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Blurring societal acceptance by lack of knowledge—insights from a German coastal population study on blue carbon

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Within the context of climate change, coastal vegetated ecosystems have the capacity for long-term carbon storage. Blue carbon refers to such carbon trapped in the oceans and coastal shelf seas. These ecosystems are under anthropogenic pressure and, to help these ecosystems to thrive and realize their carbon storage potentials, interventions require acceptance from society, in general, and adjacent coastal communities, in particular. Through a random street survey along the German coasts in 2022, quantitative and qualitative data were collected from more than 200 participants. A questionnaire comprising 50 open and closed questions was designed to assess the status quo of German coastal residents' norms and values concerning blue carbon ecosystems. Focus was put on nature conservation and climate change perceptions. The survey results reveal that most residents along the German coast valued nature conservation while idealizing nature that is seen as "untouched" by humans. Responses regarding active interventions to improve coastal ecosystem services were diverse. Blue carbon strategies are likely to operate within this area of tension. Most respondents were aware of climate change as a threat to their home region and were in favor of an increase in action against climate change there. The respondents were familiar with CO_2 reduction and avoidance strategies. However, they were less aware of measures to remove atmospheric CO_2 and the potential of storing CO_2 in ecosystems beyond afforestation measures. Due to a lack of knowledge, no consolidated public opinions on blue carbon in coastal vegetated ecosystems could be identified, blurring societal acceptance of blue carbon strategies. While these ecosystems are particularly vulnerable to human disturbance, long-term carbon storage is essential for blue carbon. Therefore, the individual acceptance of interventions from people living in close proximity to intervention sites is key for sustained success. The present article concludes that there are possibilities to co-create knowledge and acceptance as prerequisites for blue carbon interventions to possibly become efficacious.

KEYWORDS

carbon dioxide removal, climate action knowledge, coastal vegetated ecosystems, perception, Germany, Baltic Sea, North Sea

1 Introduction

At the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris in 2015, the global community agreed on limiting global warming to 2°C, preferably 1.5°C above pre-industrial levels. While the identification of a common goal is a big step toward climate action, practical solutions to achieve this goal have not yet been applied sufficiently (IPCC, 2023). A transition toward a fossil-free society, a prerequisite to reaching the Paris Agreement, does not only require new technologies and their deployment but also needs to consider questions on energy production and consumption with their related impacts on the social and physical environment (Feola, 2015; Boudet, 2019). Involving societal actors across scales in the discussions and decisions on solutions is key. Public perceptions and responses can facilitate or hamper climate action as demonstrated, for example, by the resistance against the wind energy industry (Rand and Hoen, 2017). For an understanding of how public opinions and preferences are shaped in the climate change discourse, knowledge of climate change and its communication is key (Fløttum and Gjerstad, 2017). The presence or absence of potential gains and losses, risks, uncertainties, or moral implications in the communicated 'story' helps to explain the success of climate action or resistance against it. New technologies are more easily accepted if they can be associated with known processes. In this case here, however, the new processes are associated with negative experiences, such as fracking (Cox et al., 2022; Westlake et al., 2023) or quests for final storage sites (Braun, 2017; Arning et al., 2019), even if they have little in common technically. This then has a negative effect on the acceptance of the new approaches.

Mainstream political and public discourses on climate action in the 1990s to early 2000s focused on mitigation (reducing emissions). In the late 2000s, adaptation was discussed at a similar rate, as efforts to reduce anthropogenic carbon dioxide (CO_2) did not halt or reverse the global trend of rising emissions and negative climate change impacts became increasingly evident (Görg, 2011; Mercer et al., 2011). Around 2010, as an urgent need to take climate actions to avoid a climate crisis became more prominent, large-scale engineering techniques entered the discourses (Mercer et al., 2011; Oschlies and Klepper, 2017). In light of the Paris Agreement, the Intergovernmental Panel on Climate Change (IPCC) developed recommendations to stay within the agreed 1.5°C to 2°C range. These pathways endeavor to reach net zero emissions by 2050, which includes the utilization of 'negative emissions' or 'carbon dioxide removal' (CDR) to offset hard-to-abate emissions. CDR corresponds to the capture and long-term storage of atmospheric CO_2 and has become part of the discourse (IPCC, 2018). As of today, the need for measures beyond mitigation and adaptation seems indisputable to keep climate change within the range of the Paris Agreement (Gattuso et al., 2018; IPCC, 2018; Carton et al., 2020). However, local to global levels of societal knowledge and acceptance of CDR options are under-researched.

The terms 'climate engineering' or 'geoengineering' can serve as umbrella terms for large-scale engineering techniques, including solar radiation management (SRM) techniques, which aim to lower the global temperature by, e.g., increasing the reflection of sunlight via the injection of sulfate aerosols into the stratosphere. SRM carries potential environmental and social risks (Shepherd, 2009; Ricke et al., 2010). Public and political resistance focused on SRM, and in the public perception, SRM and climate engineering became synonyms (Mercer et al., 2011; Merk et al., 2019). CDR techniques can also be seen as examples of climate engineering but have been less discussed in public. Both options might produce undesired side effects, which "may raise severe ethical, legal, and governance issues" (Oschlies and Klepper, 2017: 128). Within scientific discourses, attempts were made to place CDR in opposition to SRM and climate engineering, arguing that CDR addresses the causes of climate change (anthropogenic CO_2) rather than merely addressing the symptoms (global warming) (Kiehl, 2006; Schellnhuber, 2011). Based on the experiences with SRM, an expectation of public opposition to CDR seems plausible. However, a conclusion that excludes the public from such discourses appears to be premature (Merk et al., 2019). Marginalizing or depoliticizing the discussions on the potential impacts of CDR options on society by only focusing on sociotechnical aspects, in fact, delays the decarbonization of society (Low and Boettcher, 2020). Furthermore, controversy, exchange, and forming of opinions are a means to encourage deliberation and, with this normalization process (Hansson et al., 2022), potentially contribute to accelerating climate action.

Marine CDR options are a relatively new field within the context of CDR, including ocean alkalinization, enhancements of the physical and biological pumps, the utilization of storage sites below seafloors, and blue carbon (Gattuso et al., 2018). Blue carbon refers to atmospheric carbon trapped in the oceans and coastal shelf seas and has been included in IPCC reports since 2019 (IPCC, 2019; Hilmi et al., 2021). As coastal vegetated ecosystems (CVEs), such as mangroves, macroalgae, seagrass meadows, or salt marshes, capture more than half the CO_2 the oceans sequester, they play a critical role within the blue carbon discourse. Management activities of these ecosystems imply interferences with existing CVEs and connect social and ecological systems; therefore, these activities have social, ecological, and spatial impacts that affect adjacent communities. As the carbon captured in CDR projects has to be stored for centuries for such projects to be impactful, societal acceptance is vital. While land-based options are under great pressure from competing land uses (e.g., for afforestation, food, fodder, and biofuels), some suggest that marine nature-based CDR options might be under less pressure (Gattuso et al., 2018). While opposition against SRM and climate engineering is based on attitudes that nature should not be manipulated in such ways (Mercer et al., 2011), few technology-based blue carbon measures are thought to have more positive side effects than negative ones (Hilmi et al., 2021). Blue carbon can be perceived as an ally to create synergies with nature conservation. With the need for sustained climate action at hand, the Federal Government of Germany recently installed an "Action Plan on Nature-based Solutions for Climate and Biodiversity" (BMUV, 2023), aiming to link climate action and nature conservation and taking blue carbon activities into account. Thus, perceptions of German coastal communities on potential blue carbon interventions are highly relevant. However, previous studies on public perception focused on comparing different climate engineering or CDR options, but to the best of our knowledge, blue carbon has not been included in Germany (Merk et al., 2019, 2023) or elsewhere (Corner and Pidgeon, 2015; Carlisle et al., 2020). Furthermore, studies explicitly focusing on coastal residents' realms and their perceptions of marine CDR are missing.

