Ocean-based Negative Emission Technologies

OCEAN NETs

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Abstract: This deliverable synthesizes the results on public perceptions of marine CDR methods from the first two years of OceanNETs. The purpose is to inform the other work packages in OceanNETs and stakeholders about our results in a timely and brief manner about the ways members of the public view marine CDR specifically but also in the broader context of net-zero targets and climate policy. The deliverable summarises results of two studies: (1) focus groups held in Germany and Norway that covered ocean fertilization, ocean alkalinity enhancement, artificial upwelling and blue carbon management and (2) a deliberative survey in Norway that covered ocean alkalinity enhancement, macroalgae farming with BECCS or biomass sinking and land-based BECCS and enhanced weathering as terrestrial approaches for comparison. Participants in both studies emphasise the importance of reducing emissions and changing consumptions patterns. They hardly discuss the need to remove CO_2 from the atmosphere to reach the Paris climate goal and the concept of negative emissions seems difficult for them to engage with. Among the methods, participants prefer ecosystem-based approaches like mangrove or seagrass restoration over other methods like alkalinity enhancement or ocean fertilization. Participants are concerned about the actual feasibility of deployment at a relevant removal scale and for a longer period. Connected to this are concerns about the controllability of the deployment and the methods' impact, like difficulties to control negative environmental effects from biomass sinking at the seafloor. They also question the build-up of additional infrastructure or additional interventions into nature on top of already existing human interference. The opportunity to deliberate the methods increases participants' certainty about their assessment but only slightly changes the direction of the assessment.

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List of abbreviations, acronyms and definitions

BECCS – Bioenergy with Carbon Capture and Storage

CCS – Carbon Capture and Storage

CDR – Carbon Dioxide Removal

NETs – Negative Emission Technologies

NGO – Non-governmental organisation

OAE – Ocean Alkalinity Enhancement

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1. Introduction
1.1 Context

OceanNETs is a European Union project funded by the Commission's Horizon 2020 program under the topic of Negative emissions and land-use based mitigation assessment (LC-CLA-02-2019), coordinated by GEOMAR | Helmholtz Center for Ocean Research Kiel (GEOMAR), Germany.

OceanNETs responds to the societal need to rapidly provide a scientifically rigorous and comprehensive assessment of negative emission technologies (NETs). The project focuses on analyzing and quantifying the environmental, social, and political feasibility and impacts of ocean-based NETs. OceanNETs will close fundamental knowledge gaps on specific ocean-based NETs and provide more in-depth investigations of NETs that have already been suggested to have a high CDR potential, levels of sustainability, or potential co-benefits. It will identify to what extent, and how, ocean-based NETs can play a role in keeping climate change within the limits set by the Paris Agreement.

1.2 Purpose and scope of the deliverable

D3.4 synthesizes the results from WP3 on public perceptions of marine CDR methods from the first two years of OceanNETs. This includes the results from focus group discussions in Norway and Germany and from a deliberative survey in Norway. The purpose is to inform the other work packages in OceanNETs and stakeholder beyond the project about our results in a timely and brief manner about the ways marine CDR options are viewed specifically but also in the broader context of climate policy.

1.3 Relation to other deliverables

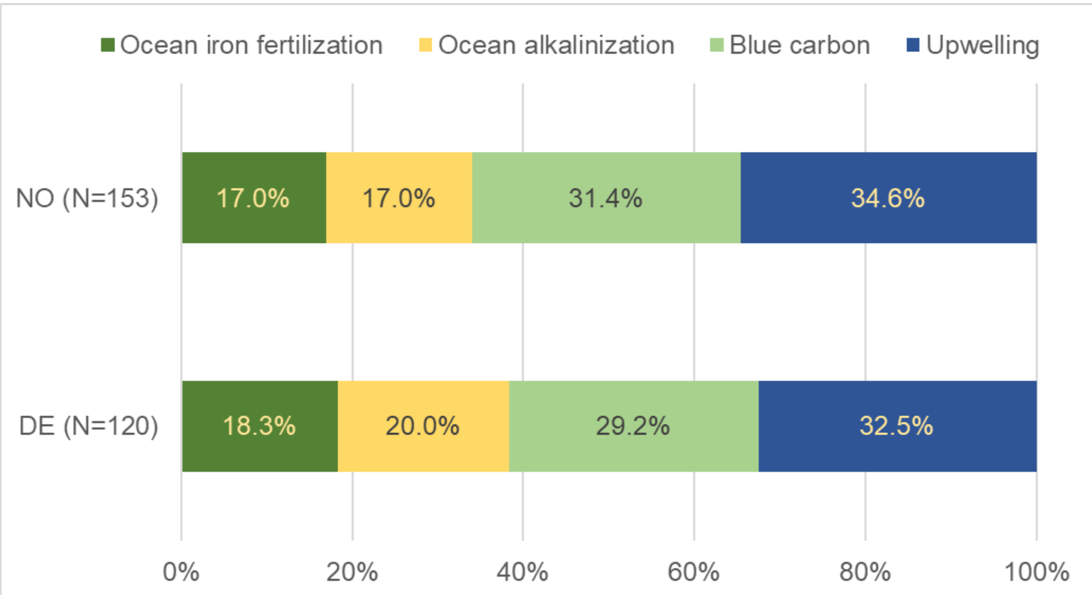
D3.4 presents the results of the data collected in the focus groups that were described in D3.1-D3.2 and summarizes the results presented in D3.3 It extends the analysis shown in D3.3. and add the more recent results from the deliberative surveys (task 3.2). Especially, the results of the deliberative survey will inform the design of the cross-country survey in task 3.3. Furthermore, the results will be part of the work package synthesis reports (D3.5 and D3.6) and the overall project synthesis (D7.10 and D7.12).

2. Summary of focus group results

In the focus groups, participants in Germany and Norway discussed a broad range of marine CDR approaches, covering ocean fertilization, ocean alkalinity enhancement, artificial upwelling and blue carbon ecosystem management. We chose these four marine CDR approaches as they are prominent in the current (scientific) debate. They span from approaches that are likely to be perceived as more natural like blue carbon management, to approaches that tend to be perceived as more technical like ocean alkalinity enhancement (OAE). Furthermore, the selection offers variation in terms of the influenced systems - ocean biology, chemistry, and physics - and the kind of substances that are introduced - nutrients, alkaline liquids or particles, large installations, or plants. We limited the number of approaches to 4 to ensure that discussion time was sufficient and to keep the amount of new information for participants manageable. Three focus groups were held in Germany and 4 groups in Norway in spring 2021 with a total of 35 participants. A short description of the study and the methods is available in the Appendix. The discussion guide and the information material are available in Veland and Merk (2021). The transcripts of the focus groups were coded and statements referring to one of the technologies were classified into 10 dimensions.

Overall, participants in both countries engaged most with artificial upwelling and coastal blue carbon management. About two thirds of all the arguments (DE: 120, NO: 153) participants made about any of the four approaches, were either about artificial upwelling or coastal blue carbon (Figure 1). While they engaged significantly less with ocean iron fertilization (DE: 18%, NO: 17% of arguments) or alkalinity enhancement (DE: 20%, NO: 17%). This implies that it was easier for participants to talk about and engage with approaches that either involved plants they can actually see (unlike phytoplankton) or physical installations. This is also reflected in participants' statements that they were not aware of either approach, that they had difficulties to form an opinion and that they asked for additional information and research especially about ocean fertilization and alkalinity enhancement.

Figure 1: Share of statements by country and technology



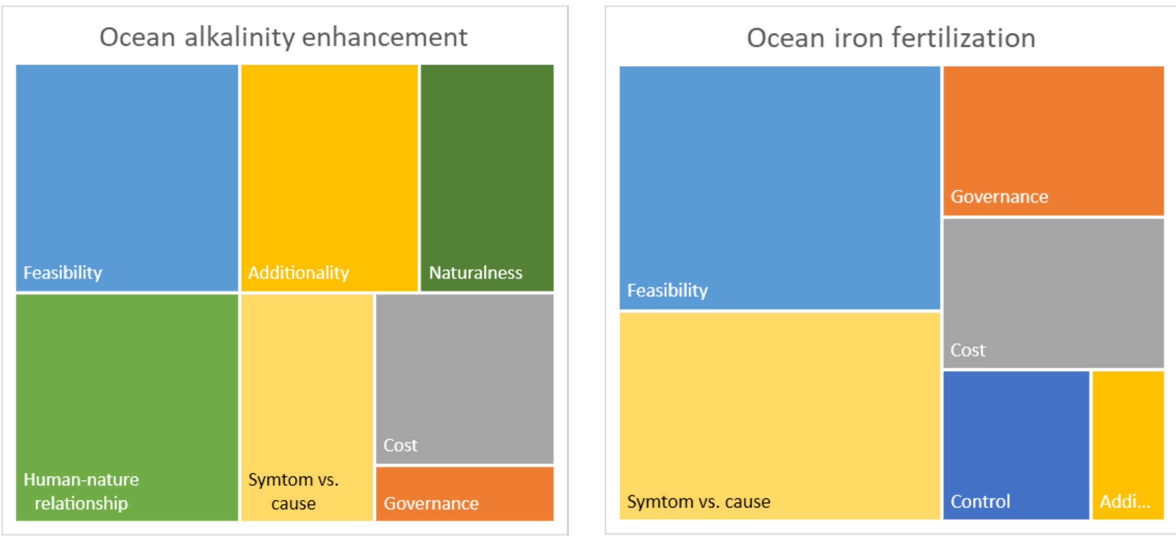
In the discussion about OAE and ocean fertilization, participants tended to discuss broader issues such as the importance of addressing the root ***cause*** of climate change, i.e. emissions, instead of the ***symptom***, i.e. removing carbon (Figure 2). This came up less often in discussions about blue carbon and artificial upwelling. The aspect of ***additionality*** was brought up in various ways. For OAE, participants were on the one hand concerned that additional mining and industrial installations would be needed and on the other hand that additional chemicals on top of past and current pollution would be added. This was also mentioned for the other approaches but to a lesser extent.

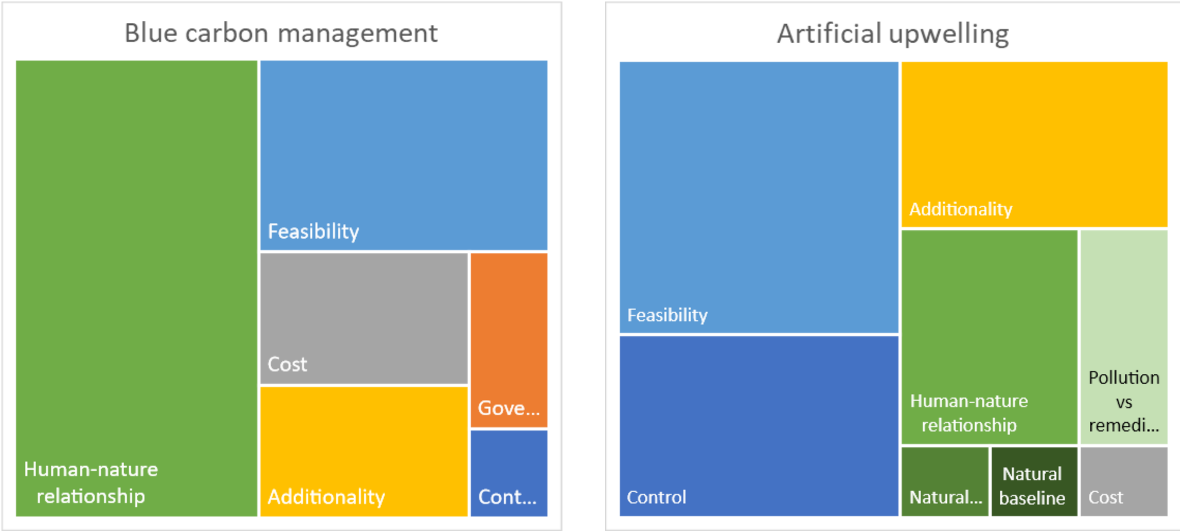
Arguments about ***feasibility*** were frequently used. Most respondents expressed a concern whether the deployment could be scaled up spatially and asked what the time horizon would be. Participants were sceptical, whether any of the carbon dioxide removal (CDR) approaches could have relevant impacts on carbon sequestration and long-term storage of CO_2. With respect to the temporal scale, participants were mostly concerned about the long-term impacts of the interventions. How long would it last, what would be the long-term impacts on ecosystems and biogeochemical cycles. Any research should first cover only small areas and time spans. Linked to this were discussions about the possibility to ***control*** the interventions and their side-effects, though participants did not bring this up for all approaches. Controllability was not mentioned for OAE but seems to be relevant for ocean fertilization and artificial upwelling.

Aspects of ***naturalness***, ***natural baselines***, the ***human-nature relationship***, ***natural baselines***, and ***pollution vs. remediation*** were relevant in the discussions of all technologies, except for ocean iron fertilization in Germany. Especially, in Norway these aspects were very prominent. For example, the return to natural baselines or balances was a recurring theme especially in Norway. ***Costs*** were discussed for all methods

When ***governance*** was discussed, there was often concern about the intentions of companies that might be interested in implementing marine CDR. Participants mistrusted their motives and were afraid of ungoverned interventions. However, these aspects were rarely mentioned in the Norwegian groups and also in Germany, participants only discussed this for some methods.

Germany





Norway

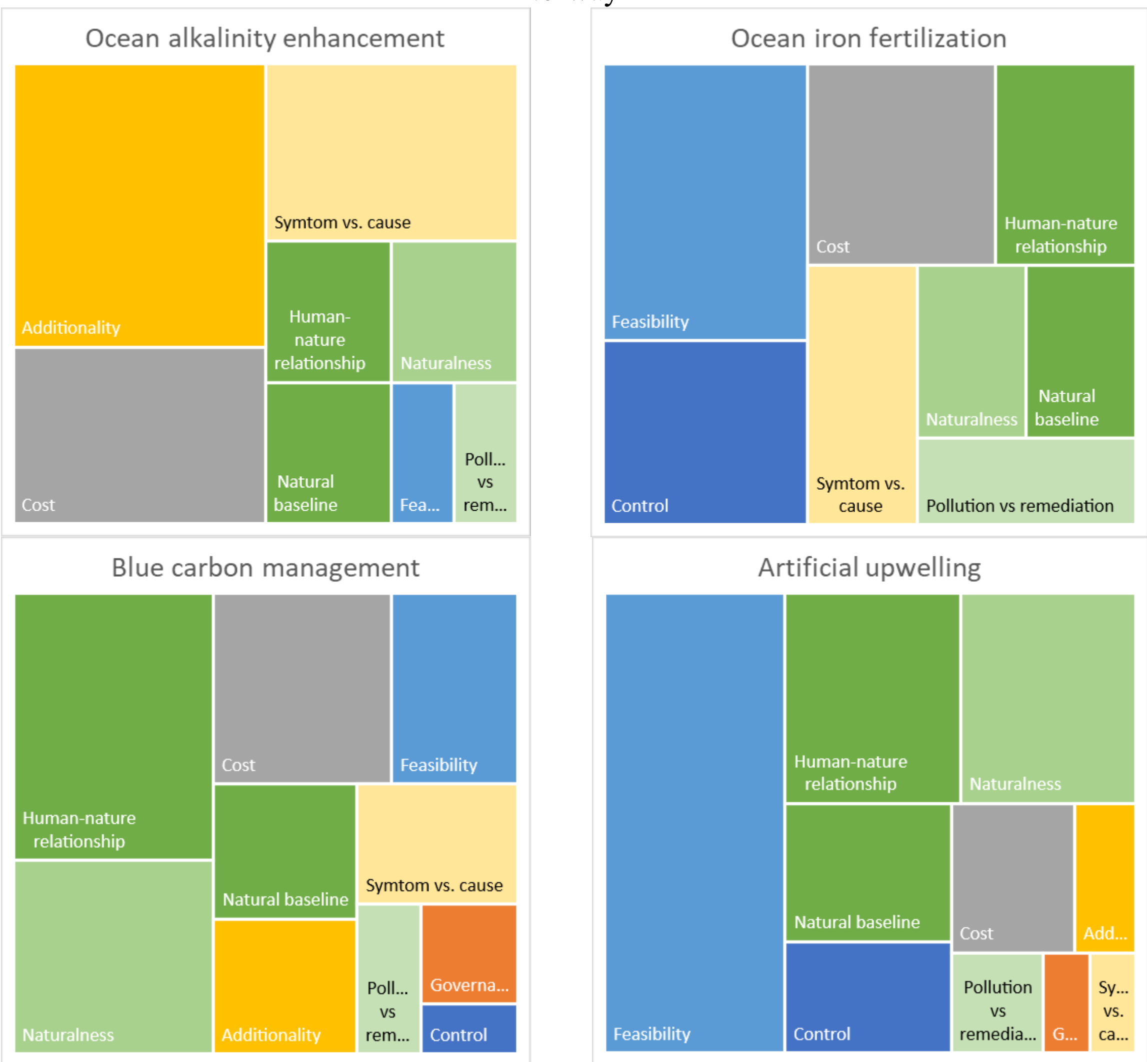


Figure 2: Classification statements made in the discussions about ocean alkalinity enhancement, ocean iron fertilization, blue carbon management, and artificial upwelling in Germany and Norway. The size of the square indicates the share of the number of statements relative to the total number of statements.
Categories: Additionality, Control, Cost, Feasibility, Governance, Human-nature relationship, Natural baseline, Naturalness, Pollution vs. remediation, Symptom vs. cause

