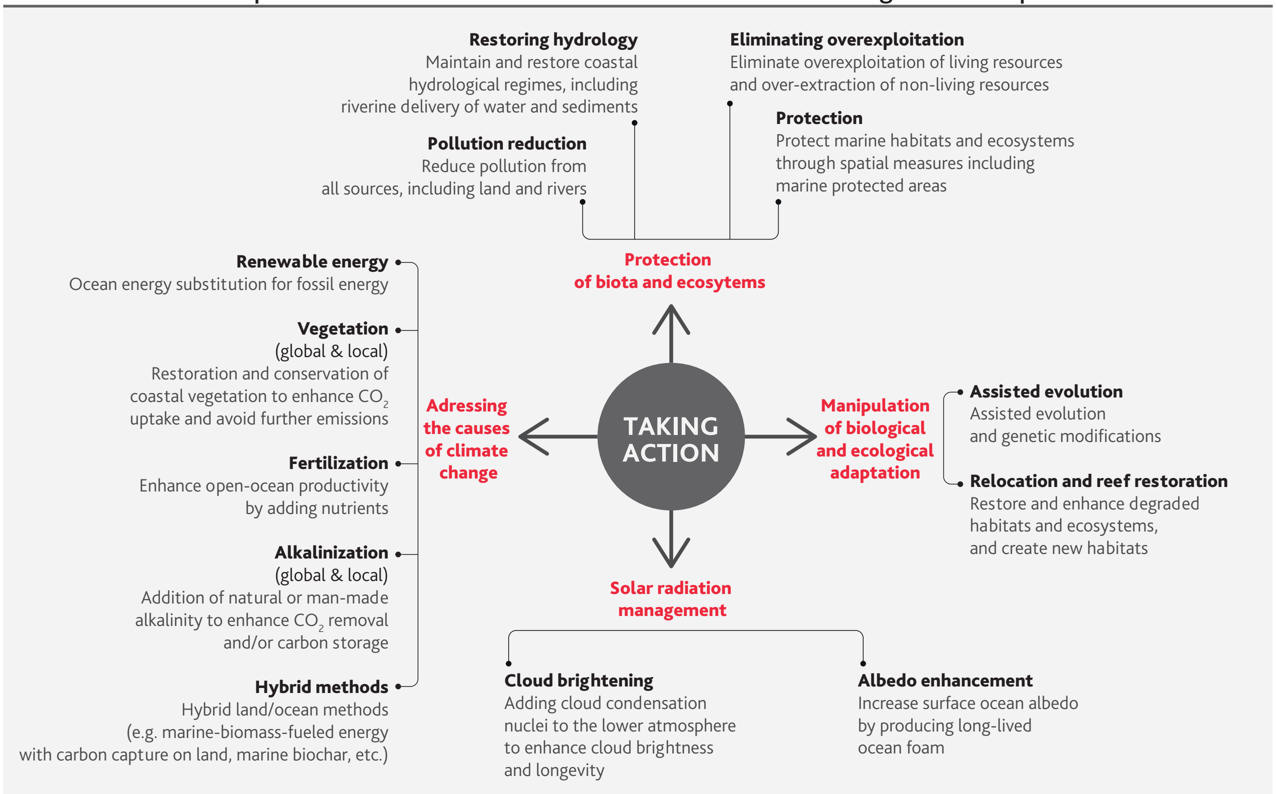
Decisions to implement any measure have to consider multiple criteria such as potential effectiveness, feasibility, co-benefits, disbenefits, cost effectiveness, and governability.

Greatest benefit is derived from the combination of global and local solutions, some of which can be scaled-up immediately.

Multiple-scale actions call for a coordinated and collaborative international response.

Video summary: http://bit.ly/2Q8ipcn

FIGURE 1. Overview of potential ocean-based measures to address climate change and its impacts



Source: Gattuso *et al.* (2018) – see footnote 1.