The objective of this article is to analyze coastal residents' perceptions of blue carbon, taking German coastal communities as a case study, to understand drivers of public acceptance and identify barriers and enablers for implementing blue carbon. The identification of people's values and their knowledge of CVEs, climate change, and blue carbon is a prerequisite. Therefore, first, we present a climate research understanding of blue carbon before further discussing the links between values, knowledge, and societal acceptance. Then,

we introduce our survey design and present our results. We identify a lack of basic knowledge regarding CDR and blue carbon in German coastal societies. Accordingly, public opinions have not yet been formed. In consequence, we recommend more public discussion on (marine) CDR and discuss strategies to co-produce climate action knowledge based on shared values to accelerate the forming of opinions, to start and settle controversies, and finally, to be able to decide if or under which circumstances blue carbon interventions might become legitimate climate action options.

2 Coastal vegetated ecosystems, blue carbon, and the German coasts

The IPCC defines that "[a]ll biologically-driven carbon fluxes and storage in marine systems that are amenable to management can be considered as blue carbon. Coastal blue carbon focuses on rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses. These ecosystems have high carbon burial rates on a per unit area basis and accumulate carbon in their soils and sediments" (IPCC, 2019: 680). Blue carbon interventions are measures along the coasts to enhance the potential of CVEs to store carbon. According to the level of intervention, these measures range from protection and conservation to the expansion of areas within or beyond former sizes and the creation of new habitats. As the shape and the scale of interventions are hardly discussed in the literature, global storage potentials are difficult to determine. According to one prominent recent study, the absolute storage potential of CVEs per year might be <2% of current emissions (Hilmi et al., 2021). Nevertheless, CDR technologies such as blue carbon can support compensation for hard-to-abate emissions (Paltsev et al., 2021).

Mangroves grow in tropical or subtropical climates and, similar to salt marshes, thrive in intertidal zones. Most seagrass species prefer shallow waters below tides but can also be exposed to tides. Macroalgae, also referred to as kelp or seaweed, grow best on solid rocks outside of tidal exposures but still need sufficient sunlight. All CVEs have socio-ecological benefits for the local communities. Specifically, mangroves, seagrass meadows, and kelp forests are areas used by fisheries as they serve as nursery habitats for valuable fish and other marine species. Salt marshes are used for pastures and tourism (Friess et al., 2020). As all CVEs protect against coastal erosion and sea level rise by accumulating sediments or slowing down wave energy, they also provide benefits for climate change adaptation (Hilmi et al., 2021). Additionally, CVEs contribute to the health, recreation, and sense of belonging of people (Conroy, 2023). Potential negative impacts on socio-ecological systems include seagrass as breeding grounds for disease carriers (Govers et al., 2017), harmful algae blooms (Gobler et al., 2017), or beach grooming related to increased flotsam.

Due to climate change, coastal development and construction, marine pollution, agriculture and aquaculture, bottom trawling and overfishing, and other intensive landscape and seascape uses, all blue carbon ecosystems suffer (Hilmi et al., 2021). In the last three decades, the global area of mangroves has shrunk to 1.04 million ha from 14.8 million ha (FAO, 2020). Seagrass meadows cover a known area of 1.2 million ha. The exact magnitude of its area loss is still uncertain but is estimated to be 34% in the past 50 years (Telesca et al., 2015). Global figures on macroalgae are rare; an analysis by Krumhansl et al. (2016) concluded a loss of 38% in the last five decades. Salt marshes have shrunk to half their historical size during the last century (Giuliani and Bellucci, 2019). Conservation activities might not only serve CDR intentions but also reduce emissions because "[i]f degraded or lost, coastal blue carbon ecosystems are likely to release most of their carbon back to the atmosphere" (IPCC, 2019: 680).

German coastal waters, from a geopolitical and ecological point of view, encompass coastal areas of the North Sea and Baltic Sea that are in mutual contact with the open sea and are administered under German legislation. The main habitat of kelp in Germany is around the North Sea island of Heligoland. Since 1989, no significant long-term trends in the standing stock have been reported along the mainland shores (Drent et al., 2017). Salt marshes dominate the German North Sea coast, "semi-natural systems that have been constructed for means of land reclamation via conversion of tidal-flat ecosystems during the late 19th and early 20th century" (Mueller et al., 2019: 2). In the present times, they also have other socioeconomic benefits for local communities, including tourism, as a source of feed or fuel, and even for the provision of medicinal remedies (Friess et al., 2020). Their extent of approximately 22,000 ha has been rather stable over the last decades (Esselink et al., 2017). Seagrass meadows in the German shelf sea are traditionally common, but their mapping is classified as incomplete (Röschel et al., 2022). Seagrass coverage seems to have heavily declined along the North Sea coast of Lower Saxony by more than 75% in recent years, from 37.6 km^2 in 2013 to 8.6 km^2 in 2019 (Küfog and Steuwer, 2020) but remain stable along the North Sea coast of Schleswig-Holstein (Dolch et al., 2017). While the reasons for these diverging trends are unknown, eutrophication, hydrodynamics, and ocean warming are commonly discussed as threats (Dolch et al., 2017; Küfog and Steuwer, 2020). The Baltic Sea coast of Germany is home to lush seagrass meadows, which cover a total area of approximately 285 km^2 in up to 8 m depth (Stevenson et al., 2022), but long-term studies to detect trends are absent (Schubert et al., 2015). The uses of seagrass as an environmentally friendly insulating material, a sustainable raw material for packaging material, or a soil conditioner in fields have only recently gained new appeal. The estimated seagrass meadow colonization potential off the coasts of Schleswig-Holstein alone is 450 km^2 (Röschel et al., 2022). However, to what extent the current forms of usage interfere with long-term CO_2 sequestration goals is a societal conflict of interest and a matter of negotiation that needs to be resolved.