The focus groups showed clear support for continued research and innovation on marine CDR, while the participants were still highly sceptical of the deployment of iron fertilization, OAE, and artificial upwelling. They showed their scepticism often in the form of asking for further information, such as the impacts on the climate, ecosystems, local communities, and the economy, to form an opinion. The support for blue carbon management was strong irrespective of its low carbon sequestration potential. This support seems to stem from a perception that marine ecosystems worldwide are damaged and in need of urgent attention. Participants were sceptical that any of the CDR approaches could sequester a significant amount of carbon. Furthermore, they were concerned about the ability to scale up deployment in time and space, unforeseen or unforeseeable effects on ecosystems in time and space, and that the availability of CDR options would be taken as a license by industry and the general public for continued pollution of the environment. Three key issues of uncertainty emerged. First, the ocean was seen as scary, mystical, or awe inspiring, rendering human action uncertain and unpredictable; second, awareness of the impacts of climate change on the ocean may depend a great deal on the public's relationship to the sea; and third, many appear unfamiliar with natural processes in the oceans that would be exploited by CDR and the related technical and lay terms.

Overall, the participants had mostly not heard about marine CDR before, but were nonetheless able to engage, to contribute their impressions and to voice their concerns. In the discussion, they often referred to events in the past or things they already knew well. There, we also see differences between the two countries: Most Norwegian participants were familiar with the sea and interacted frequently with the marine environment. Therefore, their frames of reference when discussing marine CDR were mostly related to historic and current events in the nearby marine environments. They referred to environmental issues in fjords, such as plastic and chemical pollution, poor circulation/upwelling, and the impacts of aquaculture on marine ecosystems. In Germany, participants made sense of what is happening in the ocean by referring to more generic or global issues, or by comparing it to processes on land. They more frequently mentioned plastic pollution and overfishing as key issues.

3. Summary of deliberative survey results

We use the results of the focus group to narrow down the focus of the subsequent study, a deliberative survey. While we tried to cover a broad range of only marine approaches in the focus groups, we proceed to explore whether people perceive land-based and marine methods differently. We choose two sequestration mechanisms, biological via growing biomass and rock weathering with deployment on land or in the ocean. The carbon is either stored geologically (via CCS), dissolved in water or on the seafloor. Thus, the participants of the deliberative survey evaluate and discuss the following approaches:

(1) Terrestrial BECCS, i.e. using biomass grown on land
(2) Marine BECCS, i.e. using biomass grown in the ocean
(3) Sinking macroalgae in the ocean
(4) Enhanced weathering on land
(5) Ocean alkalinity enhancement

For ocean alkalinity enhancement, we reduce the complexity compared to the focus groups and exclude electrochemical weathering and combining the production of quick lime with CCS. Besides the evaluation of the CDR methods, we dedicate about half of the discussion time during the deliberation to more general questions about net zero targets, net negative emissions, and the responsibility to remove CO_2 from the atmosphere. We aim to find out how participants perceive CDR in the broader context of climate policy and emissions reduction.

3.1 Introduction to deliberative survey research design

A deliberative survey is a particular type of mini-public that combines a deliberation and a survey. The approach was chosen for task 3.2 because it allows us to expand on the results from focus groups in task 3.1, while laying the groundwork for a comprehensive cross-country survey in task 3.3. The strengths of the deliberative survey method are that it provides a more formal measurement of opinions than the focus groups and that we can provide the participants with in-depth information, time to digest the information and a framework to deliberate together with others.

We ran the deliberative survey online in June and September 2022. A total of 89 participants discussed ocean-based negative emission technologies (NETs) during these events. Before discussing online in small groups, participants answered a survey. The survey briefly explained what CDR is and introduced the five different methods. Participants were then asked whether they felt positive or negative about the use of these technologies. They were also asked questions to measure their opinion on the risks and benefits associated with these technologies. The survey furthermore contained a few established items to measure their perception of climate change, political preferences, and more (see appendix for full survey).

After finishing the survey, participants received access to the information material. This contained a longer explanation of the role of CDR in climate policy. The role of NETs was explicitly linked to Norwegian climate goals by explaining, how CDR might be used to compensate residual emissions to reach the net-zero target. This was followed by an explanation of the five methods, including a discussion of potential risks and co-benefits of deployment and aspects particularly relevant for using them in Norway. The information material also contained twelve policy proposals:

- five proposals related to the use of CDR technologies as part of Norwegian national climate policy, and
- seven proposals on the research and deployment of the NETs in Norway

Each proposal was accompanied by pro- and contra-arguments which try to reflect the breadth of technical, environmental, social, legal, political, and ethical arguments for and against research and deployment of CDR. Participants were informed that their main task during the deliberative event was to discuss the proposals in small groups.

The deliberative event consisted of two main components, discussions in small groups and plenary sessions with invited experts who discussed and answered questions formulated by the groups. The experts were invited based on their academic qualification, their good communication skills and their experience with participating in public debates. We included university professors, researchers from independent research institutions and a representative from the Norwegian environmental NGO ‘Zero’ that had worked on relevant topics. The list of the experts who participated is provided in the appendix.

At the end of the second plenary session participants were asked to answer the second survey. This questionnaire was identical to the first except for a few items to measure, how they evaluated the deliberative event. The deliberative survey thus consists of four steps:

1. Pre-survey
2. Information material is distributed to participants

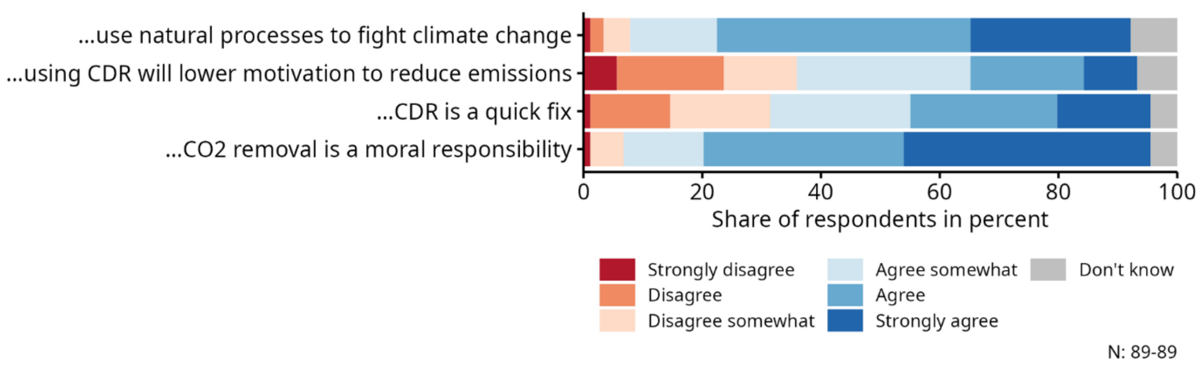
3. Deliberative event
4. Post-survey

The two surveys were also filled out by a control group that did not participate in the OceanNETs deliberation. This before and after-design with control group, allows us to run a difference-in-difference analysis of attitudinal changes among the participants. This way we can analyse the effect of information and deliberation on evaluating CDR options. The summary of the results from the deliberative survey is based on the quantitative analysis of survey responses and the qualitative analysis of group discussions. Due to the short time between the September event and the publication of this report, the group discussions in September are not transcribed yet. Therefore, the qualitative analysis of the group discussion is primarily based on data from the June event. The analysis of survey responses already contains the full data set with participants from the June and the September event. A more detailed description of the study, including recruitment, demographics of participants, the full survey and the information material is available in the Appendix.

3.2 Climate policy, carbon dioxide removal and compensation of historical emissions

The deliberative survey included several general questions on the support for removing carbon dioxide from the atmosphere (figure 3). A majority supports the general idea of removing CO_2 and consider this a moral responsibility. In line with the finding from the focus groups, most prefer using what they perceive as "natural processes". We also see that a majority of the respondent feel that CDR approaches might reduce the motivation to reduce emissions.

Figure 3: Descriptive results of items that measure general opinions on CDR. Question 10. Question wording available in Appendix.



In the first session, participants are asked to discuss proposals on climate policy and the role of CDR in national policy (Box 1). Groups generally express a cautious acceptance of removing CO_2. The support of CO_2 removal as a general concept was high compared to respondents' rather negative evaluations of specific CDR approaches (see figure 4). However, very few participants engaged with CDR as a climate policy complementary to drastic emission cuts, instead they repeatedly stressed the need to reduce emissions through individual or collective action.

Very few participants explicitly related to the concept of CDR or on how to tackle Norwegian residual emissions. Also, net negative emissions were hardly mentioned even though the information material and the arguments related to proposal 1-5 repeatedly referred to the concept. The information material and the proposals were intentionally designed to open up a discussion on how to manage residual emissions, the compensation of historical emissions, and the role of negative emission technologies to reach net-zero or even net-negative emissions.

Box 1. Proposals discussed in session 1

1. Norway should reduce emissions as much as possible to reach its 2050 climate target.
2. Norway should use methods to remove CO_2 from the atmosphere to compensate for the emissions that we cannot reduce in other ways.
3. There is an urgent need to remove CO_2 from the air as soon as possible.
4. Norway should fund more research on new methods and techniques for removing CO_2 from the air
5. Norway must not only reach the zero-emission target but should use these methods so that Norwegian emissions becomes net negative.

The main impression is that the idea of residual emissions, negative emissions and net-negative emissions seems to be hard to grasp. Although most participants engage with ideas and arguments from the information material, the key concepts were hardly referred to in the group discussions.

Some groups even explicitly express that it is hard to understand and/or to realistically think about removals when in reality we still have to figure out how to reduce emissions. In addition, several participants were concerned that removal technologies might prevent or delay changes in society or lifestyles that they thought were necessary. Most participants expressed concern about climate change, and many argued that we need to do more to fight climate change. The need to do more is arguably an indirect message from the information material. Rather than discussing the active removal of carbon from the atmosphere or the removal technologies described in the information material, the participants typically linked the need for action to more well-known issues in the Norwegian climate policy debate. Thus, the cautious but general support for CDR and the relatively negative evaluation of specific NETs in our survey can be interpreted as a result of how participants made sense of the topics they were asked to discuss.

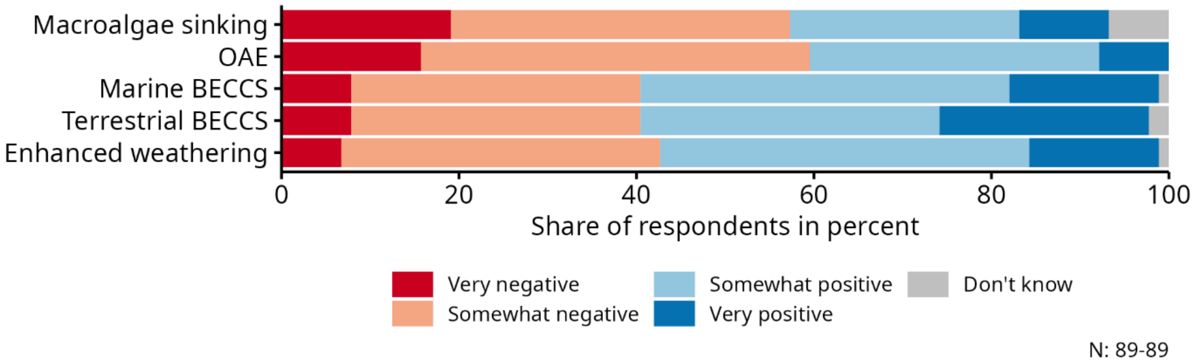
In the group discussions, we identify two opposing narratives, technology leadership vs. environmental hazards. Support for carbon removal methods is typically expressed as part of a broader technological leadership narrative. Key elements are that Norway has the wealth and relevant industries with competencies that are necessary to “do more” to fight climate change. For some participants, this narrative includes that Norway can and should take on a role as a leading country in the development and the possible deployment of CDR. Several participants think that Norway has a moral responsibility to take this role because the country has accrued its wealth from the export of fossil-fuels. In the opposing environmental hazards narrative, concerns about short-term environmental risks of NETs are used as a reason against deployment. This is sometimes linked to questions about capture potential, economic costs, and how realistic CDR methods are. In this narrative, removal is not straight out rejected, but deployment is contingent on the absence or at least better knowledge about the environmental hazards involved. We find both narratives in all groups. Although opposing, they are not mutually exclusive, and several participants express support for key ideas from both lines of argumentation.

Both narratives are also compatible with general support for more research on the topic. The group discussions (and survey data) indicate that participants support and request more accurate estimates of costs and capture potential, as well as more information on potential negative side effects from specific NETs. Many of the questions formulated at the end of the group discussions reflect the engagement and concern that such issues created.

3.3 Specific CDR methods

We designed the deliberative survey to investigate, how participants would evaluate different CDR approaches. Figure 4 shows the evaluation of the five methods in the post-survey. The share of negative evaluations varies between 40 % and 60%. Land-based approaches receive fewer negative evaluations. However, their share of negative evaluations is still substantial.

Figure 4: Respondents' perceptions of the five NETs after deliberation (Survey questions 1 – 5)



The discussions indicate that participants have somewhat different questions and concerns about ocean-based and land-based methods. Although property rights and governance are also discussed for the land-based methods, these topics tend to create more fundamental concerns in relation to the ocean-based approaches.

> Again, the question is, who owns the ocean? Do we, what shall I say, in Norway have the right to just do what we want? And what if something goes wrong? (Participant 12125, group B, June 12th)

> And the sea is so big, so if we are going to invest and use large areas for this purpose, it will be difficult to reverse the process. We have more control over what we do on land. (Participant 12139, group E, June 12th)

The quotes illustrate the open and general character of these discussion. The second quote illustrates that controllability of removal technologies is more often questioned in relation to ocean-based compared to land-based methods. This seems to be one reason why ocean-based technologies tend to be evaluated more negatively than land based (see figure 4).

Compared to the cautious support for CO_2 removal in the discussions and some survey questions (see figure 3), we observe that the specific removal approaches receive more negative evaluations. In the general discussion on CDR, we observe that the concept of removal seems to be hard to grasp. This carries over to the discussions about the technologies: Participants tend to focus on potential immediate, near-term negative side effects of CDR deployment, as the need for CO_2 removal to reach longer-term climate goals remains abstract. Thus, they tend to not make trade-offs between the potential negative side-effects of deployment and the benefits from CO_2 removal.