The Ocean Solutions Initiative is an endeavour by a group of 18 ocean experts across natural and social sciences to assess the potential of 13 ocean-based measures to reduce three major climate-related changes in the ocean (ocean warming, acidification, and sea-level rise), both globally and locally (areas smaller than 100 km²), as well as to reduce their adverse impacts on important biodiversity- and life-supporting ecosystems (coral reefs, mangroves and salt marshes, seagrass beds, and Arctic biota) and associated ecosystem services (fisheries and aquaculture for fish and bivalves, and coastal protection). This assessment is based on an extensive literature review and on 8 criteria: potential effectiveness of the measure (assuming its maximum theoretical implementation), technological readiness, lead time until full potential effectiveness (i.e., the time needed to reach full implementation), duration of benefits, co-benefits, disbenefits (i.e., negative collateral effects), cost effectiveness and governability from an international perspective. Five questions are addressed in this Policy Brief: What are the options? Are they technically feasible? Are they effective to address climate change and to reduce marine impacts? What are the uncertainties and possible collateral effects? And is global society able to implement them?

WHAT ARE THE OPTIONS?

Figure 1 provides an overview of four types of measures[2] to reduce the scale and impacts of climate change. The first two—hereafter "global measures"—aim to either reduce the cause of anthropogenic climate change by reducing greenhouse gas (GHG) emissions, or to increase their long-term removal from the atmosphere, with a focus on CO_2. The remaining two types of measures—hereafter "local measures"—aim to reduce the risk of climate change impacts locally, by reducing either climate-related changes in the ocean (i.e., site-specific acidification and warming, and relative sea-level rise) and/or the sensitivity of organisms and ecosystems to these changes.

Addressing the causes of climate change refers to the reduction of atmospheric GHG concentrations, and comprises five ocean-based measures. (1) Ocean-based ***renewable energy*** is the production of energy using offshore wind turbines and harvesting physical ocean energy (tides, waves, currents, thermal stratification). (2) The restoration and conservation of coastal ***vegetation*** seeks to enhance some ecosystems' (primarily salt marshes, mangroves and seagrasses) carbon sink capacity ("blue carbon") and avoid emissions induced by their degradation. *Vegetation*—as well as *alkalinization* (see below)—is evaluated for both local and global perspectives as it can be deployed locally to reduce the sensitivity of marine ecosystems and services to specific climate-related changes such as relative sea-level rise and ocean acidification, as well as, in theory, globally to reduce climate-related changes to the ocean. (3) ***Fertilization*** refers to the addition of soluble iron to surface waters to artificially increase primary production (where iron is the limiting nutrient) and, hence, carbon uptake by phytoplankton. (4) ***Alkalinization*** is the addition of alkaline substances derived from land-based minerals or synthetic chemical sources or from locally available marine material (e.g., dead shells) which consume CO_2 and/or neutralize acidity. (5) Land-ocean ***hybrid methods*** include the use of the ocean and its sediments to store biomass, CO_2 or alkalinity derived from terrestrial sources

2. For a detailed description of the 13 measures considered in the study, see: https://www.frontiersin.org/articles/10.3389/fmars.2018.00337/full#supplementary-material.

(e.g., crop residue storage on the seafloor, marine storage of CO_2 from land-based bio-energy or from direct air capture of CO_2), and also techniques such as using marine plants to fuel biomass energy with carbon capture and storage on land (marine BECCS).

Solar radiation management (SRM, also known as sunlight reflection methods) seeks to enhance albedo in the atmosphere or at the Earth's surface in order to increase the proportion of solar energy that is reflected back to space. It comprises two main ocean-based measures. (6) *Marine* ***Cloud brightening*** involves the large-scale aerial spraying of seawater or other substances into the lower atmosphere to increase clouds' sunlight reflection capacity. (7) Surface ocean ***albedo enhancement*** would be achieved by generating long-lived micro-bubbles or foam at the ocean surface.