In addition to the potential benefits for nature, climate, and eventually humans, marine CDR in general and blue carbon in particular can also be instrumentalized against climate action. The effectiveness, permanence of storage, cost-effectiveness, and governability of most marine CDR approaches, including blue carbon, are abundant with uncertainties (Gattuso et al., 2021; Williamson and Gattuso, 2022). Overselling CDR by building unrealistic expectations has the potential to slow or stop political action and industrial transition (Low and Boettcher, 2020; Boettcher et al., 2021). However, within the academic debates on blue carbon, conserving, restoring, and enhancing coastal vegetation are seen as low-regret measures, providing hardly any disadvantages (Gattuso et al., 2021).

3 Knowledge, values, and acceptance

For collective climate action, social learning creates knowledge of what to do, how to do, and why to do it (Pelling et al., 2008; Berkhout, 2012; Goldberg et al., 2020). Social institutions carry out actions as

routines, which are understood as efficient and appropriate procedures when facing conventional or unconventional situations (Berkhout, 2012). Learning is needed to develop routines and adjust them when adapting to socioecological changes (Pelling et al., 2008). With that in mind, we will introduce different types of knowledge and their meaning for action. Linking types of knowledge with concepts of societal acceptance, we create a robust understanding of prerequisites for climate action and apply it to blue carbon interventions along the German coasts.

As a first approximation, the rationale for an individual action is based on expected outcomes. Within rational thinking, the expectation of a positive outcome or utility as a motivator for action is based on knowledge (Hawthorne and Stanley, 2008). However, attributions that the outcome is positive or useful are based not only on rational facts but also on individual values and perceptions. Society matters, as values are created, adapted, and persist not only on individual levels but also in greater societal contexts (Lepak et al., 2007). In the context of climate action and broader fields of socio-ecological studies, different knowledge claims with unequal qualities regarding action are common (Lauer, 2017). Formal or scientific knowledge is distinguished from local, traditional, or indigenous knowledge. In the context of dissemination—e.g., via formal or informal education or apprenticeship—distinctions between explicit and implicit or tacit knowledge are common. As explicit knowledge, or simply "information," can be transferred by documents (Gorman, 2002), formal education is linked to formal and scientific knowledge. However, on the one hand, as long as information or bites of information are not embedded in social settings, formal knowledge alone has no depth and does not often lead to action. Implicit or tacit knowledge, on the other hand, is based on experience and unfolds as skills and routines gained by the practical contact with facts or events. Hence, tacit, local knowledge is obtained via action and is more likely to create further action. Depending on the context, local knowledge can be synonymous with practical knowledge or action knowledge. However, in climate change contexts, most people lack adequate experience with ongoing and, even more so, with future changes so that local knowledge and skills' adaptation to future challenges is constrained. In this respect, awareness and suitable action require the application of scientific knowledge and its translation into and merging with local knowledge to generate a new type of knowledge, which then is able to foster climate action (Lauer, 2017; Fink et al., 2021). The type of action knowledge co-produced by researchers, policymakers, practitioners, and members of the wider public alike (Kothari and Wathen, 2017) and needed in a transdisciplinary climate change setting is what we refer to as 'climate action knowledge'.

Value systems are cognitive structures that produce meaning and shape desires within individuals and society. Values serve as standards or criteria to guide action, judgment, and choice, among other things (Rokeach, 2000). Most values are shared within human societies. However, priorities and interests may differ between individuals, societies, and cultures and expressions that similarly depend on context and culture; therefore, values can be conflicting (O'Brien, 2009), but values are also changeable and versatile. Context dependencies and social learning are ways to explain existing dynamics and changes in value systems and subsequent actions from individuals and societies. Eventually, the purpose of values can be framed as "to enjoy a fuller life [and to] make an impact […] theoretical sophistication has to be followed by action" (Prilleltensky, 2001: 760). Action, again, can be associated with individuals as well as society. On the individual level, examples of climate action are shifts to renewable energy or the use of public transport. Social action can, on the one hand, imply individual action as civic engagement, e.g., volunteering in social work. On the other hand, social action is associated with building and executing community development or social movements (Morsillo and Prilleltensky, 2007). On a societal level, the latter can lead to social change, e.g., changing forms of regulation or governance by installing climate laws and climate organizations.

Individual and societal acceptance of any measures is based on expectations of possible outcomes and, therefore, is driven by knowledge and values. Acceptance is an act of giving consent to something, which implies a perception of being beneficial or at least adequate (Cohen et al., 2014). It can be expressed actively by support or engagement and—in case of non-acceptance—by active resistance or by passively fatalistic letting it go. Acceptance is likely to increase with enhanced levels of integration and participation. A low level of participation is a one-way communication providing information, whereas mutual flows of communication and rights in decision-making indicate higher levels of integration. High levels of participation and integration can lead to ownership and identifying actions and outcomes (Kumar, 2002), which, in turn, indicate tacit knowledge and acceptance. Technical and economic feasibilities, which might also affect societal acceptance (Wüstenhagen et al., 2007), are beyond the scope of this article.

For measures with spatial impacts—blue carbon actions imply interferences with socioecological coastal environments—acceptance likely differs between general public opinions and adjacent local communities. On the one hand, the installation of measures can be embraced by the general public and yet fail due to local resistance. The phenomenon of "not in my backyard" (NIMBY, see Van der Horst, 2007) has demonstrated in many instances that even generally accepted measures, once they are to be implemented locally, evoke resistance from the locally affected population as soon as they interfere with a home region. On the other hand, measures that are generally disapproved of can thrive with appropriate incentives in local communities (e.g., job generation), whereas neither the general public nor local communities should be understood as a single homogeneous community of interest. However, local welfare (Cohen et al., 2014), in-depth knowledge, and participation are shown to increase acceptance (Segreto et al., 2020). Overall, for lasting and desirable outcomes and acceptance, the societal embeddedness of these actions in norms and values is crucial (Pelling et al., 2008; Goldberg et al., 2020).

4 Street survey—methods

This study consists of a two-part population survey conducted as a random street survey in open public spaces along the German coasts. In March 2022, 132 local residents were interviewed on both coasts of Schleswig-Holstein, and in July 2022, 90 people participated in the same survey on the coast of Lower Saxony. The participants were between 16 and 88 years of age. Compared to the population of the federal states of Schleswig-Holstein and Lower Saxony, most of the age groups in the survey differed <20% from state averages. Only the 16–25-year-old age group was overrepresented by almost 50%, while

the 36–45-year-old age group was underrepresented by 40%. The mean age was 49 years, and 52% of the participants were female, reflecting the states' populations in mean age and gender. Twelve survey locations were chosen to represent the rural and urban coastal populations of Schleswig-Holstein and Lower Saxony as well as the North Sea and Baltic Sea (see Figure 1). Places were selected according to size and infrastructure (more than 1,000 inhabitants and busy public spaces) and represent different administrative districts. Surveys were mainly conducted on the street, in public places, in pedestrian zones, and in front of supermarkets. A question about the place of residence was to be answered with the respective postal code, and an analysis was carried out regarding residency. This information was used to apply a rurality index (Küpper, 2016) to give each place of origin a rurality value based on several indices, such as the density of settlements and the proportion of agriculture and forestry in a municipality or the distance to large centers. At each selected location, 11–24 interviews were conducted. Most of the 222 participants answered all questions, so the sample size is generally between 218 and 222.