The analysis of the discussions reveals some central associations participants have with the various technologies. As already seen in the focus group discussions, participants' associations are typically linked to personal experiences and public debates. For several of the methods we see that the focus on environmental consequences is mainly driven by how easily the participants can relate to this aspect, compared to the arguably more abstract aspects like technological readiness level, capture potential, or the economic costs. The first assessments of the removal technologies seem to be driven by how they can be associated with personal experiences and public debates. This observation suggests that it is reasonable to expect variation in how different communities and cultures will evaluate specific CDR approaches and what concerns the public will have about them.

Bioenergy with Carbon Capture and Storage (BECCS)

Growing biomass on land for bioenergy generation coupled with CCS is the CDR approach most often used in modelling studies. Large energy crop plantations compete with food production and natural ecosystems for the scarce resources land, water, and fertilizer. Growing the biomass for bioenergy generation in the ocean instead could remove the pressure on these resources, while also providing the benefit of energy production.

Terrestrial BECCS

Land-based BECCS is the first CDR approach the groups discuss (proposal 6 and 8). All groups express predominantly negative views on land-based BECCS. Although this approach is evaluated relatively positive in the survey, participants nonetheless discuss it critically. Participants state that it is important to protect existing agricultural land and the limited food production in Norway. They are also concerned with the sub-optimal conditions to grow plants for bioenergy in the cold climate. Participants in two groups express support for proposal 6, primarily highlighting the high technological maturity of terrestrial BECCS. Overall, groups are more supportive of proposal 8 which demands to limit BECCS to sustainable biomass cultivation. Many participants express support for a combination of energy from biomass residues and CCS. This reflects the concerns about ***additionality*** of human interventions into the environment by CDR deployment raised in the focus groups.

Box 2. Proposals on terrestrial BECCS

6. Norway should use land-based bioenergy with carbon capture and storage (BECCS)
7. Norway should expand storage sites for CO_2
8. Limits should be set for the use of biomass for bioenergy and BECCS which ensure that negative consequences for the environment and society are low

For both proposals we find that most groups mainly use arguments from the information material, but when they justify why a particular aspect is relevant for them, they typically provide examples from their own experience or from events in Norway. For example, several participants stress the importance of protecting agricultural land because they think there is not enough agricultural land in Norway and that domestic food production is too low. This reflects current political debates in Norway.

The groups also discussed a proposal that was specifically about the storage component of BECCS, namely the expansion of the Norwegian CCS storage capacity (Proposal 7). This was added so the groups would discuss the storage solution separately from the sequestration method, i.e. the biomass production on land or in the ocean. A majority supports proposal 7, and some explicitly say that storage sites are necessary to reach climate targets. Several participants have detailed knowledge of Norway's existing CCS infrastructure. However, some participants are critical of the proposal. Typical counter-arguments are the risk of leakage from storage sites, the energy needed for capture and transport, and that CCS might lower the motivation to reduce emissions. Still, the general impression is that the majority is familiar with and support storage in geological formation. CCS has played an important role in the Norwegian climate debate for several decades and has broad support from political parties and environmental NGOs. Comparative surveys show that the Norwegian population is relatively supportive of and knowledgeable about CCS (Merk et al., 2022; Whitmarsh et al., 2019).

Therefore, the more positive evaluation of methods that rely on CCS in the deliberative survey (see figure 4) could be driven more by the familiarity with the storage solution than the biological capture method. The storage component might spark more controversial discussions in other countries.

Marine BECCS and macroalgae sinking

For capture by macroalgae farming, we proposed two ways to store the CO_2 – the use for bioenergy generation combined with CCS and sinking the biomass in the deep ocean (Box 3). In many groups the two approaches are actively compared. All groups are more critical toward macroalgae sinking than marine BECCS, a result also reflected in the survey responses (see figure 4). The main reasons are perceived lack of ***controllability*** and concerns about the impermanence of storage. Biomass sinking is often associated with dumping waste in the sea and is seen as an "out of sight, out of mind"-approach that is categorized as an old-fashioned way of managing waste. Discussing the two approaches, many participants reflect on their own experiences of living close by the sea and their perceptions of the maritime industries in Norway. For example, participants often take up the counter-argument to proposal 10, that open-ocean farming is harder and more expensive to control given the harsh weather at sea. The other pro- and contra arguments for proposal 10 are mentioned a lot less often.

Box 3: Proposals on marine BECCS and macroalgae sinking

9. Norway should grow macroalgae in coastal areas and use the biomass for BECCS.
10. Norway should grow macroalgae far out at sea and the biomass should be sunk in the deep sea.

Proposal 9, to farm macroalgae for BECCS in coastal areas, evokes discussions about the Norwegian experiences with salmon farming. As it has become an industry over the last decades salmon farming has raised public debates and local conflicts (Osmundsen and Olsen, 2017). The industry has created income and employment in rural areas, but has also detrimental environmental consequences, such as pollution, problems with sea lice and genetic interaction with wild salmon. Many participants associate macroalgae farming with such developments and are concerned about again creating problems caused by industrial aquaculture and monocultures. Some participants stress the need for ***governance*** of how the coast and the open ocean is used. The following exchange of views between three participants illustrates several of the above-mentioned aspects:

> If we learn more about how we can efficiently and environmentally soundly grow macroalgae for removal, then it may also become easier afterwards to grow algae for food production. We grow things in the sea today, salmon farming is a good example. So, there is a lot of knowledge that is transferable. (Participant 12115, group D, June 12th)
>
> This thing with salmon farming, it shows that there are things that we were initially very positive about, but it has major environmental consequences, due to the fact that there are a lot of of things to be taken into consideration. (Participant 12104, group D, June 12th)
>
> Totally agree. You have to do things the right way. And that is very easy to say, and not so easy to do. But that's when research comes in, so that we can have control over the environmental consequences of what we do. (Participant 12115, group D, June 12th)

In general, we see that participants show a great trust in research and that more research is considered important to ***control*** environmental impacts of NETs.

Enhanced weathering and ocean alkalinity enhancement

The proposals for enhanced weathering on land and ocean alkalinity enhancement, i.e. ocean liming, have in common that their deployment would require extensive mining and grinding activities to produce the rock powder (Box 4). In the info material, we did not introduce more sophisticated approaches for OAE such as electrochemical weathering (as we had done in the focus groups) to lower the complexity and to improve comparability between land-based and ocean-based deployment. As the technical readiness level of OAE is low and basic research is still needed, proposal 12 is mostly about the support for research and whether OAE should be deployed as soon as possible or whether respondents prefer a more precautionary approach.

Box 4: Proposals on enhanced weathering and ocean alkalinity enhancement

11. Norwegian authorities should support farmers so that enhanced weathering becomes part of Norwegian agriculture.
12. Norwegian authorities should fund research on ocean liming and closely monitor research on the topic. The method should be introduced as soon as we get promising research results.

It is not widely known that the chemical processes of weathering or changing alkalinity captures CO_2. Accordingly, participants find it more abstract and more difficult to grasp compared to biological capture by photosynthesis. Again, discussions focus on the short-term environmental impacts of deployment but also of the necessary upstream activities. Participants frequently mention the negative experiences with mining and high energy need for grinding and transporting the rock. In the survey, about 60% of the participants evaluate OAE negatively, while this share is considerably lower for enhanced weathering (43%, Figure 4).

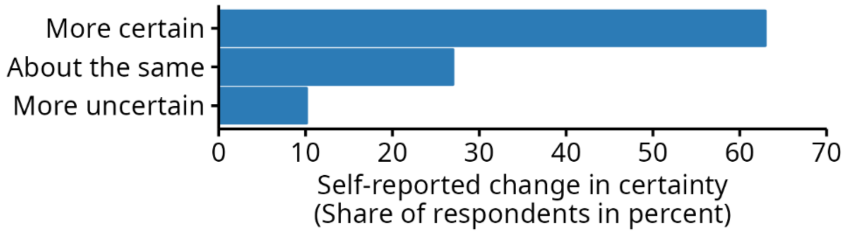
The discussions show mixed views. Several participants like the proposal on enhanced weathering and consider this CDR approach promising, others consider it as something that could be worthwhile to test on a small scale. Counterarguments typically focus the potential negative effects on Norwegian agriculture. For OAE, we observe that most participants support funding research on the method. Several participants associate it with the perceived success of reducing acidification of lakes and rivers in Norway by liming. Although almost all participants support funding research, several are sceptical of using the method “as soon as we get promising research results”. They think promising results are insufficient and stress the importance of knowledge that allows full ***control*** over the environmental consequences on ***nature***.

3.4 What did the deliberation change? Did it change anything?

Researching public perceptions of novel technologies or topics that are not widely known or complex, faces the dilemma that while participants have to receive at least basic information before they can discuss or evaluate the issues at hand, the framing of this information will necessarily influence their answers. The assumption is that the more time people have to digest information and the more different voices they hear about it, the easier it will be for them to form an opinion independent of the framing of the initial information (Fishkin, 2018). Carbon dioxide removal and net negative emissions are a good example for this problem, as the public has currently little or no knowledge about CDR and the options available. At the same time, there is the call to increase citizens’ involvement in Responsible Research and Innovation (RRI) processes and policy design to improve the quality and the public support of policies. Although such initiatives can be problematic (see Rip, 2018), public deliberation and engagement have been shown to increase issue knowledge and can positively influence the quality and legitimacy of decisions (Curato & Böker, 2016; Michels, 2011; Niemeyer, 2014).

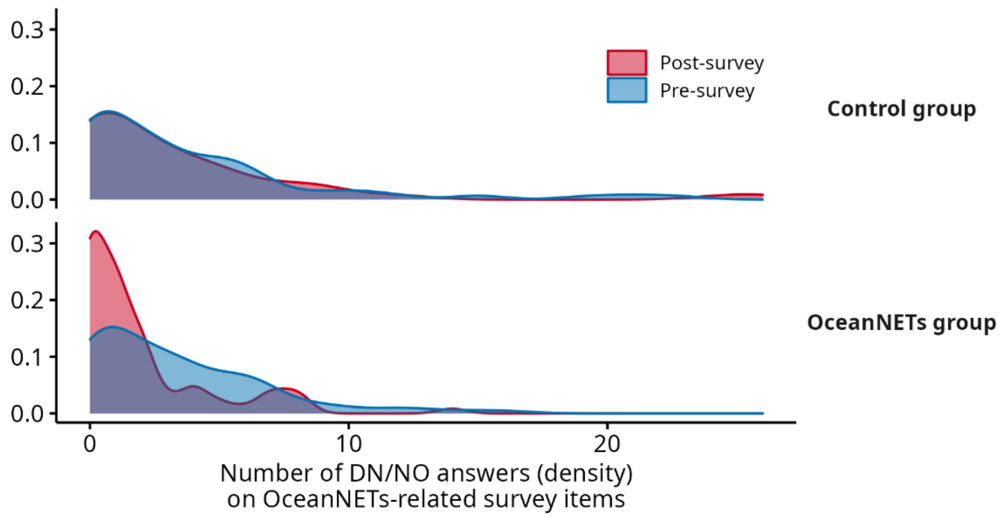
We, therefore, ran the deliberative survey to find out how and whether the treatment, i.e. the information material, the deliberation in small groups, the plenaries with experts discussing questions from the groups, and the time spent on CDR change participants' opinions in the post-survey compared to the pre-survey. In our treatment group are the 89 people who participated in the OceanNETs deliberative event. In addition, we compare their responses to the answers of the control group with 117 people who answered the identical survey, but did not receive additional information on CDR and participated in a deliberation on another topic. The design allows us to compare the change in answers between survey 1 and 2 between the two groups. Significant differences in how the answers in the two groups changed can be attributed to the treatment, as the comparison with the control group rules out the effects of external events or impacts of just participating in any deliberation independent of the topic.

Figure 5: Do you feel more certain or more uncertain about your views on different methods of removing CO_2 from the air after you participated in the deliberation?



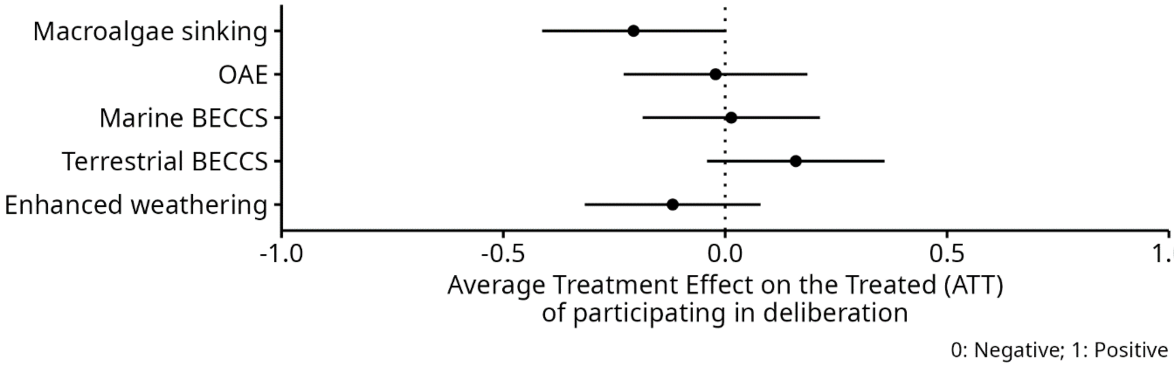
Our results clearly show that participation in the deliberative event increased self-reported certainty and decreased the number of "Don't know"/"No opinion" answers. Figure 5 shows the self-reported change in certainty after receiving the information material and participating in the deliberative event. The results indicate that this increased their confidence. This finding is also reflected in the reduction of the average number of "Don't know"/"No opinion" answers among participants in the OceanNETs group between survey 1 and 2 (figure 6). This change is much smaller in the control group, the observed change can therefore be attributed to the experimental treatment.

Figure 6: Average number of Don't know/No opinion-responses per participant in pre- and post-survey, for the OceanNETs group and the control group. Based on 28 survey items.



Another question is whether the participants in the OceanNETs deliberation changed their views on the removal technologies, when they were given the opportunity and time to form an opinion. We analysed this by comparing the average change in the response to an item between the treatment and the control group. Figure 7 shows the average treatment effect on the treated (ATT), i.e. the change between the pre- and the post-survey in the treatment relative to the change in the control group. We find a significant shift in the assessment of macroalgae sinking which participants perceive more negatively after the deliberation. For the other CDR approaches, we do not find significant changes in the evaluation (survey question 1-5).

Figure 7: Average treatment effect on treatment group, evaluation of five removal technologies with 95%-confidence interval



The results clearly show that more information and the deliberative event increased self-reported certainty and that participants formed an opinion on more questions. However, we only find a significant change in the opinions for one item due to the deliberation. We expected that participants might change their opinion because they had little knowledge about the approaches before and heard different views during the deliberation.

First, we believe that the survey design could have reduced the effect of the information material, as we had to briefly explain key concepts and aspects about the technologies to the participants in the survey. The short introductions to the evaluation questions provided an explanation similar to the main content of the information material, but less detailed than the full OceanNETs information material (see complete survey and information material in the appendix). This potentially reduces the treatment effect since all participants received at least some information on the technologies.

Second, data from the group discussions indicate that most participants did not engage with the concept of removal as something different from other and more well-known climate change mitigation measures. The group discussions most often centred around well-established narratives in the public debate on climate policy in Norway that emphasize the country's technology leadership and its historical responsibility as the nation's wealth is founded on the exploitation of fossil fuels. Technological optimism pervades and few groups have in-depth debates about the technologies. Like in the focus groups, we observe that participants refer to other topics or events they are familiar with when they comment on the CDR methods. This indicates that the treatment – the information material, the group discussions, and the plenaries – had a somewhat limited impact on how the participants perceive CDR and the technologies.

For the future work in WP3, these results from the experiment are helpful because they indicate that the short information in the survey was appropriate to help participants express their opinion on the topic. Our results indicate the difficulties associated with survey research on this topic and they will inform the design the cross-national survey in task 3.3.