The protection of biota and ecosystems comprises four measures. (8) ***Pollution reduction*** refers to the abatement of the release of anthropogenic harmful substances in order to limit both hypoxia (i.e., lack of oxygen) and ocean acidification in coastal waters, and lessen the sensitivity of marine organisms and ecosystems to climate-related changes. (9) Restoring hydrological regimes (***restoring hydrology***) relates to the maintenance and restoration of marine hydrological conditions (including both the tidal and riverine delivery of water and sediments) to minimize local climate-related changes. (10) ***Eliminating overexploitation*** aims at ensuring the sustainable use of living resources to maintain biologically safe limits and ecosystem function, as well as of non-living resources (e.g., sand, minerals) to avoid irreversible ecological damages. (11) ***Protection*** refers to the conservation of habitats and ecosystems, primarily through marine protected areas (MPAs), for example to enhance productivity of the surrounding areas which can help buffer against climate impacts.

The manipulation of biological and ecological adaptation includes two measures. (12) ***Assisted evolution*** involves genetic modification and release of organisms with enhanced stress tolerance. (13) ***Relocation and reef restoration*** involves the restoration of degraded coral and oyster reefs,[3] and the potential creation of new habitats hosting more resilient species.

Other ocean-based measures have been proposed (e.g., large-scale seaweed aquaculture for supplementing cattle feed to reduce methane emissions and counteract acidification locally, and abiotic methods of removing or stripping CO_2 from seawater), but they are not considered here due to the very limited knowledge available.

ARE THESE OPTIONS TECHNICALLY FEASIBLE?

The technical feasibility criterion combines the present technological readiness and lead time until full potential effectiveness. Global measures generally exhibit lower technical feasibility than local ones. While this is especially the case for *fertilization*, *cloud brightening*, *alkalinization*, *albedo enhancement* and *hybrid methods*, there are exceptions. *Renewable energy* and *vegetation* (global) are global measures which score high while local measure *assisted evolution* scores low. Options with highest technical feasibility are *protection*, *restoring hydrology*, *eliminating overexploitation*, *reducing pollution* and *relocation and reef restoration*.

In addition to technical feasibility *per se*, knowledge and practical experience on these different measures vary substantially. While some of the 13 measures assessed here are at a very-early or experimental stage, some have already been implemented and refined, sometimes over many decades (e.g., *renewable energy*, *vegetation*, *eliminating overexploitation*, *protection*).

ARE THEY EFFECTIVE TO ADDRESS CLIMATE CHANGE AND REDUCE MARINE IMPACTS?

Results confirm that global measures (e.g., *renewable energy*, *fertilization*, *alkalinization*, *cloud brightening*) have the highest potential effectiveness to reduce climate-related changes at the global scale. *Reducing pollution*, *eliminating overexploitation*, *assisted evolution*, *relocation and reef restoration* are well suited to locally reduce risks to ecosystems and ecosystem services, with some also being effective in moderating local ocean acidification (e.g., *reducing pollution*, *alkalinization*) and relative sea-level rise (e.g., *vegetation*, *protection*, *restoring hydrology*, *relocation and reef restoration*).

From an ecosystem and ecosystem services perspective, solutions that target ocean warming and acidification are more relevant to reduce the impacts on coral reefs and Arctic biota, whereas mangroves and salt marshes would benefit more from solutions that are most effective to reduce the impacts of sea-level rise. Due to co-benefits in minimizing the impacts from non-climate drivers, *eliminating overexploitation*, *restoring hydrology*, *reducing pollution*, *vegetation* and *protection* are the most effective local measures to maintain healthy conditions for coastal protection, fin fisheries, and fish and bivalves aquaculture.