The questionnaire included 10 open-ended and 40 closed questions and was structured into four chapters: place attachment and environment, regional climate change, political participation, and sociodemographic data. For the closed questions, the respondents were presented with a Likert scale with options to agree or disagree with given statements using five predefined answers: "yes," "rather yes," "rather no," "no," or "do not know." *Spearman's correlation coefficients* between closed questions were calculated with SPSS. For the interpretation of correlations mentioned in this article, only those correlation coefficients were taken into account, which were statistically significant ($p = 0.01$) and exceeded rather weak relationships ($\rho > 0.2$) (Schober et al., 2018). Open questions provide in-depth insights into people's values, opinions, experiences, and how people draw links between topics.

For each trip, four students were coached, and together with the corresponding author, the mixed-gender group conducted one-on-one surveys. Coaching, taking notes of verbal reactions and non-verbal expressions, and holding reflection sessions twice per day supported the comparability of the survey results independent of the interviewer and interpretations of presented answers. The first question focused on place attachment ("Heimat") and possible threats to it in order to identify values. Then, we asked specific questions about nature and the environment to avoid spillover effects—people's perception of "Heimat" and threats to it should not be biased by the study's focus on nature and climate change. Supported with pictures of the German CVEs (salt marshes, seagrasses, and macroalgae), participants were asked to freely name their associations with these CVEs and to express attitudes in the context of nature conservation topics. In the second part, people could give their views on climate change, negative emission technologies, and the meaning of CVEs in this context. The third part focused on political dimensions; one's willingness to

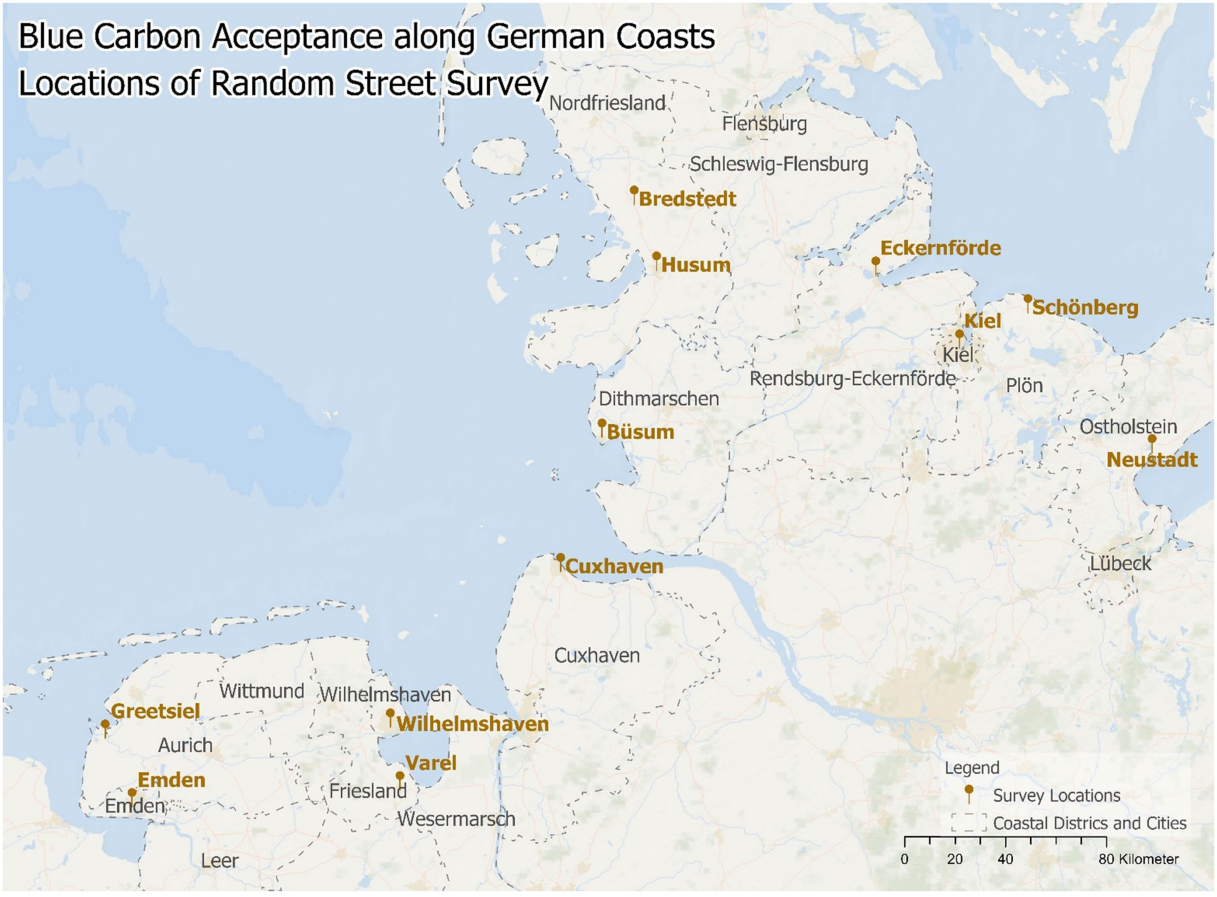

FIGURE 1
Map of survey locations.

voluntarily engage in decision-making processes shaping the region is this article's focal point. The objective was to identify patterns and correlations between local identity, knowledge, and values in the context of potential blue carbon climate interventions.

5 Results

5.1 Values and threats, place attachment, and nature

To set a base on what people value, the first open questions were "What is typical for your home ("Heimat")?" and "What is nature for you?" Both questions were answered by 220 and 221 out of the 222 participants, respectively, and the characteristics respondents refer to when asked about home and nature overlap, as landscape elements and physical environmental features dominated both answers. "Home" was associated with coastal features such as "water," "the sea," "wind," and "air." They not only list such elements but feel attached to them, as this quote exemplifies: "This is where my soul breathes. I cannot live in warm countries. I need wind and I need water." (female, born in 1966). Regarding "nature," the top answer was "forests" (58 times), and most other answers related to the coastal landscape, such as "beach" (25) and "the sea" (24), while five respondents directly mentioned salt marshes. People mentioned qualities (e.g., tranquility and fresh air) 170 times, and people mentioned activities 74 times, which indicates special place attachments. In their own words, nature is "when I go out in the morning at 6 o'clock on the mudflats - there is no one on the way" (female, born 1962), or "when everything can grow wild without intervention" (female, born 1950). While respondents explicitly refer to the absence of civilization 111 times (e.g., untouched, no houses, and no cars), they referred to socio-culturally produced elements, such as meadows (19), gardens (12), dykes (9), or parks (5) as being elements of nature, 83 times. The contradictions in the role of humankind and its activities toward nature (separated vs. forming) seem independent from place, age, or gender.