4. Summary of results and implications for researching public perceptions of marine CDR

Table 1 summarizes the results from the focus groups and the deliberative survey on the perceptions of the 8 CDR methods we assessed. Prior awareness about negative emissions is low among our participants and it seems difficult for them to engage with the concept of removing CO_2 from the atmosphere and compensating historical emissions in this way. This is also not taken up even though especially Norwegian participants perceive a national responsibility to pioneer climate change solutions as the national wealth is founded on the exploitation of fossil fuel reserves. Despite our framing of CDR as a complement to drastic emissions reductions, the extensive information and explicit proposals about net zero targets, participants in both studies focus on the importance of reducing emissions and changing consumptions patterns and hardly discuss the need to remove CO_2 from the atmosphere to reach the Paris climate goal. That CDR will probably be necessary on top of these changes in lifestyles, seems to be an inconvenient truth. They are, however, able to understand the general idea of the CDR methods we present and to formulate questions, thoughts, and concerns. Furthermore, there is a wide-spread support for research connected with an underlying expectation that research can ultimately lead to complete certainty and controllability.

Table 1: Summary of public perceptions of eight NETs studied in WP3, combined results from focus groups (FG) and deliberative survey (DS). Data source, associations, concerns and indication of public support.

CDR approach	Data	Associations	Concerns	Public support
Artificial upwelling	FG	Offshore wind energy	Feasibility	Low
Blue carbon ecosystem management	FG	Natural process	Invasive species Human interventions going wrong	High
Ocean fertilization	DS	Marine pollution	Feasibility and controllability	Low
Ocean Alkalinity Enhancement	FG & DS	Marine pollution, freshwater liming	Additionality, mining, energy footprint, controllability	Low
Enhanced Weathering	DS	Fertilization	Mining, energy footprint	Low/Medium
Macroalgae farming	DS	Aquaculture	Monoculture, pollution	
With sinking		Waste dumping at sea	Controllability, impermanence of storage	Low
With CSS		CCS as climate solution	Additionality related to CCS	Low/Medium
Terrestrial BECCS	DS	Agriculture, CCS as climate solution	Land-use, food production	Low/Medium

Among the methods, participants prefer ecosystem-based approaches, like mangrove or seagrass restoration, over other methods like alkalinity enhancement or ocean fertilization. The first ones are perceived as ***natural*** and thus most likely as benign, while the latter are associated with marine pollution and a ***human interference with nature***. Participants are generally concerned about the actual ***feasibility*** of deployment at a relevant removal scale for a longer time period. Connected to this are concerns about the ***controllability*** of the deployment and the methods' impact, like difficulties to control negative environmental effects from biomass sinking at the seafloor. A perceived lack of ***control*** over the sea and ocean currents might also partly drive the more negative perception of marine options compared to land-based capture and storage. Participants also question the build-up of ***additional*** infrastructure or additional interventions into ***nature*** on top of already existing human interference. Therefore, using residues for BECCS instead of dedicated energy crops or electrochemical weathering using brine from already existing desalination plants instead of newly mined material is perceived more favourably.

As there is no public debate about CDR yet, we find that people often associate the methods with issues and debates they are already familiar with. These connections shape the debate on the approach, e.g. when artificial upwelling is associated with offshore wind energy participants will use arguments and address concerns from the debate on wind energy. Associations stem partly from individual experiences, like living close to a fish farm, partly from public debates, like the Norwegian discourse on aquaculture, and partly from national identities, like the appreciation of wilderness in Norway. The differences between the discussions in Germany and Norway show this very nicely: Germans' relationship with the sea is more observing and distant, most participants think of themselves as standing at the coast and observing the ocean. Norwegian participants interact with the ocean, as they work with it or spend their free-time going out on a boat. National specificities also influence the overall perceptions of an approach. An example is the positive perception of CCS in Norway that influences the overall evaluation of BECCS.

The next step in our analysis of public perceptions of marine CDR will be a comparative cross-country survey. Based on the results of the focus groups and the deliberative survey, we will on the one hand elicit the relationships with the ocean to account for cultural differences. On the other hand, we will explore variations in the perceptions of the four key dimensions naturalness feasibility, controllability, and additionality and the way these affect the views on marine CDR.

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Appendix

I. Recruitment and methods for focus groups

In Norway, 4 two-hour online focus groups were held mid-March 2021, the first of which was a pilot group to test the graphics and the interview guide. The Norwegian participants were recruited via a social media and newspaper advertisement campaign targeted at persons living in Bergen (coastal). In total, 20 people attended the four focus groups with 2-7 participants per group. In Germany, 3 two-hour online focus groups were held in late March 2021. The participants were recruited by the service provider IPSOS and selected based on their age, gender, and educational background to create diverse groups and include a broad variety of opinions. Participants lived either in Berlin (inland) or Hamburg (coastal). In each of the 2-hour-sessions 5 people participated. Every participant received about 50 Euro.

About half of the German participants were female, while the Norwegian groups had a slightly higher share of female participants. The median age group was 40-49 in both countries. In Germany, eight out of 15 participants had a university degree, while 14 of the 20 Norwegian participants had at least a university degree. In terms of demographics the groups are comparable, but the level of education is higher among Norwegian participants. In addition, the Norwegian groups also included participants with a degree in marine sciences or jobs in the maritime sector.

The discussions were facilitated by two moderators and structured in the following way: Respondents were asked about their relationship to the sea, their perceptions of the environmental status and management of the oceans. Using graphics, one of the moderators explained the natural carbon cycle and the perturbation caused by anthropogenic CO_2-emissions. We presented four CDR approaches in the following order also using graphics: i) ocean fertilization, ii) ocean alkalinization, iii) artificial upwelling, and iv) blue carbon management. In addition, respondents were asked to compare the four technologies, and to reflect on the priorities for responsible research and innovation (RRI) on marine CDR methods. A more detailed description of the data collection, the discussion guide and the information material are available in Veland and Merk (2021).

II. Recruitment for deliberative survey

Participants were recruited by a random draw from the Norwegian population register. The register contains an almost complete list of residents in the country. The near-perfect sampling frame ensures that all members of the target population have an equal, non-zero chance of being invited to the deliberative survey. To the deliberative Survey in June, citizens were recruited over the phone by a professional survey agency. To the deliberative survey in September participants were recruited through the Norwegian postal office's digital post infrastructure. The deliberative event takes 4-hours and participants who participated were compensated with 1000 NOK (approx.100 Euro).

We drew 24000 potential participants from the population register. We aimed for approximately 400 participants, 200 to the OceanNETs group and 200 to our control group. It turned out to be more difficult to recruit to the deliberative survey than we anticipated. In addition, some of those recruited did not finish the pre-survey and a lower share than what we anticipated turned up at the deliberative events.

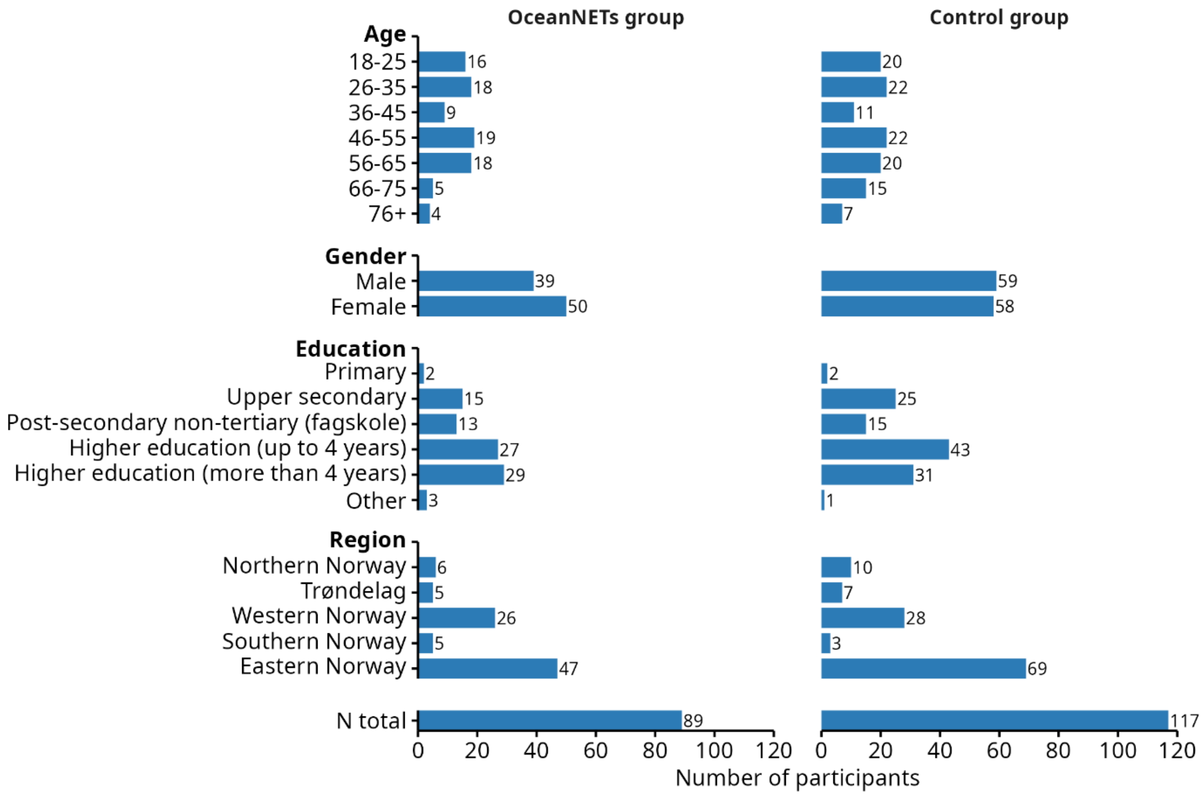
We held the deliberative surveys online in June and September 2022. Our dataset includes 206 participants, 117 in the control group and 89 in the OceanNETs group. 50 of our participants were part of our event in June, 39 in September.

We believe that several factors contributed to the problems with recruitment and high drop-out rate. The topic we invited participants to discuss is abstract and difficult to grasp. The event takes four hours and took place on a Sunday. The deliberation for our control group took place on a Saturday and fewer participants dropped-out from this group. We collected data from the recruitment phase and a full analysis of drop-out rates is planned in order learn how the recruitment and organization of these events can be improved.

III. Demographics of deliberative survey participants

Figure 8 shows the distribution of socio-demographic characteristics in the treatement and teh control group. The distributions are similar in both groups. Only for gender we observe a surplus of female participants.

Figure 8: Demographics for OceanNETs group and control group



IV. Description of deliberative survey method

The deliberative survey consists of four steps:

1. Pre-Survey
2. Information material is distributed to participants
3. Deliberative event takes place
4. Post-Survey

After being recruited, participants were invited to answer the **first survey**. The survey briefly explained what NETs are and introduced them to five different technologies. Participants were then asked whether they felt positive or negative about the use of these technologies. They were also asked questions designed to measure their opinion on the risks and benefits associated with these technologies. The survey also contained a few established items to measure their perception of climate change, political preferences, etc. (see full survey below).

After finishing the survey, the participants were given access to the **information material**. This contained a longer explanation of the role of CDR in climate policy. The role of NETs was explicitly linked to Norwegian climate goals by explaining how these technologies might be used to remove residual emissions to reach the net-zero target. This was followed by an explanation of the five technologies, including a discussion on potential risks and co-benefits of using them and aspects particularly relevant for using them in Norway. The information material also summarized the capture potential, energy need, technological readiness level, deployment costs, and potential environmental and social co-benefits or risks in a table.

The information material also contained **twelve policy proposals**:

- five proposals related to the use of CDR technologies as part of national Norwegian climate policies, and
- seven proposals on the research and deployment of the NETs in Norway

Each proposal was given arguments supporting it, and arguments criticizing it. Participants were informed that the main activity for the deliberative event was group discussions of these proposals. Four or three days before the deliberative event, the participants received an e-mail that reminded them to read the information material. The aim of the information material and the deliberation is to help participants form an informed opinion (Fishkin, 2018). The **deliberative event** had two main components, discussions in small groups and plenary sessions with invited experts.

We used an online format where **participants met on a purpose-made platform**.[1] The platform features an automated moderator that facilitates the discussions in small groups by timing the agenda, managing the queue of speakers, encouraging more quiet participants to speak, and thus allowing equitable participation.

When participants log on to the digital platform, they are randomly assigned to discussion groups. Based on experience with this kind of online deliberation, each group contained ten to twelve participants. The discussion groups started with a short video explaining how the

[1] We used Stanford Online Deliberative Platform (SODP). A presentation with screenshots and features is available at https://stanforddeliberate.org/

platform works. They also watched a 4-minute-long pre-recorded video that repeated the main messages and facts from the information material.

The **first group session** asked the participants to discuss proposals one to five, that focus on climate policy and the role of CDR. They were given one hour to discuss these proposals. The platform provides video and audio to the participants; it also provides a structure to the discussion by showing the participants the proposals they are intended to discuss. The participants can see the proposal they are currently discussing and the suggested arguments against and in favour of it. The platform is programmed to help the group spend an equal amount of time on each proposal and introduce a new proposal when appropriate. The participants can also propose to move forward on the agenda if a majority supports the proposal, the platform introduces the next topic. Participants use a button to request to speak, and the platform automatically creates a list of speakers. Speaking time for each turn is limited to one minute. The platform automatically nudges passive participants, asking them to request to speak.

After discussing the first set of proposals the **participants are asked to formulate questions**. The groups are given the opportunity to discuss the questions proposed and time to rephrase them. The participants in a group can vote on the questions that they would like to be asked. The groups typically formulated between 2 and 6 questions. Although the platform only allows them to vote forward two top questions from each group, the time set aside for the plenaries allowed us to ask all of the questions formulated by the groups to the experts. The participants could also formulate questions during the plenary on a chat, this was only visible to the moderator and the experts. Most on the questions from the chat was also discussed by the experts.

These questions are then used as the content for a **plenary session**, where experts on these topics will discuss and answer the questions. The experts were invited based on their academic qualification, their good communication skills and their experience with participating in public debates. A list of the experts that participated is provided below.

The first plenary session lasted for 45 minutes and focused on the question that were formulated in the groups based on proposal 1 to 5. After the first plenary there was **a one-hour lunch break**. Participants then logged on again and discussed proposal 6 to 12 that focused on the possible deployment of NETs. The **second group discussion** followed the same format as the first. It started with a short 4-minute introductory video that repeated the relevant main message from the information material. Then followed a discussion on the seven proposals from the information material. The second group discussion lasted for 75 minutes and was followed by a one hour long plenary session. At the end of the **second plenary session** participants were asked to answer a **second survey**. This survey was identical to the first apart from a few items to measure how they evaluated the deliberative event.

This is a pretest/posttest **control group design**, allowing for difference-in-difference analysis of attitudinal changes among the participants. In this design the information material and the deliberative event (step 2 and 3) also serve as an experimental treatment. This allows us to measure if, and how, the information and deliberation changes the participants opinion on the survey items. In order to establish that any changes in the respondents' attitudes come from the information material and/or the discussions they have taken part in during the deliberation, their responses are compared to a control group that has not received the information material and that has not discussed the proposals. Instead, the control group discussed different policy proposals on an entirely different topic, the use of artificial intelligence in public sector decision making (AI). Both groups responded to the same survey with questions about AI and NETs.

Since both groups answered questions about both topics but only discussed one of them, they serve as control groups for each other.

Surveys were conducted with Qualtrics survey software, administered by email to the participants. Data from the June and September event is pooled. The deliberative event produced three types of data: Group discussions that are recorded, written questions from the groups to the plenaries and recording of the plenaries.

Because of the short period of time between the September event and the deadline for this report, we mainly base our analysis on the qualitative analysis of the discussions that took place in June. The impression from the discussion that took place in September is that they followed the same pattern as in June event. Data from both events were recorded. Data from the group discussions in June has been transcribed. This material has been analysed with NVIVO software. The group discussions are, to some extent, pre-structured by the proposals and arguments presented in the information material. Proposals and arguments were also repeated on the deliberative platform and thus visible for the participants while discussing. This setup shaped the arguments voiced by participants in the groups. However, the participants were free to choose which arguments to take up, which ones to ignore and what other arguments to make. The questions they formulated for the experts also indicate topics of importance and concern. In our qualitative analysis of group discussion data, we take the exogenous structure of the group discussion into account and focus on the topics and arguments that participants engaged with the most.

