Key global ocean drivers, impacts, and solutions

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Global carbon budget (2007-2016)

33.4 Gt CO\textsubscript{2}/yr (88%)

+ 

4.8 Gt CO\textsubscript{2}/yr (12%)

Le Quéré et al. (2017)
Global carbon budget (2007-2016)

33.4 Gt CO$_2$/yr (88%)

4.8 Gt CO$_2$/yr (12%)

Atmosphere
46%

Vegetation
30%

Oceans
24%

30 millions tonnes CO$_2$ per day

Le Quéré et al. (2017)
Ocean: actor and victim of climate change

Ocean
93%

Heat

Warming

Melting ice
3%

Continent
3%

Atmosphere
1%

Carbon dioxide
26%

Land
30%

Atmosphere
44%

Ocean
~100%

Water

Melting ice
3%

Continents
3%

Atmosphere
1%

Ocean: actor and victim of climate change

- **Heat**
  - Melting ice: 3%
  - Continent: 3%
  - Atmosphere: 1%

- **Carbon dioxide**
  - Land: 30%
  - Atmosphere: 44%
  - Ocean: 26%

- **Warming**
  - Ocean: 93%

- **Acidification**
  - Ocean: ~100%

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Magnan et al. (2015)

Carbon dioxide:
- Ocean: 26%
- Land: 30%
- Atmosphere: 44%

Heat:
- Melting ice: 3%
- Continent: 3%
- Atmosphere: 1%

Warming:
- Ocean: 93%

Acidification:
- Ocean: ~100%
Ocean: actor and victim of climate change

- **Heat**
  - Melting ice: 3%
  - Continent: 3%

- **Carbon dioxide**
  - Land: 30%
  - Atmosphere: 44%
  - Ocean: 26%

- **Water**
  - Ocean: 93%
  - Atmosphere: 1%

- **Warming**
  - Ocean: ~100%

- **Acidification**
  - Ocean: 93%

- **Sea level rise**
  - Ocean: 93%

Magnan et al. (2015)
Monitoring is essential

Global Ocean Acidification Observing Network
Monitoring is essential

Global Ocean Acidification Observing Network

Sauzède et al. (2017, FMS)

Neural network using S, T, P, O2, lat, lon, time
Future scenarios

Fuss et al. (2014)

Carbon Dioxide Information Analysis Center.

Many require net negative emissions (that is, BECCS exceeding fossil fuel emissions) in 2100. Data sources: IPCC AR5

Increase (right of panel into five climate categories in 2100.

Figure 1 | a requirement for gross negative CO₂ under the 2° climate change. Importantly, some of the model the link between CO₂ (gross negative emissions). Both approaches between reducing emissions and BECCS an economic optimization driven by a choice in IAMs, negative emissions are an outcome of on how this is technically achieved. For model intercomparison of ten ESMs found the compatible net CO₂ emissions requirements. ESMs simulate temperature stabilization levels.

Historical emissions from fossil fuel combustion and industry and 10.3 ± 2.9 Gt terrestrial carbon sinks is 9.2 mean removal of CO₂ annually in 2050, corresponding to baseline 2050 CO₂ emissions. Huge

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CO₂ emissions (Gt CO₂ yr⁻¹)

Year

Historical emissions

Net-negative global emissions

Fuss et al. (2014)

RCP8.5 3.2–5.4 °C
Relative to 1850 - 1900

RCP6 2.0–3.7 °C

RCP4.5 1.7–3.2 °C

RCP2.6 0.9–2.3 °C

>1,000 ppm CO₂eq
(172 scenarios, RCP8.5)

720–1,000 ppm
(148 scenarios, RCP6)

580–720 ppm
(144 scenarios, RCP4.5)

480–580 ppm
(509 scenarios, no equivalent RCP)

430–480 ppm
(116 scenarios, RCP2.6)

2014 estimate –

0

1980 2000 2020 2040 2060 2080 2100

World CO2 emissions and the extent of net negative emissions and bioenergy with carbon capture and storage (BECCS)
What does it mean for the ocean?

Gattuso et al. (2015)
What does it means for the ocean?

Gattuso et al. (2015)
What does it mean for the ocean?