All 222 participants reacted to the statement "Certain areas should be protected from human utilization," 203 respondents completely agreed, and another 9 people answered, "rather yes" (see Figure 2); and 60% of participants agreed to the statement, "environmental and nature conservation have already had a lot of success in this region." Living along the North Sea or Baltic Sea shows insignificant, negligible correlations, but age positively correlates with seeing success. However, 20% of the respondents being unsure and 20% of them denying success might still be a sign of skepticism (see Figure 2). The statement "My environment is destroyed" invoked mixed reactions with almost as many yes as no answers. Many people reacted emotionally and explained their choice of answer. The younger the respondents were, the more likely they agreed with the statement.

To avoid spillover effects and to ensure an understanding of values, the very broad question "What are threats to the region?" was placed between questions about 'home' and 'nature.' The most feared threat is "flooding" (see Figure 3). Flooding and synonyms thereof were mentioned 60 times (28%). In addition, climate change (28 times) and sea level rise (19 times) were frequent, spontaneous answers, sometimes in direct relation to flooding. Other climate-related hazards were "storm," "wind," "weather," "drought," or "forces of nature" (26 times in total), some of which might also relate to

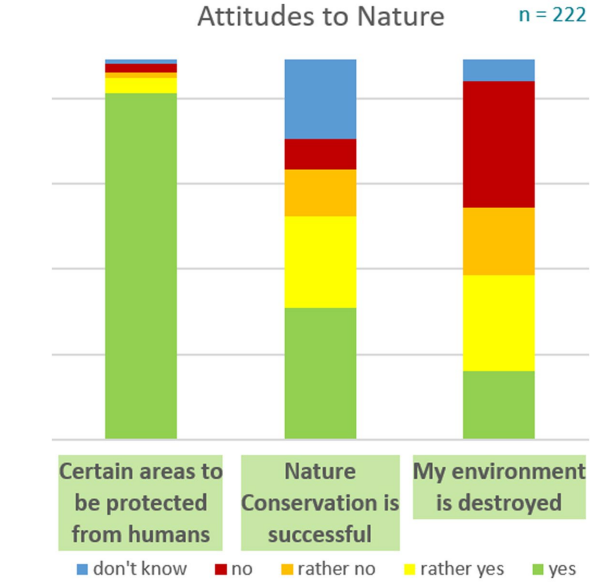

FIGURE 2
Attitudes toward nature.

flooding or climate change. While another 59 times nature and environment were in focus, e.g., man-made environmental and sea "pollution" or "environmental destruction," economic and sociodemographic threats moved participants too. A total of 33 individuals (15%) named "tourists" or "tourism" as a threat to the region, and others were concerned about increasing prices in housing and the youth moving out of the region. In Lower Saxony, poverty, unemployment, and dependency on a single company (Volkswagen) are issues of concern.

5.2 Engaging with CVEs

In the second part of the survey, respondents were shown photographs of coastal vegetation depicting salt marshes on the Frisian coast, a seagrass meadow in the Baltic Sea, and macroalgae in the North Sea and were asked 'What is the relevance of marine and coastal plants such as salt marshes, seagrasses, and seaweed to your home?' Participants could associate on a general level and explicitly give statements to the individual ecosystem. Of the 222 participants, a majority of 134 respondents answered with a general association to the shown ecosystems, and only 23 respondents could not give any answer. Specific reactions were reported for salt marshes by 75 respondents, seagrasses by 56 respondents, and macroalgae by 58 respondents. After a first reaction that an association is difficult to give, the ecosystems were judged as generally important. In more detail (see Figure 4), 79 individuals stated that these ecosystems are good for nature, e.g., for animals and biodiversity. Twenty-seven times respondents mentioned other co-benefits such as coastal protection or water quality enhancement. Twenty-three individuals explicitly attached them to their own *Lebenswelt*, and 21 individuals spontaneously stated that they think these ecosystems are worth protecting, for example: "These biotopes are important, vital for survival. Can

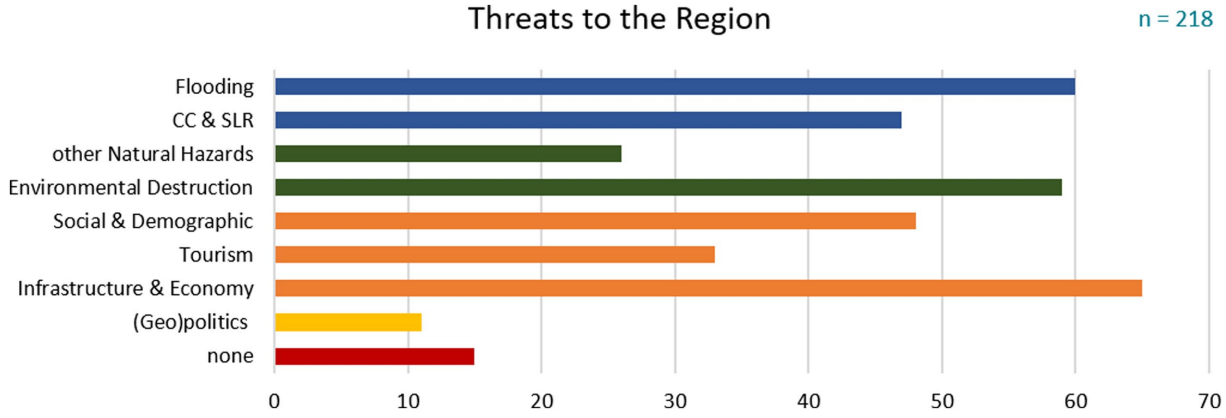

FIGURE 3
Perceived threats to the home region.

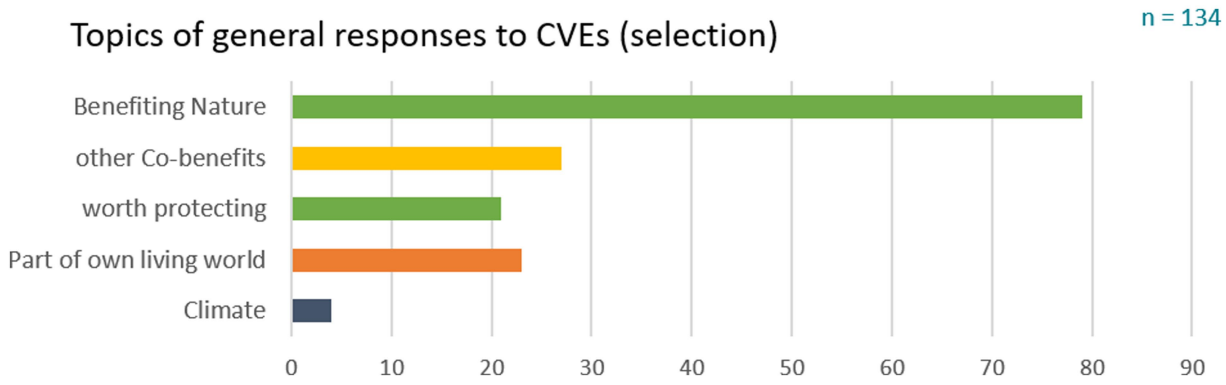

FIGURE 4
General statements on coastal vegetated ecosystems.

we please stop ruining them? That would be great!" (male, born 1987). Four participants attempted to link the ecosystems to climate or climate change, and two had reservations about these ecosystems.