V. List of experts that participated in the plenary sessions

Dankel, Dorothy Jane
Associate professor at Department of Biological Sciences, University of Bergen. PhD (2009) in Fisheries management, several research projects related to biological, scientific ethical complexity. Active in the Norwegian public debate on several issues, including the social aspects of technology application and risk management. Participated at plenary in June

Drange, Helge
Professor at Geophysical institute, University of Bergen. PhD (1994) in biogeochemical oceanography, leader of several climate research projects and networks the last decades. Very active in the Norwegian public debate, appointed member of several governmental reports on both climate change policy and Ocean policy. Participated at plenary in June

Lauvset, Siv Kari
Senior Research at NORCE - Norwegian Research Centre. PhD (2011) in chemical oceanography, several research projects on the carbon cycle in the oceans and ocean acidification. Participant in the Global Carbon Budget initiative. Participated at plenary in September.

Olsen, Are
Professor at Geophysical institute, University of Bergen. PhD in chemical oceanography, several research projects on the carbon cycle in the oceans and ocean acidification. Long and varied experience in public outreach activities. Participated at plenary in September.

Mørk, Martine
Advisor at Zero, a Norwegian environmental organization, working with implementation of negative emission technologies. Master thesis from Norwegian University of Life Sciences (NMBU). The thesis discusses CDR and its implantation in Norwegian climate policy. Long experience in media and public debates on climate policies and CDR. Participated at plenary in June and September.

Røyne, Anja
Senior Lecturer at the Faculty of Mathematics and Natural Sciences, University of Oslo. PhD in Physics (2011). Very active on science communication through various blogs, podcasts and publications. Won an award for her work on popularizing science in 2018. Published a popular science book on the role of CDR in 2020. Participated at plenary in June and September.

VI. English translation of Norwegian language survey

Introduction

In this survey you will be asked questions about climate change and methods for removing carbon dioxide (CO_2) from the air, as well as some background questions about you.
In addition, you will be asked questions about the use of artificial intelligence in administration. You do this because another group will be discussing these questions on the same weekend, and your answers will be compared with theirs.
The survey is part of a research project led by NORCE - Norwegian Research Center, in collaboration with the University of Bergen and Stanford University. There are no right or wrong answers. We are looking for the opinions of the citizens of Norway.
All responses are anonymised.
Please note that it is not possible to go back in the survey to change answers.
Good luck!

Climate change and methods to remove carbon dioxide (CO_2) from the air

We humans cause global warming when we burn coal, oil and gas to produce goods, when we travel, when we cut down forests and when we produce food. This leads to emissions of greenhouse gases, especially carbon dioxide (often abbreviated to CO_2), which accumulates in the air.
The more greenhouse gases in the air, the stronger the so-called greenhouse effect, which warms the earth and changes the climate. To avoid even more warming, we must stop emitting these gases and switch to renewable energy such as hydropower, wind power and solar power. In addition, we can take CO_2 out of the air.
Taking carbon dioxide out of the air has not yet been tried on a large scale. But it may be necessary to meet the goal of limiting global warming to 1.5 degrees Celsius this century. Removing carbon dioxide from the air can have different effects on nature and society, depending on the technology. This is the reason why this research project wants to find out what people in Norway - such as you - think about different methods of removing CO_2 from the air.
Now we will present some ways of removing carbon dioxide (CO_2) from the air. We present five methods that use plants or crushed stone. They can be carried out either on land or in the sea.
We want you to tell us what you think about each of these five methods. You will also have the opportunity to say in your own words what you think about the methods after they have all been presented.

Methods that use plants - either on land or in the sea

Plants, whether on land or in the sea, absorb carbon dioxide (CO_2) naturally from the air as they grow. In order to remove CO_2 from the air, it is possible to plant crops and use them to create bioenergy which can in turn be used for electricity or heating.
When bioenergy is used, CO_2 will normally be released back into the air. To avoid this and rather remove CO_2 permanently from the air, we can capture it and store it in cavities deep underground, for example in empty oil and gas fields. This method is called bioenergy with carbon capture and storage (BECCS). In theory, CO_2 can leak from the storage location. This would have no immediate effects on people's health and safety at the storage site, but the leaked CO_2 would escape and have a negative effect on the climate. Storing CO_2 has been used on a smaller scale for many decades in the oil industry. Methods have therefore been established to select storage locations where the risk of leaks is small.
A first method is to grow plants on land for bioenergy. This can take up large agricultural areas and may require more water and fertiliser, which could lead to conflicts with food production and with the protection of forests and natural diversity.

Question 1: To what extent are you positive or negative about bioenergy with carbon capture and storage to remove CO_2 from the air, when the plants used are grown on land?

a) Very negative
b) Somewhat negative
c) Somewhat positive
d) Very positive
e) No opinion
f) Don't know

An alternative method is to grow macroalgae in the sea and use this for bioenergy with carbon capture and storage. Agricultural land will then be saved, but the areas where macroalgae production takes place will no longer be able to be used for fishing or shipping. The macroalgae farms can take away nutrients from natural ecosystems.

Question 2: To what extent are you positive or negative about bioenergy with carbon capture and storage to remove CO_2 from the air, when the plants used are grown in the sea?

a) Very negative
b) Somewhat negative
c) Somewhat positive
d) Very positive
e) No opinion
f) Don't know

A final method based on plants:
It is also possible to permanently remove carbon dioxide from the air by sinking macroalgae to the seabed. This can be done instead of using macroalgae from the farms for bioenergy with carbon capture and storage.
Parts of the collected carbon would then remain there for a long time, but how much of the carbon, and for how long, is still uncertain. In areas of the open sea, it would be easier to sink seaweed rather than transport it to land to produce energy. At the same time, it would also be more difficult to set up and look after the plantations out at sea.

Question 3: To what extent are you positive or negative about sinking cultivated macroalgae to the seabed to remove $CO_2$from the air?

a) Very negative
b) Somewhat negative
c) Somewhat positive
d) Very positive
e) No opinion
f) Don't know

Methods that use crushed stone - on land or at sea
When rock weathers, it reacts with the greenhouse gas carbon dioxide in the air, binding it permanently in the soil or in water carried to the sea by groundwater and rivers. Natural weathering breaks down rocks and slowly dissolves them. It can be caused, for example, by changes in temperature and water currents.
We will be able to speed up weathering and remove more CO_2 from the air by grinding up special types of rock, such as silicates, and spreading it over fields and soils.
This can be good if the soil is nutrient-poor, and can make the sea less acidic. Less acidity in the sea could help organisms that form shells and live in the sea – for example corals – and which are now threatened. But it is important to make sure that the stone dust does not contain dangerous levels of

heavy metals. Stone and gravel must be obtained from quarries, and new quarries must be created. Grinding and grinding stone and gravel requires a lot of energy.

Question 4: To what extent are you positive or negative about spreading ground stone on fields and fields, to remove CO_2 from the air?

a) Very negative
b) Somewhat negative
c) Somewhat positive
d) Very positive
e) No opinion
f) Don't know

It is also possible to remove carbon dioxide from the air using a similar method in the ocean.
Water naturally absorbs CO_2 from the air at the sea surface, and stores it permanently in the water. We will be able to speed up this process, and remove more CO_2 from the air, by grinding up special types of rock and spreading it in the sea.
The stone dust also makes the water less acidic. Man-made emissions have made the ocean more acidic and therefore threaten marine animals that depend on building shells, such as coral reefs. Stone dust will be able to counteract such ocean acidification.
Stone and gravel must be obtained from quarries, and new quarries must be created. Grinding and grinding stone and gravel requires a lot of energy. It is still unknown what the effect on marine animals and marine plants would be of spreading such rock dust in the sea.
Question 5: To what extent are you positive or negative about spreading stone dust in the sea to remove CO_2 from the air?

a) Very negative
b) Somewhat negative
c) Somewhat positive
d) Very positive
e) No opinion
f) Don't know

Question 6: Based on what you know so far, do you think Norway should work actively to remove carbon dioxide (CO_2) from the air?

a) Yes
b) No
c) Don't know

Question 7: All these methods that remove carbon dioxide from the air are fairly new. Before reading about them in this survey, had you ever heard of methods being developed whose main purpose was to remove carbon dioxide from the air?

a) No, I had never heard of it
b) Yes, I had heard a bit about it
c) Yes, I had heard a lot about it

Question 8: To what extent do you agree or disagree with the following statement?

1. I believe that the production of bioenergy (burning plant material) in combination with carbon capture and storage will be good for the climate.
2. I am concerned about the consequences that the cultivation of macroalgae may have on the marine environment.
3. I believe that the cultivation of macroalgae is an opportunity to create new jobs.
4. I believe that spreading stone dust in the sea could be good for the environment in the sea.

a) Strongly disagree
b) Disagree
c) Somewhat disagree
d) Somewhat agree
e) Agree
f) Strongly agree

g) No opinion h) Don't know

Question 9: Please read the following statement and indicate whether or not this is of concern to you.

1. Methods to remove CO_2 from the air can lead to further pollution of the sea
2. Spreading rock dust on fields and fields can do more harm than good
3. Growing plants on land can lead to an increase in food prices

a) Not concerned at all b) Not concerned c) Somewhat concerned
d) Somewhat concerned e) Concerned f) Very concerned
g) No opinion h) Don't know

Question 10: To what extent do you agree or disagree with the following statement?

1. We have a moral responsibility to remove CO_2 from the air.
2. Removing CO_2 from the air is not a solution, just a short-term plaster on the wound.
3. If we use the methods mentioned here to remove CO_2 from the air, it will give us less motivation to reduce CO_2 emissions.
4. I think we should use natural processes to combat climate change

a) Strongly disagree b) Disagree c) Somewhat disagree
d) Somewhat agree e) Agree f) Strongly agree
g) No opinion h) Don't know

Question 11: To what extent do you agree or disagree with the following statement?

1. Large plantations of macroalgae are unnatural.
2. The spread of stone dust disturbs the order of nature.
3. Enhanced weathering is just a natural process.
4. Modern agriculture tampers with nature.

a) Strongly disagree b) Disagree c) Somewhat disagree
d) Somewhat agree e) Agree f) Strongly agree
g) No opinion h) Don't know

Question 12: How concerned are you about climate change?

a) Not worried at all b) A little worried c) Somewhat worried
d) Concerned e) Very worried f) No opinion
g) Don't know

Question 13: To what extent do you agree or disagree with the following statement?

1. Technological innovations will solve the climate problems.
2. I feel morally obliged to reduce my emissions.

a) Strongly disagree b) Disagree c) Somewhat disagree
d) Somewhat agree e) Agree f) Strongly agree
g) No opinion h) Don't know

Question 14: Norway aims to reduce greenhouse gas emissions to prevent harmful climate change. In order to achieve the goal of reducing emissions, a number of measures have been initiated. Overall, what do you think of the efforts being made to reduce greenhouse gas emissions in Norway?

a) The effort is far too b) The effort is too small c) The effort is a little too

small
d) The effort is appropriate
e) The effort is a little too big
f) The effort is too great
g) The effort is far too great

Question 15: To what extent do you agree or disagree with the following statement?

1. People who work for technological solutions to environmental problems underestimate the risks.
2. People who say we shouldn't tamper with nature are naive.
3. Humans have no right to tamper with the natural environment.
4. I would prefer to live in a world where people leave nature alone.
5. Changing nature can lead to the downfall of humanity.

a) Strongly disagree
b) Disagree
c) Somewhat disagree
d) Somewhat agree
e) Agree
f) Strongly agree
g) No opinion
h) Don't know

[the following questions only appeared in survey 1]

Question 16: What is your highest completed education? If you have several educations at the same level, choose the one that is most relevant to you.

a) No completed education
b) Primary school level
c) Secondary school level
d) Vocational school level (includes educations that are based on upper secondary school, but which are not approved as university and college education)
e) University and college level, up to 4 years
f) University and college level, more than 4 years (includes research training)
g) Other

Question 17: Which party would you vote for if there were a parliamentary election tomorrow?

a) Fremskrittspartiet
b) Høyre
c) Venstre
d) Kristelig Folkeparti
e) Miljøpartiet de grønne
f) Senterpartiet
g) Arbeiderpartiet
h) Sosialistisk Venstreparti
i) Rødt
j) Others
k) I am not eligible to vote
l) I would not vote

Question 18: How much trust or distrust do you have in scientists?

a) Very high trust
b) High trust
c) A little trust
d) Neither trust nor distrust
e) A little mistrust
f) High mistrust
g) Very high mistrust
h) Don't know

Question 19: In politics, people often talk about the "left side" and the "right side". Below is a scale where 0 represents those who are on the far left politically, and 10 represents those who are on the far right politically. How would you place yourself on such a scale?

a) 0 Left…………..10 Right
b) Don't know

[the following questions only appeared in survey 2]

Question 20: You answered a survey on the same topic a little while ago. Have you heard anything more about methods to remove CO_2 from the air after this?

a) No, I have not heard anything about this afterwards
b) Yes, I have heard a bit about this afterwards
c) Yes, I have heard a lot about this afterwards

Question 21: The idea of removing carbon dioxide from the air to combat climate change affects my feelings about climate change in the way that:

a) I find it much more frightening
b) I find it more frightening
c) I think it is neither more nor less frightening
d) I find it less frightening
e) I find it much less frightening

Finally, we would like to ask a few questions about your experience of the event you have taken part in.

Question 22: On a scale of 0 to 10, where 0 is "waste of time," 10 is "extremely valuable," and 5 is right in the middle, how valuable was each of the following sections in helping you clarify your views on the issues?

1. The smaller group discussions
2. The information material
3. The plenary discussions
4. The event as a whole

a) 0 Waste of time ……………10 Extremely valuable
b) Haven't thought about it

Question 23: And, to what extent do you agree or disagree with the following statements?

1. Everyone had the opportunity to participate in the discussion
2. The members of my group participated relatively equally in the discussions
3. The technical arrangement ensured that conflicting arguments were considered
4. The important aspects of the cases were covered in the group discussions
5. I learned a lot about people who are different from me - about what they and their lives are like

a) Strongly disagree
b) Somewhat disagree
c) Neither agree nor disagree
d) Somewhat agree
e) Strongly agree
f) Haven't thought about it

Question 24: Do you feel more certain or more uncertain about your views on different methods of removing CO_2 from the air after you participated in the deliberation?

a) More uncertain
b) About the same
c) More secure

Question 25: If the politicians asked your deliberation group about their views on various methods of removing CO_2 from the air, to what extent would you trust or distrust your group's assessment of this topic?

a) Great trust
b) Some trust
c) Some mistrust
d) Great mistrust

Question 26: While you were discussing methods to remove CO_2 from the air, there was another group of people like you who were discussing the use of artificial intelligence in management. If the politicians asked this group about their views on the topic they were discussing, to what extent would you trust or distrust the group's assessment

a) Great trust
b) Some trust
c) Some mistrust
d) Great mistrust

VII. Information material

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Deliberation on Carbon Dioxide Removal

June 12, 2022

Dear participant!

Welcome to our discussion event (a deliberation) on greenhouse gas emissions and different methods for carbon dioxide removal (CDR) from the air. This deliberation is organized by the research institute NORCE – Norwegian Research Centre in collaboration with Stanford University in the United States.

At the mini public on **Sunday, June 12, at 10:00 to 15:00**, you will discuss with the other participants and provide us with your views on removing carbon dioxide from the air and different methods to do this.

The discussion will take place digitally, and you will receive a link to the meeting room in advance. Along with the link, you will also receive practical information about the implementation of the event and a schedule for the day. We use a digital solution that should be suitable for everyone and that does not require technical expertise. However, it is an advantage if you have access to a PC with a microphone and speaker.