Gattuso et al. (2015)
1. Ocean strongly influences the climate system and important provider of key services

2. Impacts already detectable, high risk of impacts well before 2100, even with a low emission scenario

3. Immediate and substantial reduction of CO₂ emissions to prevent massive and mostly irreversible impacts

4. As CO₂ increases, the protection, adaptation, and repair options become fewer and less effective
“Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels…”
Paris Agreement

1.5 °C mostly based on ocean matters
Gap between reductions needed and NDCs is alarmingly high.

A large gap exists between 2030 emission levels and those consistent with least-cost pathways to the 2°C and 1.5°C goals respectively. The 2°C emissions gap for the full implementation of both the conditional and unconditional NDCs for 2030 is 11 to 13.5 GtCO$_2$e. The gap in the case of the 1.5°C target is 16 to 19 GtCO$_2$e.

Assessment scenarios show that least-cost trajectories are lower than emissions of greenhouse gases should not exceed 2 GtCO$_2$e in 2050 if the 2°C target is to be achieved with higher than 66 percent chance. The level for 1.5°C has been reported with higher than 90 percent probability and is about 2 GtCO$_2$e higher than the central estimate for the 2°C pathways. However, few studies are available that present least-cost pathways starting from 2020 that could meet the 1.5°C by 2100 with higher than 66 percent probability. These studies indicate a much lower requirement of around 2 GtCO$_2$e, which is higher than the central estimate for higher than 90 percent probability, and is about 20 GtCO$_2$e higher than the central estimate for the 2°C pathways. The number of published studies on this topic is considered too few to include in the report, but it is expected that further analysis of these 1.5°C pathways with higher than 66 percent probability will be included in the 2018 report.

Figure ES.2: Greenhouse gas emissions under different scenarios and the emissions gap in 2050; median estimate and 10th to 90th percent range.

- **Baseline**: Emissions trajectory without any mitigation actions.
- **Current policy trajectory**: Emissions trajectory with current policy actions.
- **Unconditional NDC case**: Emissions trajectory with unconditional NDC actions.
- **Conditional NDC case**: Emissions trajectory with conditional NDC actions.

The blue area shows pathways limiting global temperature increase to below 2°C by 2100 with a > 66% chance.

The purple area shows pathways limiting global temperature increase to below 1.5°C by 2100 with a 50 to 66% chance.
Gap between reductions needed and NDCs is alarmingly high

**UNEPI (2017)**

[Diagram showing annual global total greenhouse gas emissions (GtCO₂e)]

- **Baseline**
- **Current policy trajectory**
- **Unconditional NDC case**
- **Conditional NDC case**

**Key Graphical Elements**

- **2°C range**
- **1.5°C range**

**Graphical Description**

- **Blue area** shows pathways limiting global temperature increase to below 2°C by 2100 with > 66% chance.
- **Purple area** shows pathways limiting global temperature increase to below 1.5°C by 2100 with 50 to 66% chance.
- **Remaining gap to stay within 2°C limit**
- **Remaining gap to stay within 1.5°C limit**

**Median estimate of level consistent with 2°C**
- 42 GtCO₂e (range 31-44)

**Median estimate of level consistent with 1.5°C**
- 36 GtCO₂e (range 32-38)

**Note:**
- The graph illustrates the gap between current policy trajectories and the conditional and unconditional NDC cases for 1.5°C and 2°C targets. The conditional NDCs are shown to be significantly lower than the unconditional NDCs, indicating a need for stronger commitments to meet the Paris Agreement targets.
Possible approaches

**Mitigation (reducing sources of GHG)**

- Renewable energy
  - Energy substitution for fossil energy

- Increase energy efficiency

- Carbon capture and storage
  - Sequestration of CO2 underground on land and under sea floor
  - Direct air capture and storage

- Bioenergy with carbon capture and storage
  - Crops are burnt in power plants to generate energy and resulting CO2 is captured and stored

- Biochar and soil carbon
  - Carbon, including from partly burnt biomass added to soil

- Afforestation and reforestation
  - Including blue carbon from marine and coastal vegetation to enhance CO2 uptake and avoid further emissions

- Enhance open-ocean productivity
  - by adding nutrients and cultivating marine plants

- Enhanced weathering and alkalinization
  - Addition of natural or man-made alkalinity to enhance CO2 removal and/or carbon storage

- Pollution reduction
  - Reduce pollution from all sources, including land, rivers and black carbon

- Biodiversity preservation
  - Protect habitats and ecosystems through spatial measures including marine protected areas