Answers given about the individual ecosystems focus on specific benefits. Salt marshes were connected to a wide variety of benefits. Mostly, they were valued for coastal protection (16 of 75), e.g., "No coastal protection without salt marshes!" (female, born 1940), land reclamation, and birds. Seagrass serves as a vitally important habitat for hatching and breeding fish (21 of 56). Out of 58 respondents, 18 mentioned macroalgae as a food source. However, not every respondent voiced support for macroalgae; 15 respondents raised concerns—mostly seeing them as a sign of environmental pollution, e.g., seeing them as a "danger, grows too much due to pollution" (a man born in 1952).

Following the open statements, participants were asked to assess predefined statements on nature conservation, an active expansion of the previously discussed CVEs, and some co-benefits. Out of the 222 respondents, 169–205 of them answered with a general "yes" to the direct closed questions, if salt marshes, seagrass, or macroalgae are worth conserving. Another 5–13 people chose the answer "rather yes." The conservation of salt marshes and seagrasses is valued more than macroalgae. However, even with macroalgae, only 7% of those with an opinion disagreed or rather disagreed that these ecosystems should be preserved. When asked whether these ecosystems should be actively expanded, 51–56 respondents (approximately 25%) could not answer. Although more than half of the participants agreed, 10–20% rejected such ideas (see Figure 5). Probably, the widespread perception that nature should be "untouched" explains the differences in whether CVEs should only be conserved or also actively expanded (see also Walsh, 2020). When directly asked about coastal protection and improvement of water quality, hardly anyone disagreed (see Figure 6), though individuals sometimes stated that their knowledge on the subject was limited.

Most coastal residents along the German coast have formal and tacit knowledge about different ecosystems. Regarding CVEs, people value all three ecosystems, but they felt most attached to salt marshes and least to macroalgae. Knowledge declines accordingly. Whereas local knowledge of salt marshes is common, as coastal residents actively spend time in these ecosystems, knowledge of seagrass appears more formal and weaker. Opinions on macroalgae differ, as, on the one hand, people appreciate it as food or just as part of nature. On the other hand, people built up tensions associating macroalgae with pollution, a phenomenon which is more common with green-blue algae (cyanobacteria) or microalgae (phytoplankton) in German coastal waters (Gobler et al., 2017; Dai et al., 2023).

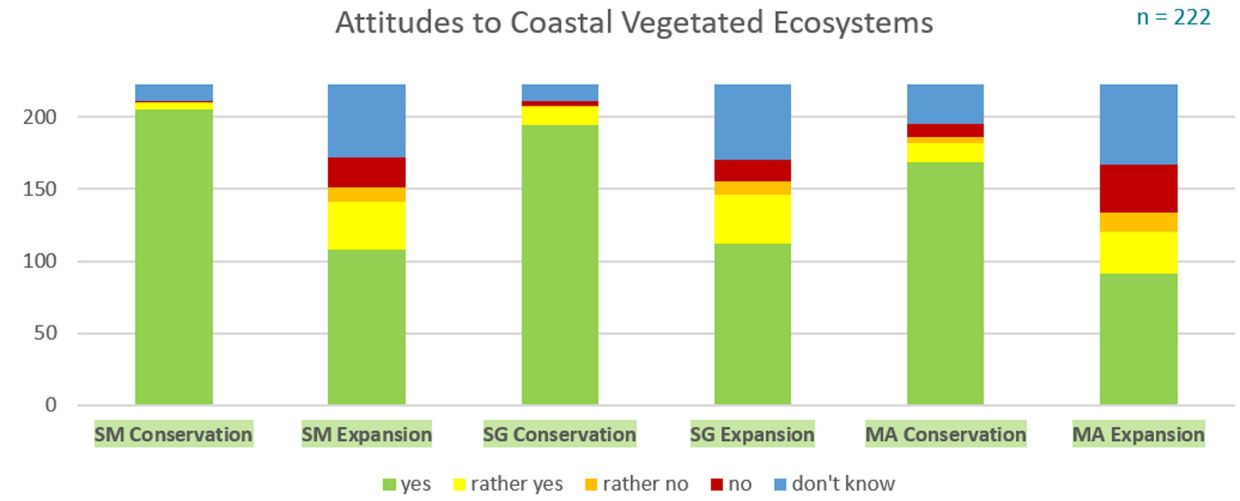

FIGURE 5
Attitudes to CVEs. SM, salt marsh; SG, seagrass; MA, macroalgae.

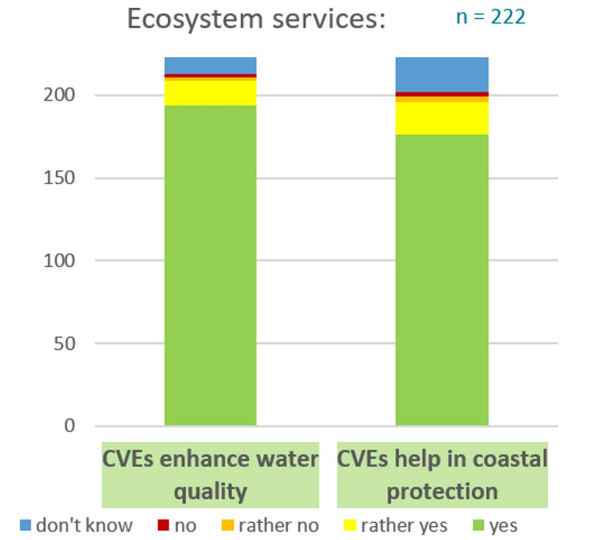

FIGURE 6
Ecosystem services of CVEs.

5.3 Climate action, negative emissions, and potentials for political participation

People along the German coasts are familiar with the term "climate change." Out of 220 participants, 195 confirmed that it is man-made (see Figure 7) and 185 (84%) see climate change as a threat to their home region. The open question on threats to the region (see Figure 3) revealed that the survey participants along the German coasts perceive climate and climate change-related hazards as the most frequent threats. The perception of climate change as a serious threat is consistent, mutually corroborative, and independent of place, age, or gender. With the statement, "In this region, enough is already happening in the fight against climate change," 152 respondents (69%) disagreed, 29 people (13%) were unsure, and 42 respondents (19%) said that their region responds sufficiently toward climate change. These answers point to a general willingness to do more against climate change in their region. Nevertheless, explicit measures might still cause resistance and reveal NIMBY mentalities.