We recommend that you read the information material carefully. It provides a short introduction to the topic we will discuss. It also contains a number of concrete proposals to be discussed during the event on June 12. During the event, experts with relevant expertise on the topics we discuss will also participate. You will have the opportunity to ask them questions that arise when you read the information material and questions that come up during the group discussions.

We will start out by explaining the greenhouse effect that causes climate change and some of its impacts on humans and the environment. This is followed by what can be done to reduce greenhouse gas emissions and what Norway's role is. We introduce the idea to remove CO_2 from the air to offset emissions and counteract the impact of CO_2 emissions in the past. Then we present four specific methods for removing CO_2 from the air that could be used in Norway. Finally, you will find twelve concrete proposals that you will discuss in groups on June 12. Some of the words in this information material might sound unfamiliar to you. We therefore include a ↗**glossary** on page 11 and 12 that explains the most important words.

The aim of the discussion is to hear people's individual views after having learned about the relevant issues and discussed pros and cons in the group. We would like that you introduce arguments to the discussion that you think are important. Our research group aims to provide balanced information, but it is not intended to be complete. It is also not our aim to cover all topics that might be relevant for the discussion about the different CDR approaches. However, the information provides a good start for discussing the different approaches. The participants are *not* asked to make a joint statement at the end of the day.

We hope that you will enjoy being part of the discussion on June 12 and look forward to hearing more about your thoughts on this topic.

Best regards

Jon Harald Kaspersen
Executive Director NORCE Health and Society

Gisle Andersen
Project Leader

Keeping global warming below 1.5°C:
How can Norway stop adding more ↗greenhouse gases to the atmosphere in the future?

Climate change and its effects
In the ↗Paris Agreement, Norway, together with many other countries, has set the goal to keep global warming below 1.5 degree Celsius (1.5°C) by the year 2100.

Since the beginning of the industrialization, the ↗average global surface air temperature has risen by about 1.2°C. This global warming is caused by high emissions of greenhouse gases such as carbon dioxide (CO_2) or methane. Greenhouse gases are, for example, released when coal, oil and gas are burnt, forests are cleared, or when ruminants like cows digest their food. This leads to a strong increase of greenhouse gases in the atmosphere, i.e., the air around us.

If we do not significantly reduce greenhouse gas emissions, the average global temperature could rise by about 2.0–3.6°C or more by 2100 compared to pre-industrial time. An increase of the average temperature by 1.5°C or more will have severe consequences. The more greenhouse gases are emitted, the more it will rise. Figure 1 illustrates the increase in risks and impacts on humans, animals, plants, and infrastructure as average temperatures rise.

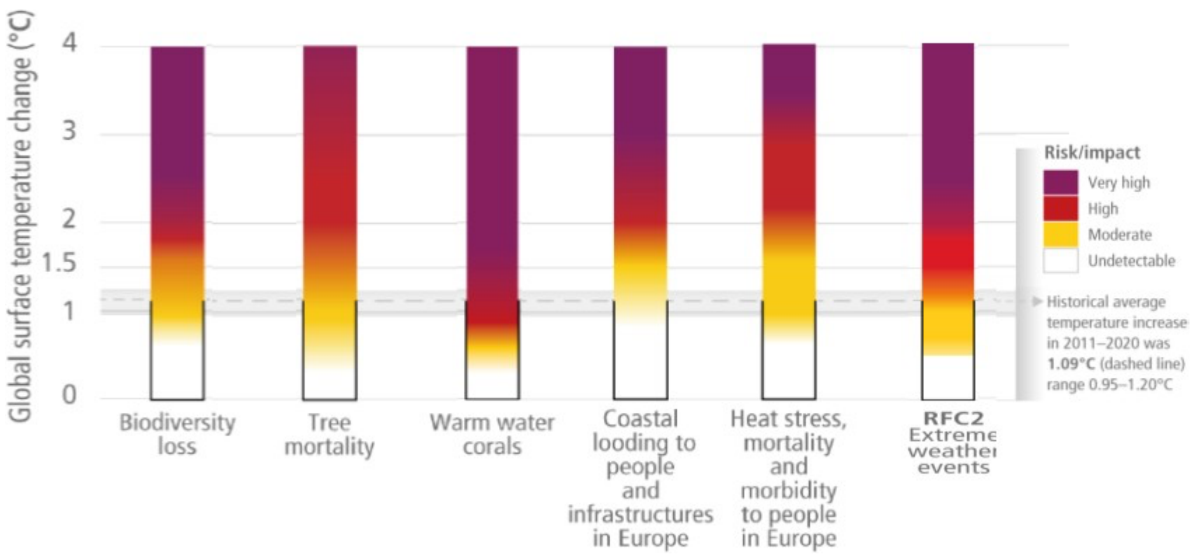


Figure 1.
Examples for the impacts on humans, animals, plants, and infrastructure such as roads, bridges, energy generation, or water supply, at various levels of temperature increase; Adapted figure from IPCC (2022). The figure illustrates how the risk of significant negative consequences is assumed to increase significantly if the global temperature increase is more than 1.5 degrees. The description of the consequences is described for the whole earth together.

At 1.5°C warming we will see more of the following impacts:

- Heat waves will last longer, be warmer and occur in more regions. This can cause droughts, crop failures and shortfalls in water supply. The heat stress can increase mortality.
- Heavy precipitation (rain, snow, or hail) events will occur more frequently. This can lead to floods and landslides.
- Glaciers and sea ice will continue to shrink; this severely threatens ecosystems and will cause biodiversity loss.
- A large share of warm water corrals will disappear due to rising water temperatures and ↗ocean acidification. This will affect the species that depend on the coral reefs and their survival.
- The sea level will rise sharply which endangers coastal areas. This is a danger for many of the world's most populous cities and, more locally, for the coastal areas in Norway.

Decrease emissions as much as possible
To limit global warming to 1.5°C, we should decrease the emissions strongly in the coming years and they should become net zero by the mid-century. Net zero refers to the balance between the amount of greenhouse gases emitted and the amount removed from the air. We reach net zero emissions of CO_2 when the amount of carbon dioxide we emit is no more than the amount removed. In sectors such as transportation, industry, and housing energy supply can be switched to renewable energy like wind, solar, and hydro power so that the emissions are significantly decreased. The Norwegian government has pledged to reach net zero by 2050, and there is political agreement to achieve this goal.

Box 1. Carbon Capture and Storage (CCS) – geological storage of carbon dioxide (CO_2)

With CCS, carbon dioxide is captured during a production process before it can escape into the air. The carbon dioxide is then stored deep underground in porous rock formations. These are the same type of rock formations that create oil and gas fields. There are therefore many suitable storage locations under the seabed in the North Sea. This is also called geological storage. As long as stored carbon dioxide is not released into the air, it cannot add to the greenhouse effect anymore.

In suitable storage locations there is a low risk of carbon dioxide leaking into the atmosphere. Chemical processes in the bedrock also mean that the risk of emissions is reduced over time, for example by incorporating CO_2 into new minerals. Should the carbon dioxide leak, there is no immediate health risk for humans and animals, but it will contribute to climate change again.

The underground storage of carbon dioxide has been used for more than 30 years in the oil and gas industry. Norway plans to store carbon dioxide under the seabed in the North Sea. The project is called Northern Lights. The project has a storage capacity of 1.5 million tons of carbon dioxide per year. From 2025, the plan is for 0.8 million tons to be captured at the cement factory Norcem in Brevik and the waste incineration site Fortum outside Oslo, and then stored under the North Sea.

Residual emissions

Certain products that we need are produced in ways that cannot be made completely emission-free. Examples are cement, chemical industry, and agriculture. These industrial processes lead to so-called **residual emissions**. In Norway, annual residual emissions are estimated at around 22 million tons (Mt)↗CO_2 equivalents in 2050. Total emissions in Norway in 2021 were around 50 Mt CO_2 equivalents[1]. About half of the residual emissions can be captured directly before the gases are released into the air, and stored underground using carbon capture and storage (CCS) technology (for more information, see Box 1)

Other residual emissions – approx. 11 Mt CO_2-eq. per year by 2050 in Norway – are not possible to capture before they are released into the air. Examples of this can be found in animal husbandry or plowing and fertilizing fields. For emissions that cannot be avoided, carbon dioxide should be simultaneously removed from the air as a counterbalance to achieve **net zero emissions** (see illustration in figure 2).

Unless we manage to reduce emissions quickly, net negative emissions will be needed to limit global warming to 1.5°C by the end of the century[2]. **Net negative emissions** means that more carbon dioxide is removed from the air than what is emitted. This way, the amount of carbon dioxide in the atmosphere will decrease and the greenhouse effect will slowly be reduced.

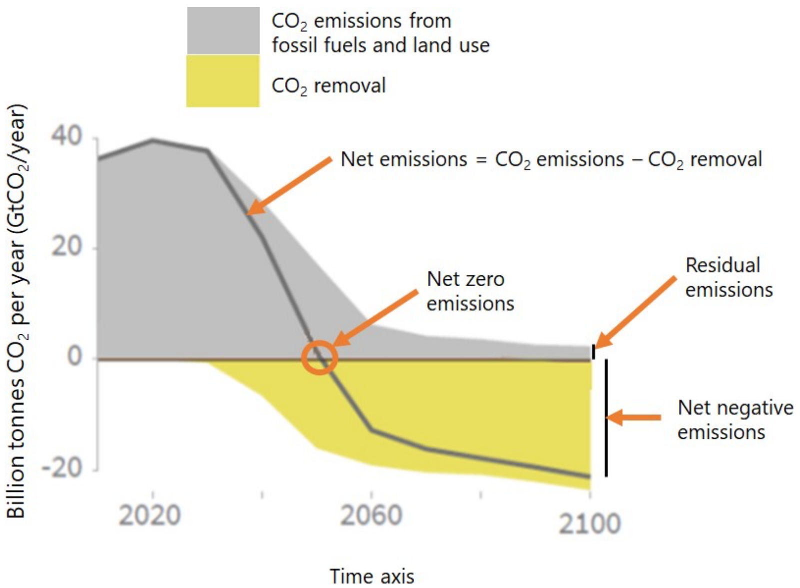
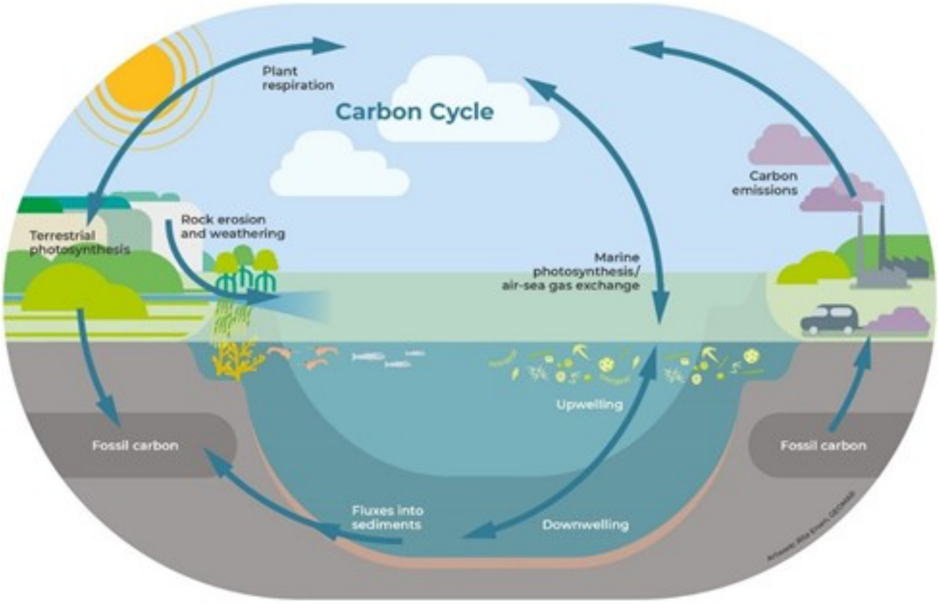


Figure 2.
*Illustration of **net emissions**, **net zero emissions**, **residual emissions,** and **net negative emissions**. The figure is adopted from the UN climate panel's report from 2018 and adapted. It illustrates the relationship between net emissions, net zero emissions, residual emissions and net negative emissions worldwide. The figure shows a possible development for the rest of this century, where emissions fall rapidly towards 2050, but where there will still be a need for negative emission technologies to reach the 1.5°C target.*

[1] DNV (2021): *Energy Transition Norway 2021*. https://www.dnv.com/Publications/energy-transition-norway-2021-212201.
[2] Intergovernmental Panel on Climate Change (2022). *Climate Change 2022: Mitigation of Climate Change*. Summary for Policymakers. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

Removing CO_2 from the air
In nature, there are biological and chemical processes, like photosynthesis or weathering, that filter carbon dioxide from the air and store it as carbon in plants, soils, rocks, and the ocean. Other processes, like plant respiration or decay, and the burning of fossil fuels release carbon into the air in the form of carbon dioxide. The movement of carbon between air, land, and sea is called the carbon cycle.



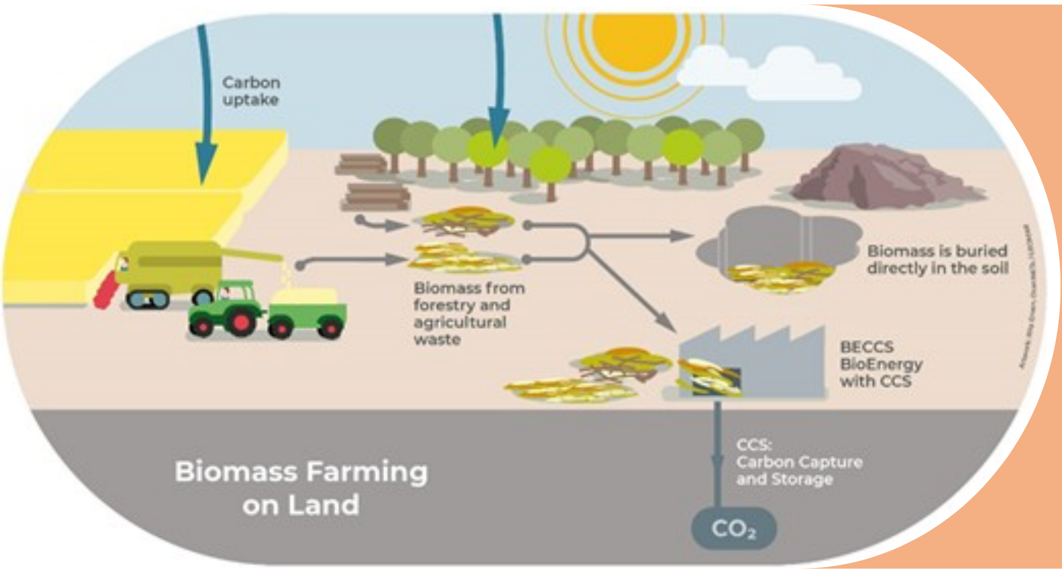
During our deliberation we will discuss four ways to remove CO_2 from the air by enhancing these biological and chemical processes on land or in the ocean.

Plants on land or in water absorb carbon dioxide via the biological process of photosynthesis as they grow. The plants store the carbon until they die and decompose again. Then most of the carbon dioxide is released into the air again. We can exploit such biological processes to capture more carbon dioxide. In the deliberation, we will discuss two methods that utilize such biological processes. On land we can grow more biomass (plants), and in the ocean we can grow macroalgae. Both methods can remove more carbon dioxide from the air.

Rocks, such as basalt, react in a **chemical process** with rain and atmospheric carbon dioxide as they erode and weather. This chemical process binds the carbon dioxide and therefore reduces the amount of carbon dioxide in the air. The speed of the weathering process is determined by factors such as temperature, water flow, plants growing on rocks and processes in the soil. The carbon that is captured in such processes is transported over time to the sea with groundwater and river water. Chemical processes that capture carbon dioxide also take place between the **ocean surface** and the air. This process causes the ocean to become more acidic and is often called ↗ocean acidification. Over time, downward currents in the ocean will move this water to the deep ocean where the carbon remains for a long time.