All measures however have limitations in their potential to reduce climate-related changes and associated impacts. For example, *albedo enhancement* has a large potential effectiveness in moderating ocean warming, but the duration of the effect is only as long as the albedo stays high (likely to be days to months for ocean foams), that is, as long as implementation efforts are sustained. Moreover, as SRM in general, *albedo enhancement* does not address ocean acidification, since atmospheric CO_2 levels will continue to increase, unless emissions completely end or there is active CO_2 removal. Another example is *vegetation*, for which physical limits come into play to restrain effectiveness: even with very high carbon storage and avoided net emissions, the *vegetation* measure is constrained by the limited global area of potentially-vegetated habitats (although initiatives are artificially expanding that area, e.g. using seaweed aquaculture). At the local scale also, available space for potentially-vegetated habitats is limited due to human coastal occupancy (buildings, infrastructures, activities). However, in contrast to *alkalinization*, the effects of *vegetation* can theoretically be close to permanent as long as the plant biomass is maintained or increased in the face of natural and anthropogenic pressures.

3. The restoration and protection of other coastal habitats (seagrasses, mangroves, and salt marshes) are scored in the Vegetation measure.

WHAT ARE THE UNCERTAINTIES AND POSSIBLE COLLATERAL EFFECTS?

Several measures investigated by *The Ocean Solutions Initiative* exhibit large uncertainties, primarily due to the lack of testing and deployment at scale, and the lack of associated scientific literature describing successes and failures. This is especially true for global measures (except *renewable energy*), for which recommendation for large-scale deployment seems premature. In contrast, several local measures are low-regret options as they have multiple co-benefits and few—if any—disbenefits; they are however far less effective to address the global problem. Additional uncertainty results from the lack of scientific insights on the future potential effectiveness of these various measures under contrasting global warming scenarios, by 2100 and beyond. Another concern is that all measures have trade-offs or present risks of negative collateral impacts that could be very high. Collateral effects are partly unknown due to the complexity of the dynamics of the ocean (including the ocean/atmosphere interface) and of open-ocean and coastal ecosystems. For example, large-scale *alkalinization* scores high in terms of potential effectiveness to reduce ocean acidification globally. However, its feasibility and benefits must be weighed against the financial costs and environmental impacts of mining or producing vast quantities of alkaline material, distributed at the global scale, and the potential biotic impacts of the trace elements or contaminants that the added material might contain.

IS GLOBAL SOCIETY ABLE TO IMPLEMENT THEM?

The findings highlight the need to consider global and local solutions together. A large diversity of stakeholders is necessarily involved, thus relying on efficient international cooperation. Accordingly, the present study targets the international community dealing with the issues of climate change and biodiversity. This community is structured around major United Nations conventions such as the Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). Global governability (i.e., governability from an international perspective) considers the capability of the international community to implement ocean-based measures, manage associated conflicts and take advantage of cross-scale benefits. The assessment relies on the well-supported premise that the global governability of a measure increases with its effectiveness and the predictability of its effects, the presence of national-level net benefits, the co-benefits expected and the absence of disbenefits, the presence of enabling institutions, and willingness shared amongst relevant actors.

Not surprisingly, global governability is especially high for *protection*, *vegetation* (global and local) and *relocation and reef restoration*. Conversely, SRM measures (*cloud brightening* and *albedo enhancement*) have low global governability, especially because their implementation raises classical questions in international cooperation, notably the reluctance of nations to unilaterally take on extra costs that may reduce their own economic competitiveness. *Renewable energy* stands in an intermediate position: renewables are increasingly cost-effective compared with fossil-fuel based energy, thereby providing national-level incentives for their implementation (and although acceptability at local scale can be challenging).

While global ocean-based measures aiming at reducing GHG emissions, removing CO_2 from the atmosphere or increasing sunlight reflection, are more effective in addressing the global climate problem, their implementation is difficult due to challenges not only in technology and sometimes cost, but also in governance. In contrast, most local measures aiming at reducing either climate-related changes locally and/or the sensitivity of organisms and ecosystems, have several co-benefits and few—if any—disbenefits, but they are far less effective to address the large-scale challenge. Any ocean-based solution should rely on the combination of global and local measures, some of which could be implemented or scaled-up immediately.

AFFILIATION OF AUTHORS

Affiliations are available both at https://www.frontiersin.org/articles/10.3389/fmars.2018.00337/full and at https://www.iddri.org/en/publications-and-events/policy-brief/ocean-based-measures-climate-action

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