In the next step, a yes/no question was asked: "Do people know ways to extract greenhouse gases like CO_2 out of the atmosphere?" However, 122 of the 222 participants (55%) responded negatively for this aspect. If the participants responded positively, two consecutive open questions followed: First, respondents were asked to give at least one example, and second, respondents were asked to express concerns about this example (see Figure 8). In total, 100 respondents (45%) shared ideas on how this might be done. Therefore, 24 people mentioned activities to reduce emissions but not to remove emissions, such as driving electric cars. The remaining 76 respondents mentioned methods of CO_2 extraction (99 times). Mostly, more nature-based solutions were mentioned (80 times) with a focus on planting trees (47 times). Less frequently, respondents mentioned the rewetting of peatlands (15 times) or CVEs (7 times). Apart from more nature-based solutions, 19 people mentioned technical solutions. Those participants who gave detailed answers were asked about their concerns. Only 7 had related concerns, of which 4 were connected to nature-based solutions and 3 regarded technical solutions. They viewed nature-based solutions as limited and time intensive, and technical solutions as difficult to apply and as potential safety risks. Twelve respondents did not stick to the topic and mentioned concerns against coal plants, fracking, or the production of batteries.

When asked about their contributions to their home ("Heimat"), two-thirds of the respondents viewed themselves as actively engaging in their home region, which is a comparatively high rate of respondents having an answer to the question (see for comparison Ratter and Weig, 2012). Most respondents were engaged in social activities such as caring for the elderly, and a quarter of the respondents voluntarily engaged in keeping their environment clean and unpolluted. Furthermore, 96 respondents organized themselves in clubs mostly regarding sports, allotment gardening, the church, or nature conservation. Half of our respondents agreed with the statement, "I want to be more engaged in decision-making processes," while the

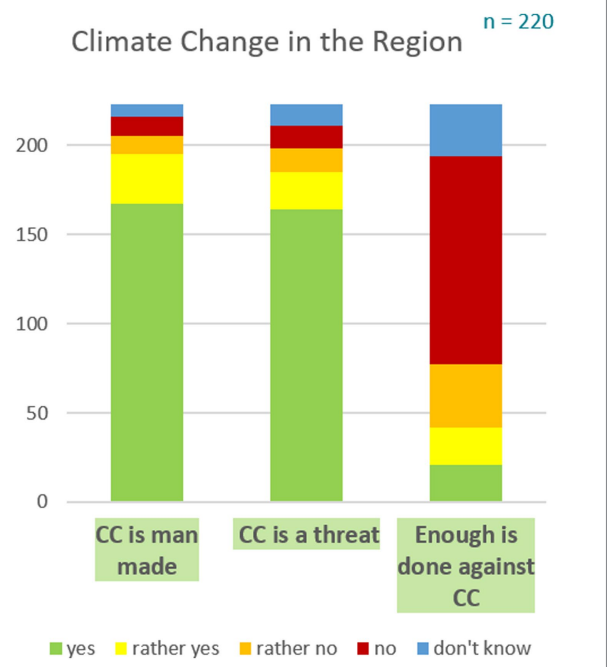

FIGURE 7
Statements on climate change in the region.

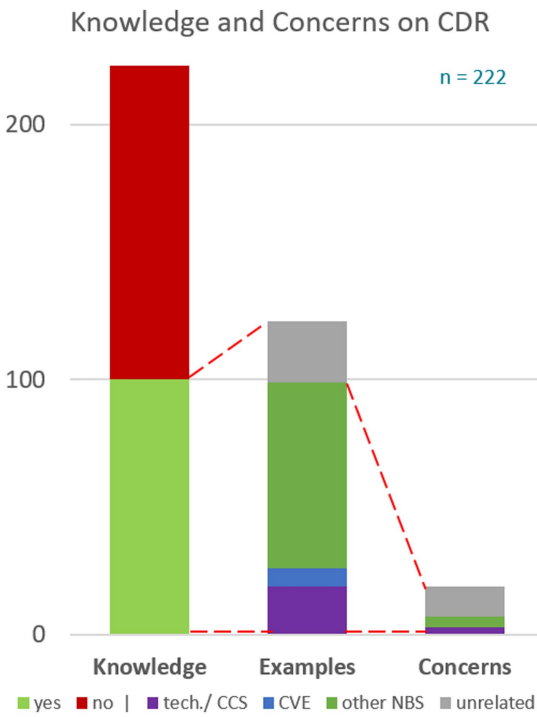

FIGURE 8
Knowledge and concerns on CDR measures (open answers on "Examples" could fit multiple categories).

other half disagreed. The same reactions appeared to the following statement, "I could contribute new ideas in such decision-making processes" (see Figure 9). "Being engaged" and "wanting to be more engaged in decision-making processes" show no significant correlations. Correlations show that the motivation for political engagement decreases with age. As age and having children correlate, parents also show less motivation to participate in decision-making processes. People from Lower Saxony are slightly more willing to engage than people in Schleswig-Holstein.

6 Discussion: blue carbon lack of knowledge along the German coasts

The survey confirmed the results of previous studies on place attachment among German coastal populations. Similar to our findings, related studies have concluded that German coastal residents have had a strong attachment to their coastal environment for decades (Döring and Ratter, 2018; Döring and Ratter, 2021). People feel emotionally attached to their home region and its cultural, socio-economic, and environmental specifics (Ratter and Gee, 2012; Döring and Ratter, 2021). While the installation of national parks along the German North Sea in the 1980s was perceived to be an intervention in the foundation of values on "Heimat" by many and accompanied by massive protests (Walsh, 2020; Döring and Ratter, 2021), the majority of the respondents in this study perceived nature conservation organizations as successful. This aspect supports the concepts of acceptance, values, and perceptions being dynamic (Pelling et al., 2008; O'Brien, 2009; Hansson et al., 2022).

Many respondents were aware of climate change and considered it a threat to their home region. A comparable study conducted 10 years ago revealed similar findings: 33% of the German North Sea Coast population was afraid of storm surges and climate change, with 10% mentioning clear-cut terms like "climate change" or sea level rise (Ratter and Gee, 2012). A comparison indicates persistence in the perception of the threat of flooding and increasing fear of climate change. Our study thereby confirmed the links between knowledge, perception, and action, as most respondents wanted an increase in action against climate change. The respondents were familiar with CO_2 reductions and respective avoidance strategies. However, they were less aware of CDR options. Apart from afforestation, Western populations are not adequately informed about CDR activities, or even about ongoing pilot projects (Carlisle et al., 2020), and German coastal residents are no exception. CVEs are known and valued for enriching biodiversity and coastal protection. Regarding salt marshes, recreational activities and high levels of local, tacit knowledge already seem widespread among German coastal residents. As deeper coastal waters are less accessible, local knowledge of and experiences with seagrass and macroalgae are less intense. CVEs were linked with coastal protection but not with climate action.