We can exploit such chemical processes to capture more carbon dioxide. In the deliberation, we will discuss two methods that have been proposed to utilize such chemical processes. On land, you can spread rocks (such as basalt) that has been crushed into fine dust on the terrain. The same type of finely crushed rocks can also be spread in the sea. This can also increase the absorption of carbon in the sea and can make the sea less acidic. Both methods can remove more carbon dioxide from the air.

Biomass cultivation on land



Plants take up (absorb) carbon dioxide from the air as they grow. The more plants grow, the more carbon dioxide is absorbed, but the carbon dioxide is released again when the plants decompose or are burnt. One way to remove and store carbon dioxide is to use the plants for bioenergy production. Normally, carbon dioxide is released into the air again when the bioenergy is used. Instead, carbon dioxide can be captured before the greenhouse gas is released using CCS technology (see Box 1). The carbon dioxide can then be permanently stored underground. This method is called bioenergy with carbon capture and storage (BECCS).

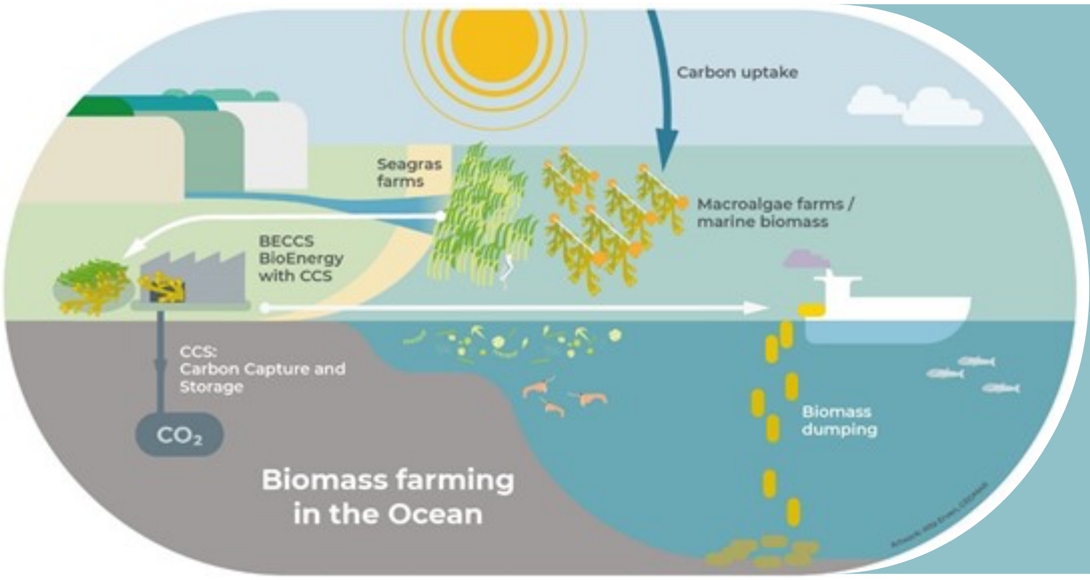
Bioenergy with carbon capture and storage can be used for electricity production or heating. Scenarios suggest that bioenergy could provide up to 20 percent of global energy supply in the future[3], although estimates vary considerably.

Cultivating plants for the production of bioenergy can take up large areas of land and may also require additional water supply and fertilizer. This could increase food prices as the demand for land becomes higher. When monoculture plantations are dominant, when large quantities of pesticides are used, or when natural forests are cut down, biological diversity and natural ecosystems will be harmed. To minimize these negative effects, the cultivation of biomass can be limited to land that is not well suited for food production.

Bioenergy is widely used, but there are still only a few facilities that combine it with CCS. Feasibility depends on the further development of the removal process and the geological storage capacity for carbon dioxide. For example, there are some projects in Sweden that plan to combine BECCS with heat production.

[3] *IEA Bioenergy Annual Report 2021*. https://www.ieabioenergy.com/blog/publications/iea-bioenergy-annual-report-2021/

Macroalgae farming in the ocean



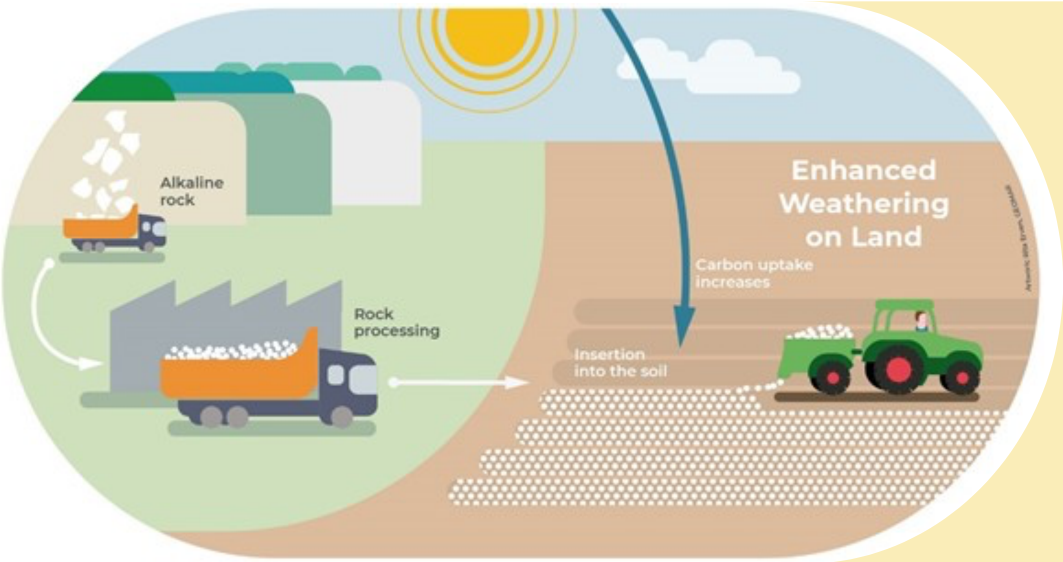
Macroalgae are leafy plants that grow in the sea, either on the seabed in shallow water or floating just below the sea surface. Just like plants on land, macroalgae absorb carbon dioxide as they grow. Macroalgae can be used for bioenergy with carbon capture and storage (BECCS). To absorb even more carbon dioxide, macroalgae can be grown in facilities located in coastal areas, but also in facilities further out in open waters by being attached to ropes. If the macroalgae are not harvested and used for the production of bioenergy, they can also be sunk into the deep sea. It has not yet been tested how long carbon dioxide remains in the deep sea with this method, but scientists assume that some of it will be removed from the air for centuries.

There is a possibility that the cultivation of macroalgae will be able to reduce eutrophication along the coast and thus reduce the pressure on the natural ecosystems. In that case, this can in turn provide protection for the coastline and a habitat for other species.

Although macroalgae can be grown in most marine areas, and the theoretical potential to capture carbon is high, these areas can then not be used for fishing, shipping, or other commercial activities in the ocean. If one uses areas far out to sea, it will be more difficult to install, monitor and maintain facilities for macroalgae. Furthermore, large-scale macroalgae facilities can provide reduced access to nutrients for the plants in the natural ecosystems and lead to the spread of diseases or parasites if foreign types or monocultures are cultivated. In addition, other marine life can become trapped in the ropes to which the plants are attached.

Currently, macroalgae are mainly cultivated for food. The technology to couple bioenergy generation from macroalgae with CCS is still being developed and tested. There is uncertainty related to the environmental impact of sinking large quantities of macroalgae in the deep sea.

Enhanced weathering



Carbon dioxide is captured naturally when silicate rocks, such as basalt, weather. Weathering is a gradual decomposition or dissolution as a result of the physical and chemical impact of natural forces over a long period of time. *Enhanced* weathering aims to accelerate this process. To achieve this, rocks are mined, crushed to powder, and spread on land, usually on agricultural land. From the fields, the dissolved carbon is transported with groundwater and river water to the ocean where it remains permanently. Part of the carbon will be bound chemically to the soil and stored on land.

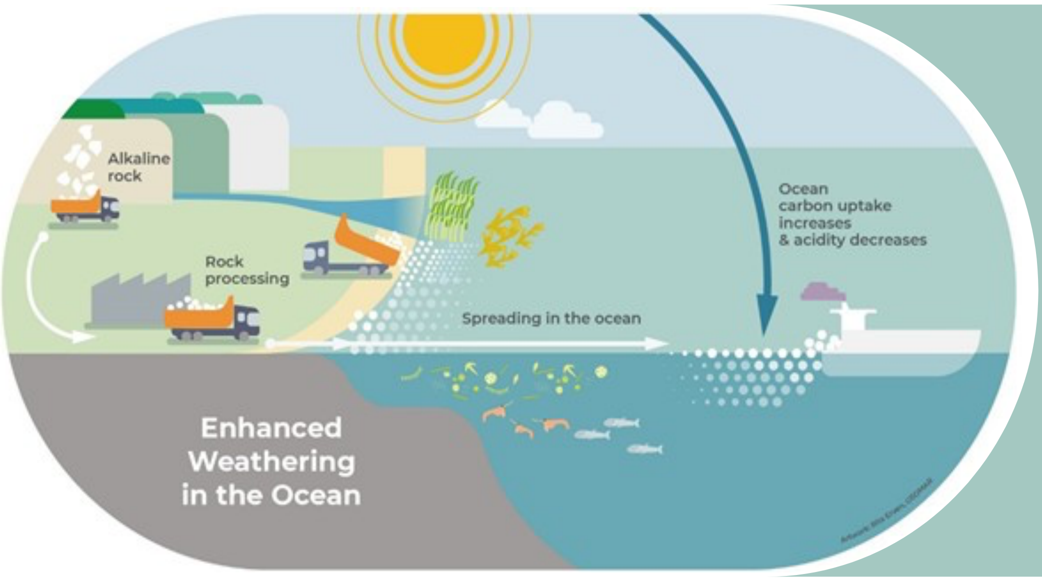
Enhanced weathering is often used on agricultural land because the crushed rock can improve soil conditions, reduce the need for pesticides and improve crops because nutrients are added. Furthermore, minerals in the crushed rock can reduce the problem of acidic soil as a result of fertilization and counteract ocean acidification via the runoff to the ocean.

Increased weathering can, however, have a negative impact on the soil's biodiversity at the micro level. It is therefore important to ensure that the rock powder does not contain harmful amounts of heavy metals.

If all the agricultural land in the world and additional forest land was used to achieve the method's full potential, the amount of rock powder needed annually would be comparable to the amount of coal mined each year. Large-scale quarries would have to be established that could have potentially negative consequences for the environment and the landscape. However, it is not only rock that can contribute to increased weathering. Mining waste, cement, ashes, and slag can also be used for the same purpose. Energy is needed to crush rock into powder. Therefore, more renewable energy plants would have to be built so that crushing rock into powder does not contribute to even more emissions of carbon dioxide.

On a small scale, rock powder has long been used on agricultural land to improve soil fertility. Currently, there are small field experiments in countries such as the USA, Malaysia, and Brazil, partly with the aim of improving nutrient-poor soils. Research into effectiveness and potential side effects is still needed to provide more accurate estimates of methods for removing carbon dioxide from the air.

Ocean alkalinity enhancement - Ocean liming



The chemical process behind ocean liming is similar to enhanced weathering on land. Alkaline substances such as ground carbonate and silicate rocks, e.g., limestone or basalt, is spread in coastal areas or in the ocean with the help of ships. As the alkalinity of the upper ocean layer increases, the seawater's capacity to absorb carbon dioxide from the air and store it permanently increases.

Strengthening the ocean's alkalinity also has a positive side effect, it can counteract ocean acidification. Ocean acidification is one of the consequences of higher carbon dioxide content in the air, which in turn leads to a higher absorption of carbon dioxide in the ocean. Ocean liming can mean that dissolved CO_2 in the ocean does not make the sea water as acidic. Ocean acidification harms calcifying marine organisms such as corals and mussels. The rock powder may contain trace metals such as iron, magnesium, cadmium, or nickel. Iron can act as fertilizer and promote algae growth which can stimulate further carbon dioxide capture from the air. However, if cadmium and nickel are released in higher doses, they can be toxic to plants, animals, and small organisms.

The environmental effects of mining and crushing rock to increase the alkalinity in the ocean and of enhanced weathering on land are similar. At full utilization, the required amount of stone will be considerable. If the rock dust is to be spread in the ocean, ships are also needed. Mining and crushing of rock is energy-intensive. The energy should be generated from renewable sources such as solar, wind or hydropower to avoid further emissions from burning fossil fuels. The resources required to implement alkalinity enhancement in the ocean can thus also have an impact on the environment on land. These impacts can be limited if only already available silicate waste from other activities, such as quarrying, is used.

Testing of alkalinity enhancement in the ocean is at an early stage, and it is still unclear how life in the ocean will react to the change in alkalinity and how the process will work. To find out more, research is ongoing. Experiments are for example taking place just outside Bergen, where the environmental consequences of increased alkalinity in closed water pipes submerged in the ocean are being studied.

How much of these methods must be used to compensate Norwegian residual emissions?

- To compensate Norway's 11Mt CO_2 of residual emissions an area about half the size of Rogaland-4400 km² - would have to be used for macroalgae farming.
- About 0.5 Mt of CO_2 could be compensated by using the residues, i.e., manure, food waste and crop residues, that are available in Norway for bioenergy with carbon capture and storage. This is less than 5% of residual emissions.
- About 33 Mt of basalt would have to be spread on Norwegian agricultural soils every year to offset the countries residual emissions.
- For ocean liming, the figures are a little more uncertain, but between 2 and 10 tons of rock powder for every Norwegian must be spread into the ocean each year to compensate for 11 million tons of residual emissions.

Comparison of methods

In the table below, we have compared the four methods. The comparison is based on five main criteria: How much CO_2 the method is believed to be able to remove on a global level (blue bars). Whether the method will create or require energy. How ready or mature the method is (orange bars). How expensive the method is assumed to be ($ tokens). Finally, we have included expected effects the method will have on the environment and society.

Table1. Overview of methods presented

	Biomass cultivation on land with CCS	Macroalgae farming in the ocean with CCS	Enhanced weathering	Ocean liming
Global capture potential per year	■■■■■	■	■■■■	■■■■
Energy	Produces surplus	Produces surplus	Uses energy	Uses energy
[1]Technical readiness	■■■■■■■■■ Ready to deploy	■■■■■■□□□ In development	■■■■□□□□□ Works in laboratory	■■□□□□□□□ The technology concept is defined
[2]Costs per ton of captured CO_2	$ - $$$	$$ - $$$	$ - $$$$	$ - $$$
[3]Effects depend on where, how much, and how the methods are used				
Natural ecosystems & biodiversity	🟡	🟢🟡	🟢🟡	🟢🟡
Ocean acidification	⚪	⚪	🟢	🟢
Soils	🟡	⚪	🟢🟡	⚪
Land use conflicts	🟡	⚪	⚪	⚪
Quarrying and mining	⚪	⚪	🟡	🟡

Explaining the symbols			
■ About 1 Gt CO_2	⚪ No effect	🟢 Potentially positive effects	🟡 Potentially negative effects

[1]One filled square means that basic principles have been observed. Technological maturity is a gradual process. When all nine fields are filled, it means that the technology is fully developed and has been in operation over time.

[2]One $ symbol corresponds to approximately 50 US dollars per ton of CO_2.

[3]Positive effects of reduced climate change have not been taken into account.

Glossary

Biomass
Biomass is the total mass of all living organisms in an area. This can be, for example, plant products (firewood), fertilizer, forest waste (bark, chips) and other biological waste. The material in the biomass was formed in the present, unlike the organic material in fossil energy, which was formed on earth in the distant past.

CO_2-equivalents
It is common to measure greenhouse gas emissions in CO_2 equivalents. The different greenhouse gases work with different strengths. It also varies how long it takes before the strength of the gas is exceeded and no longer provide heating. When converting to a CO_2 equivalent, all such factors are considered, and the global warming potential is calculated in a hundred-year perspective.