- Assisted evolution
  - Assisted evolution and genetic modifications

- Restoration and enhancement of habitats, ecosystems and ecosystem services; ecological engineering

**Supporting biological and ecological adaptation**

- (including ecosystem-based management)

- Managing solar radiation

- Cloud brightening
  - Adding cloud condensation nuclei to the lower atmosphere to enhance cloud brightness and longevity

- Surface albedo enhancement
  - For example, by thickening sea ice or producing long-lived ocean foam

- Space-based methods
  - Using reflective particles and screens

- Aerosol-based methods
  - Adding sulfate and other aerosols in the stratosphere

- Community-based adaptation
  - Enhance local social capital, gender equity, traditional knowledge...

- Infrastructure-based adaptation
  - Building standards, hard defences...

- Relocate and diversify economics activities

- Relocate people
  - Coastal retreat and migration

- Change practices and policies
  - Resource use, consumption modes urban planning, regulation...

**Adaptation**

- Pollution reduction (increasing sinks of GHG)

- Sunlight reflection

- Community-based adaptation

- Infrastructure-based adaptation

- Relocate and diversify economics activities

- Relocate people

- Change practices and policies

- Resource use, consumption modes urban planning, regulation...

- Community-based adaptation

- Infrastructure-based adaptation

- Relocate and diversify economics activities

- Relocate people

- Change practices and policies

- Resource use, consumption modes urban planning, regulation...
The Ocean Solutions Initiative

- Assess potential of ocean-based measures to:
  - reduce changes in three major climate-related drivers globally and/or locally
  - reduce adverse impacts
- Expert assessment based on 8 criteria:
  - environmental effectiveness
  - technological readiness
  - lead time until full potential effectiveness
  - duration of benefits
  - co-benefits
  - disbenefits
  - cost effectiveness
  - governability from an international perspective
Addressing the causes of climate change

Renewable energy
Ocean energy substitution of fossil energy

(global & local) Vegetation
Restoration and conservation of coastal vegetation to enhance CO2 uptake and avoid further emissions

Fertilization
Enhance open-ocean productivity by adding nutrients

(global & local) Alkalization
Addition of natural or man-made alkalinity to enhance CO2 removal and/or carbon storage

Hybrid methods
Hybrid land/ocean methods (e.g. marine-biomass-fueled energy with capture on land, marine biochar, etc.)

Protection
Eliminate overexploitation of living resources and over-extraction of non-living resources
Protect marine habitats and ecosystems through spatial measures including marine protected areas

Assisted evolution
Assisted evolution and genetic modifications

Relocation and reef restoration
Restore and enhance degraded habitats and ecosystems, and create new habitats

Pollution reduction
Reduce pollution from all sources, including land and rivers

Solar radiation management

Vegetation restoration and conservation of coastal vegetation to enhance CO2 uptake and avoid further emissions

Gattuso et al. (sbm)
Protection

- Restoring hydrology
  - Maintain and restore coastal hydrological regimes including riverine delivery of water and sediments

- Eliminating overexploitation
  - Eliminate overexploitation of living resources and over-extraction of non-living resources

- Pollution reduction
  - Reduce pollution from all sources, including land and rivers

- Protection
  - Protect marine habitats and ecosystems through spatial measures including marine protected areas

Protection of biota and ecosystems

Gattuso et al. (sbn)
Solar radiation management

Cloud brightening
Adding cloud condensation nuclei to the lower atmosphere to enhance cloud brightness and longevity

Albedo enhancement
Increase surface ocean albedo by producing long-lived ocean foam

Gattuso et al. (2008)
Manipulations

Manipulation of biological and ecological adaptation

Assisted evolution
Assisted evolution and genetic modifications

Relocation and reef restoration
Restore and enhance degraded habitats and ecosystems, and create new habitats

Gattuso et al. (sbn)
Conclusion and key messages

- Climate change already affects marine and coastal ecosystems and their services
- Paris Agreement has the potential to avoid the unmanageable but one must manage the unavoidable
- Urgent need for ambitious global mitigation and local adaptation: ocean provides solutions for both
  - Most global measures (except renewable energy) exhibit too many uncertainties to be recommended for large-scale deployment
  - Local measures are no-regret options with huge co-benefits, can be scaled up immediately (although far less effective to address the global problem)
  - Greatest benefit is derived from the combination of global and local solutions

Gattuso et al. (sbm)
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