On a broad level, interventions in CVEs could gain high levels of acceptance and resistance, depending on the framing and motif for action. In a UK setting, Westlake et al. (2023) detected perception spillover from fracking, which could lead to negative attitudes toward geothermal energy. Our study revealed similar issues, as two participants transferred their concerns against fracking to CDR measures. Nature conservation is a familiar and appreciated motivation; however, interferences with nature due to CDR are unknown. Due to a lack of knowledge, no consolidated public opinions on blue carbon, let alone local blue carbon actions, could be identified, which blurs societal acceptance of blue carbon strategies. The participants in this study showed a willingness to personally

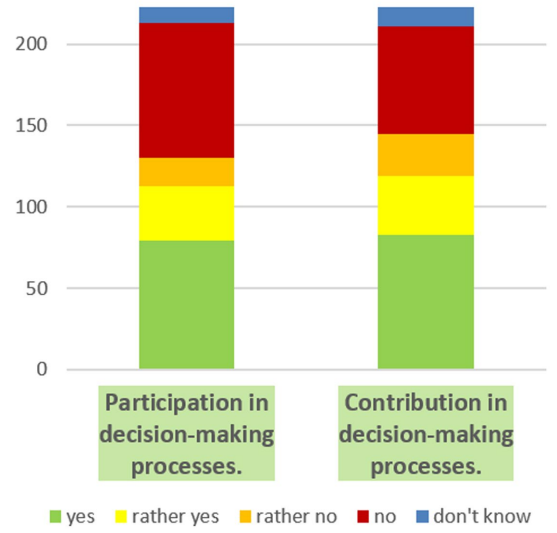

FIGURE 9
Political participation.

engage in shaping their regions, and a comparable survey on perception along the German North Sea coast confirms this result, stating that "70% of the respondents wanted more participation in decision-making processes, in particular where land use, nature conservation and coastal defense are concerned" (Ratter and Gee, 2012: 134). A higher level of publicity on blue carbon strategies and opportunities for participation would be needed to familiarize people with the blue carbon perspective on interventions in CVEs for serving climate action by storing CO_2.

The results of this study may be subject to several limitations. Descriptive statistics alone can only recognize correlations but not causalities. While the sample size allows for statements about respondents from larger regions such as the Baltic Sea compared to the North Sea or Lower Saxony compared to Schleswig-Holstein, statements on a city and district level lack appropriate sample sizes. Surveys were conducted only during the daytime, and it remains unclear to what extent the sample reflects the population concerned. Discussions on nature and perceptions of tourism might also be influenced by seasonality.

7 Combining knowledge, acceptance, and blue carbon toward climate action

Our study highlights the meaning of in-depth knowledge for societal acceptance of blue carbon climate action. As coastal ecosystems are known and valued for several socio-ecological benefits, nature conservation interventions to preserve these ecosystems and their known functions are likely to be highly accepted. Furthermore, people are sensitive to climate change as a threat and accept climate action. However, if people are only familiar with mitigation and adaptation concepts and measures but not with CDR, the latter remains vague and alien. As long as people lack knowledge of CDR, opinions and attitudes on CDR options cannot solidify and may alter, which blurs societal acceptance. Transient knowledge and fugitive acceptance are not a solid base for CDR interventions, which are designed to last for centuries. However, as demonstrated before, knowledge and acceptance are not fixed entities: they are dynamic and can be developed and changed by social learning (Pelling et al., 2008; Berkhout, 2012). How far dissemination of information on CDR and blue carbon will lead to knowledge-based acceptance of interventions, or non-acceptance, or will lead to initial controversies and later normalize to acceptance (Hansson et al., 2022) still remain to be seen. Nevertheless, the spread and growth of knowledge is a prerequisite for and often leads to societal acceptance, but the design and execution of interventions remain crucially decisive (Corner et al., 2012; Mauser et al., 2013).

There is a lack of information on the potential of CDR in general and blue carbon in particular. To counter this, it is necessary not only to provide information but also to transform information into knowledge and routines. Tacit knowledge is constructed through the active involvement of citizens. Experience and identification are links for new knowledge and an increase in acceptance. To generate knowledge on blue carbon, at least two links can serve as entry points to connect formal and local knowledge. First, since nature, nature conservation, and active engagement in these fields are already commonly valued, and CVEs services—such as being beneficial to biodiversity, spawning of fish, water quality, and coastal protection—are popular, blue carbon strategies most likely gain acceptance if framed and communicated as a part of nature conservation and not in opposition to nature conservation. Second, if climate change and, relatedly, flooding are perceived as serious threats, putting the home region at risk, and healthy coastal ecosystems are already acknowledged as stepping stones in climate change adaptation—protecting the coastline from sea level rise, erosion, and flooding—information on blue carbon interventions can connect to these threats and values.

The lack of knowledge this study identified could be an entry point for negative framings hindering acceptance, such as perception spillover from fracking (Westlake et al., 2023) or SRM (Kiehl, 2006; Schellnhuber, 2011). To keep CDR as an option open in order to stay within the range to limit global temperature increases as set by the Paris Agreement, the discourse on the design and contexts of climate change, negative emissions, and climate action as a conducive environment to introduce blue carbon projects is crucial and needs intense dialogue and participation in decision-making processes. Trustful and transparent dialogue, in combination with participation in practice, leads to experience and a co-creation of knowledge, combining local and scientific knowledge and, hence, producing climate action knowledge (Kothari and Wathen, 2017; Lauer, 2017; Fink et al., 2021). High levels of transparency, access to and participation in decision-making processes, and government accountability lead to increased knowledge and acceptance of ecosystem co-design interventions (Zimmer et al., 2022). Earlier studies on societal acceptance of renewable energy projects have shown that societal interests and objectives are changeable and that trust, accountability, and the feeling of being taken seriously are crucial for the acceptance and engagement of the local and regional population (Segreto et al.,

2020), especially if potential (blue carbon) implementers are perceived as outsiders. This approach is more difficult in deeper waters beyond the concrete *Lebenswelt* of local residents, where taking part in blue carbon activities to gain action knowledge is restricted. However, earnest activities on macroalgae and seagrasses can still reach high levels of trust and acceptance if the concepts of co-creation of knowledge and co-design in planning, implementation, and continuation are followed (Mauser et al., 2013; Segreto et al., 2020; Zimmer et al., 2022).

Finally, while many studies foresee public protest against certain CDR technologies (Oschlies and Klepper, 2017; Merk et al., 2023), based on initially increased knowledge (Merk et al., 2019), building up in-depth public knowledge is essential for CDR to gain acceptance and become efficacious. Emerging suspicion based on a lack of knowledge and communication jeopardizes entire projects. Instead, addressing discomfort can catalyze the processes of dealing with difficult experiences in ways that promote learning (Freeth and Caniglia, 2020). Resistance and initial rejections might be part of a process of familiarization and normalization (Hansson et al., 2022). This process can only be initiated by transparency, trust, and open discussions about diverging and common interests, trade-offs, and synergies. Local people's knowledge and acceptance are key to sustainable success in the long-term storage of blue carbon in particularly vulnerable coastal ecosystems.

Data availability statement

The data supporting the results of this study contain information that could compromise the privacy of the research participants. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

MF: Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, review & editing. BR: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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