Greenhouse gases
A greenhouse gas is a type of gas in the atmosphere that captures heat from the sun, creating the greenhouse effect. Without the greenhouse gases, it would have been very cold on Earth. When there are more greenhouse gases in the air, more of the heat is trapped at the earth's surface. It contributes to the temperature of the earth rising.

Eutrophication
Eutrophication is a process in lakes and other surface water inland, or in the sea, where plant production increases due to an increased supply of nutrients.

Weathering
Weathering is the breakdown of rocks, minerals, soil, and other materials through contact with air, water (ice), temperature fluctuations and biological organisms. Weathering shapes the landscape together with erosion. The main difference between weathering and erosion is where the process takes place. While the weathering crumbles the rocks in place, the eroding forces remove the loose material. The climate and the type of rock are important factors that influence how quickly weathering occurs.

Pre-industrial times
Pre-industrial times are often defined as the period before industrialization gained momentum in the late 18th and early 19th centuries. The years from the early industrial revolution between 1850 and 1900 are used as a benchmark for temperature changes because only small amounts of greenhouse gases had been released into the atmosphere at this time. There are also temperature data from before this period, but they are fewer and less reliable than the period after 1850.

Global warming
A gradual increase in the overall average temperature of the Earth's atmosphere, generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, methane, and other greenhouse gases.

Ocean acidification
Ocean acidification is a term for a change in the ocean's pH level. The ocean gets a lower pH level as a result of an increased amount of carbon dioxide (CO_2) in the atmosphere. This can have consequences for life in the sea, especially for organisms that build shells and shells/skeleton from calcium carbonate.

Monoculture plantations
Monoculture is the cultivation of the same plant species or cultural growth on the same area of land (or ocean) year after year, without alternating with other species or crops. Monoculture plantations are common practice in today's grass and grain cultivation.

The Paris Agreement
The Paris Agreement is an international agreement on climate policy. It was adopted as a legally binding agreement under the framework agreement Climate Convention at the climate summit in Paris on 12 December 2015 (COP21). Practically all UN member states have joined the agreement, including Norway.

Plant respiration
Although plants do not have specialized organs that help them breathe, respiration is still important for maintaining life and giving growth to plants. The process by which cells obtain chemical energy by consuming oxygen and releasing carbon dioxide is called plant respiration. In order to carry out respiration, plant cells require oxygen and a way to get rid of carbon dioxide, just like animal cells.

Silicate rocks
Silicate rocks are the most common rocks in the Earth's crust. They mainly consist of silicate minerals such as feldspar and quartz.

Carbon and carbon dioxide
In Norwegian, we often refer to carbon and carbon dioxide (CO_2) interchangeably. It is still good to be able to distinguish between them.

Carbon is the name of an element, in the same way as oxygen, hydrogen, gold, and copper are elements. Pure carbon occurs in nature as diamonds. Coal consists mainly of carbon. In oil and natural gas, carbon is bound to other elements such as hydrogen. Carbon is also an essential part of almost all living organisms, including us humans.

Carbon dioxide (CO_2) is a gas in which carbon is bound to oxygen. When burning wood, coal or oil, the carbon compounds react with oxygen from the air and form, among other things, the gas CO_2. The same process occurs in humans and animals that breathe in oxygen and convert it into CO_2.

Carbon dioxide makes up over 80% of the annual greenhouse gas emissions in Norway and has a lifespan of several hundred years in the atmosphere.

Proposals that we want the groups to discuss

The introduction of methods to remove carbon dioxide presents us with many issues and questions. To help the groups discuss the topics, we have formulated some specific suggestions that we would like you to consider.

Under each proposal, we have formulated arguments for why it should be done, as well as arguments for why it should not be done. Many of the arguments may be relevant to several of the proposals, however, we have not mentioned an argument more than once. The list of arguments for and against these proposals is also not exhaustive. There are many other considerations that may be relevant and that may be particularly important to you. If you have arguments that are not in the list below, we will encourage you to include them in the group you are participating in. We would love to hear what you think is important!

- Proposal 1 is about whether Norway should aim to achieve the goal of net zero emissions by 2050.
- Proposals 2 to 5 whether we should use methods to remove CO_2 from the air to achieve the goal of net zero emissions
- Proposals 6 to 10 on Norway should use one of the methods involving biomass to remove CO_2 from the air.
- Proposals 11 and 12 on using one of the methods involving weathering or sea liming to remove CO_2 from the air.

Proposal 1

Norway should reduce emissions as much as possible to reach its 2050 climate target.

Arguments for the proposal	Arguments against the proposal
The costs associated with climate change, such as extreme rainfall, changes in the natural system, floods, and heat waves, will be far higher than the costs of the measures required to achieve the goal.	Such a restructuring process will be too costly and will damage the Norwegian economy and jobs. This is too ambitious and will be a waste of taxpayers' money.
It is the northern areas that will have the largest temperature changes. This could cause major infrastructure such as roads and homes, and vulnerable ecosystems, major damage.	Norway is a prosperous and well-organized country; we will be less affected by climate change than other countries and we have a greater ability to adapt to such changes. Smaller sea ice will provide new opportunities to utilize the natural resources in the northern areas.
When we reduce our emissions, we also reduce the negative consequences of climate change on the lives of nature, society, and ordinary people.	Low-income households will not be able to afford expensive measures such as replacing all white goods or additional insulation of housing. Such a restructuring process can lead to popular resistance, as we have seen that wind turbines on land and tolls have led to.
We do not have time to wait, we have to act now. Norway is a prosperous nation that can afford to make such an investment the best for the future generations.	We need more ambitious goals than this, our really important contribution to the world will be to reduce the production of oil and gas.

Proposal 2

Norway should use methods to remove CO_2 from the atmosphere to compensate for the emissions that we cannot reduce in other ways.

Arguments for the proposal	Arguments against the proposal
IPCC says that the 1.5-degree goal is not possible to achieve without reducing emissions to net zero. For example, it is very difficult to reduce emissions from agriculture to zero. Zero emissions will therefore mean that we will have to remove residual emissions from the air if we actually take the 1.5-degree goal seriously. Methods that remove greenhouse gases from the atmosphere will reduce climate effects on both nature and society.	This diverts attention from emission reduction measures. We must place greater emphasis on reducing our emissions, the problem of residual emissions can largely be solved by stopping using products and services that lead to such emissions. Nature is already out of balance; we should not start fiddling with it even more. This is getting too expensive, who is going to pay for it?

Proposal 3

There is an urgent need to remove CO_2 from the air as soon as possible.

Arguments for the proposal	Arguments against the proposal
It will take time to introduce this type of technology and put in place the necessary infrastructure and regulations. The earlier we start the more we will learn at an early stage. We have no time to lose in the fight against climate change. If we do not start with this now, we will increase the burden that future generations will bear.	In general, we lack a scientific understanding of what we do when we remove CO_2 from the atmosphere. Regardless of the method, we should therefore be careful about removing CO_2 from the atmosphere, this can have consequences we cannot predict or control. Norway is a small country with relatively small emissions. What we do does not matter. When we first use such methods, it will be difficult to stop using them, even if we find that the method has major negative consequences for people or the environment.

Proposal 4

Norway should fund more research on new methods and techniques for removing CO_2 from the air.

Arguments for the proposal	Arguments against the proposal
Climate change is a serious problem that we are struggling to solve, we cannot help but explore methods that can prove absolutely crucial. When we develop and improve the technology needed, we will be able to sell the technology to other countries and help them with the transition. Even though Norway is a small country, what we do can still have great significance.	Following up on such vague ideas is a waste of time and money. We should concentrate on what we already know a little more about, such as reducing emissions. The countries that emit the most greenhouse gases must start this process

Proposal 5

Norway must not only reach the zero-emission target but should use these methods so that Norwegian emissions become net negative.

Arguments for the proposal	Arguments against the proposal
Norway should do this because we have the economy and technology to do it, not all countries have this opportunity. Compared to poorer countries, this gives Norway extra responsibility. Norway has made a rich profit from oil production; we should use these methods to remove CO_2 from the atmosphere and in this way make an extra contribution to the emissions that have been created through the combustion of Norwegian oil and gas in recent decades. IPCC says that net negative emissions may be necessary to reach the 1.5-degree target, especially if we are not able to reduce our emissions quickly enough.	The countries that burned Norwegian oil and gas benefited from the energy this gave them. Each country must take responsibility for its own emissions. The responsibility should be fairly evenly distributed across all countries, it would be wrong for individual countries to bear a great deal of this burden just because they have managed to organize themselves in a good way and make the economy work.

Proposal 6

Norway should use land-based bioenergy with carbon capture and storage (BECCS).

Arguments for the proposal	Arguments against the proposal
IPCC says that this method can be important to reach the 1.5-degree goal. Norway should therefore use this method as much as practically possible, which means that we utilize large areas of land and as much biomass as practically possible. This is one of the few methods to remove CO_2 that we know works and that can be used on a large scale. In any case, bioenergy will be important in replacing fossil fuels with renewable energy. Therefore, it makes sense to combine bioenergy with carbon capture and storage so that we also remove carbon permanently from the air.	The challenge is the relationship between food production and energy production. The proposal could lead to higher food prices because we use scarce resources, such as arable land, water, and fertilizer to produce energy. Most plants grow faster in a warmer climate. The conditions for growing plants that are suitable for bioenergy in Norway are therefore not optimal. Although it may make sense for other countries, it is not worth looking into it for Norway. At the global level, there are too many environmental side effects of large-scale cultivation to bioenergy. Among other things, there is a risk of deforestation and loss of biological diversity due to monocultures. Irrigation will reduce the water available for agriculture and ecosystems, fertilizers needed for such cultivation have negative consequences for soil and groundwater. We should therefore not use this method at all, such environmental consequences could affect us all even if the cultivation does not take place in other countries.

Proposal 7

Norway should expand storage sites for CO_2.

Arguments for the proposal	Arguments against the proposal
In the North Sea, there are geological formations that are very suitable for storing CO_2. Many countries lack the ability to store CO_2 within their national borders. Norway can therefore import biomass to BECCS or already captured CO_2 from abroad. Sweden, for example, has a lot of biomass left over, but no place to store the CO_2 they capture. We can cooperate with Sweden by importing CO_2 from their facilities and storing it in the North Sea. It will be good to build on the experiences we already have from carbon capture and storage (CCS), we have been doing this for more than 30 years. CCS is an essential part of the BECCS process. We should build on this and create a new industry.	This will require us to build an expensive infrastructure for transport and storage. CO_2 can leak during transport or from storage locations. We cannot be sure that CO_2 will be stored forever.

Proposal 8

Limits should be set for the use of biomass for bioenergy and BECCS which ensures that negative consequences for the environment and society are low.

Arguments for the proposal	Arguments against the proposal
We can use biomass that is left over from existing processes, such as food waste, feces, and waste from agriculture. In addition, we can only grow bioenergy plants on land that is unsuitable for food production and where there is currently no forest. We can combine this with sustainable agriculture to ensure that the disadvantages for biodiversity and ecosystems are as low as possible. The procedure also avoids negative consequences such as deforestation and reduced food production.	In Norway, we have very little biomass left over. It will only be enough to capture one per thousand of today's Norwegian emissions. Then it makes no sense for Norway to use resources to build up an infrastructure for BECCS. When commercial interests become involved, this can quickly get out of control, and the negative consequences such facilities have for society and nature will not necessarily be taken into account. Strict restrictions on where we grow plants for bioenergy and which biomass can be used also limit the amount of fossil fuels, we can replace with bioenergy we can produce and thus the amount of CO_2 we can remove

Proposal 9

Norway should grow macroalgae and in <u>coastal</u> areas and use the biomass for BECCS.

Arguments for the proposal	Arguments against the proposal
Norway has a long coastline that is well suited for such facilities. We already have a lot of relevant expertise with fish farms. Macroalgae farming can also create new jobs along the coast. In some areas, this method will give us additional benefits because the macroalgae can absorb excess nutrients and provide an attractive habitat for other species. This can be good for the ocean. This could be a new industry and could provide a basis for us to export the technology to other countries and use it for BECCS worldwide. Norway is already a leader in Europe at CCS. We need something to live on when the oil age ends. The use of macroalgae instead of land-based biomass will lower the pressure on agriculture, food prices and terrestrial ecosystems.	A large-scale investment will be costly and result in emissions from increased shipping traffic. This type of plant will also be able to increase pollution of plastic from nylon ropes and the like. We have already experienced that salmon farms can have significant environmental consequences, monoculture of macroalgae can also prove to have negative consequences for marine life. We know too little about how large-scale cultivation of macroalgae will affect ecosystems along the coast. No one has shown that this method actually works on a large scale. It is wrong that bioenergy from macroalgae will be profitable. This will be an expensive form of energy and cannot compete with what it costs to produce electricity from hydropower. Breeders and energy companies should rather concentrate on what they actually can. The sea may seem infinitely large, but these facilities can quickly come into conflict with the fishing industry, which has been an important part of the Norwegian economy and provided a basis for settlement along the coast for thousands of years.

Proposal 10

Norway should grow macroalgae <u>far out at sea</u> and the biomass should be lowered into the deep sea.

Arguments for the proposal	Arguments against the proposal
The sea is large and there is plenty of space where we can place facilities that are not in the way of anyone. Macroalgae farming can be beneficial for the fishing industry because it creates zones where the fish are protected from fishing. This can help secure fish stocks against overfishing and can become part of Norwegian fisheries management.	It is not easy to set up such facilities far out at sea. It will be expensive and difficult to monitor. And it will result in increased emissions from the ships that will maintain the facilities. It is uncertain how much of the macroalgae will actually sink to the seabed. Some of it will be eaten by fish. It is also uncertain how long CO_2 stored in the biomass actually remains removed from the air. Therefore, it is uncertain how much carbon this method will actually help remove from the air. We have little knowledge about the ecosystems in the deep sea, we should not disturb them by dumping more biomass than what naturally sinks.

Proposal 11

Norwegian authorities should support farmers so that enhanced weathering becomes part of Norwegian agriculture.

Arguments for the proposal

Norway has access to stone that is suitable, and we have plenty of renewable energy to crush it without extra emissions of greenhouse gases.

The method can be good for the soil regardless of how much CO_2 is actually captured. This can in any case increase productivity and reduce the problem of run-off of manure that pollutes watercourses and fjords.

Properly introduced, the method may provide increased income for Norwegian farmers

Arguments against the proposal

Most farms in Norway are small and the landscape is hilly. Enhanced weathering will be more efficient in countries with large agricultural areas and where there is a hot and humid climate.

Mining creates large wounds in the landscape and has negative environmental consequences, like the contamination of soils, water, and the ocean by the materials used for mining.

We should not make special rules that force farmers to do this, they know best what will work in the soil they cultivate.

We should rather use our renewable energy to reduce emissions from industry, we should not waste much energy on this method.

The environmental consequences are too uncertain, for example, can the method have negative consequences for humans?

Proposal 12

Norwegian authorities should fund research on sea liming and closely monitor research on the topic. The method should be introduced as soon as we get promising research results.

Arguments for the proposal

Norway is at the forefront internationally in research on marine life. We should use these knowledge environments, such as the Institute of Marine Research and the Bjerknes Center, to find out if this method is a good idea.

Norway is a coastal nation; we know how the sea works and how we can use it. We also have everything needed, a well-developed maritime industry, access to suitable stone and renewable energy to crush it.

Arguments against the proposal

When we first start spending money on such a method, it quickly becomes so that we will start with this no matter what the researchers find out, although research shows that it is difficult to predict what the global ecological consequences will be far in the future. time.

We must avoid polluting fjords and seas more than we have already done. Promising research results are not enough. Before we can use this method, we need to know much more about what consequences this will have for marine life and fisheries or how much the CO_2 method will actually remove.

We might get into trouble with other countries along the coast like the UK, Denmark, Sweden, or Germany when we run experiments in the sea or even start using ocean liming on a larger scale because we are connected via the ocean.

If we do not pay close attention to the emissions associated with each step in the process, from mining to the spread of the rock, these can, in the worst case, lead to even higher greenhouse gas emissions.