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Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways

NETP analogues and Social License to Operate

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Lead beneficiary for this deliverable: UCAM

Editors/Authors: David Reiner, Lucrezia Nava, Celina Scott-Buechler

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Partners

VTT – VTT Technical Research Centre of Finland Ltd, Finland
PIK - Potsdam Institute for Climate Impact Research, Germany
ICL - Imperial College of Science Technology and Medicine, United Kingdom
UCAM - University of Cambridge, United Kingdom
ETH - Eidgenössische Technische Hochschule Zürich, Switzerland
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RUG - University of Groningen, Netherlands
INSA - Institut National des Sciences Appliquées de Toulouse, France
CMW - Carbon Market Watch, Belgium
UOXF - University of Oxford, United Kingdom
SE - Stockholm Exergi, Sweden
St1 - St1 Oy, Finland
DRAX - Drax Power Limited, United Kingdom
SAPPI - Sappi Netherlands Services, The Netherlands

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Executive Summary

Negative emissions technologies and practices (NETPs) are increasingly important to meet ambitious climate goals in Europe, as enshrined in the European Climate Law. In order to successfully contribute to net-zero and net-negative goals, however, NETPs will need to secure social license to operate (SLO) at local, national, and European scales. Previous research has shown that there is currently low public awareness of NETPs, meaning that the public at large, and indeed many key stakeholders, may be still forming opinions of carbon dioxide removal (CDR) as a whole as well as of individual NETPs.

In order to facilitate SLO, it is important for policymakers to understand how key stakeholder organisations are positioning themselves with regard to NETPs. Do some stakeholders favour certain NETPs over others? Do some organisations show greater affinity for CDR in general than others? Further, do sentiments toward NETPs change over time and geography? To assess the state of policy discourse around CDR in Europe, we collected over 200 documents produced by leading organisations, including reports, blog posts, and white papers. Text mining and sentiment analysis tools were used to assess sentiments expressed in the documents including carbon removal as a whole (compared to related concepts such as net-zero, climate change mitigation and CCS), as well as individual NETPs, such as afforestation/reforestation, biochar, bioenergy with carbon capture and storage (BECCS), soil carbon sequestration, direct air carbon capture and storage (DACCS), enhanced weathering and ocean-based removal.

We find that the number of documents published on NETPs increased markedly in the past two years (2020-21) compared with the previous nine years. This surge reflects growing stakeholder interest in engaging in public and policy discourse on the relative merits and potential roles (or lack thereof) for NETPs. Further, we find that the greatest number of documents were reports, which tend be longer, more formal representations of organisations' positions than website content or blog posts. Thus, a growing number of organisations are clearly interested in exploring NETPs in depth, oftentimes conducting original research to articulate their views. As policymakers work to distil information on NETPs and assess their deployment potential, these studies form a growing body of non-academic knowledge from which to draw. Given the rapid growth in the past two years, however, it is difficult to extrapolate temporal trends in sentiments. Only after a few more years of discussion and debate will it be possible to gain a better understanding of the dynamic evolution of SLO over time.

We also find that, overall, the organisations producing documents on NETPs tend to view them favourably. Indeed, our analysis showed positive average sentiment scores across all categories, both with regard to carbon dioxide removals in general, which nevertheless is seen less favourably than related concepts such as net-zero and climate adaptation/resilience, and for most NETPs. This includes geologic-storage removals, which prior research has found the public to be more sceptical of than approaches that are perceived to be "natural" or "working with nature." It is possible that organisations have greater exposure to and therefore more nuanced understandings of NETPs than the general public. However, in line with previous research, afforestation/reforestation had higher positive sentiments than most NETPs, especially BECCS, which is seen less favourably. The only exception to the average sentiment score being positive is enhanced weathering, which is discussed in only few organisational documents and is mostly associated with negative sentiments in these limited number of documents. By contrast, ocean-based removal, also little considered, has the highest sentiments. Given the small number of documents reviewed for both options, caution is warranted in drawing any robust conclusions since just a few more documents on he subject would change the overall score.

Despite overall positive sentiment scores for most NETPs, there were differences in the polarity of opinion. Specifically, we found the largest differences in positive and negative scores for afforestation/reforestation, suggesting large differences of opinion that might come from decades of discussion that have exposed the pros and cons. The less-discussed NETPs, namely enhanced weathering and ocean-based removal, conversely, had respectively low positive scores and high negative ones and high positive scores and low negative ones, suggesting a lower level of polarity among stakeholders. It seems, therefore, that while in certain contexts debates tend to shift public perceptions towards convergence, in the case of NETPs the tendency (at least based on recent documents) is greater polarisation.

Finally, we found significant differences in sentiment toward NETPs across geography and sectors: organisations in Western and Northern Europe, which also produced the greatest number of documents, were far less likely to express positive sentiments regarding carbon removal, and in particular DACCS, compared to other regions. Similarly, certain sectors tend to view specific NETPs more favourably, for example, CDR developers see BECCS more favourably and soil carbon sequestration is viewed negatively by the agroforestry sector but positively in the energy sector. As the European Union considers whether, where and how to implement carbon removal policies, policymakers should carefully consider geography as well as sectoral clusters and their role in determining the likelihood of achieving local and regional SLO.

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1. Introduction

A growing body of literature underscores what integrated assessment models have assumed for most of the 21st century: negative emissions technologies and practices (NETPs) are increasingly important tools to help keep global warming below 1.5°C (Deliverable 2.2; Deliverable 7.2). Indeed, it is estimated that by the end of the century, between 400 and 1,000 gigatons of carbon dioxide, approximately 10 to 25 years' worth of current emissions, may need to be securely removed from the atmosphere (Minx et al., 2018). Yet the potential contribution of NETPs to achieve these targets remain uncertain (Nemet et al., 2018).

Importantly, it remains unclear if NETPs will have sufficient social license to operate (SLO), defined as an "ongoing approval and broad acceptance of society to conduct its activities" (Prno & Slocombe, 2012, p. 1). Previous research indicates that the deployment of NETPs is "internationally contested" and characterised by divergent views among key stakeholders (Dowd & James, 2014; Dowd et al., 2015) – see also Deliverable 5.3 on the topic. However, obtaining SLO is essential for large-scale deployment of NETPs. In many countries, public engagement on potential development projects is voluntary but can be appealing as means to prevent conflicts with communities that can stall or even halt progress (Holley & Mitcham, 2016). In some countries, like Sweden and Finland, policies require that the environmental impact assessment stage of permitting processes include public participation, often modulated by third-party organizations (Söderholm et al., 2015).

At present, there is low public awareness around NETPs (Cox et al., 2020; Selma et al., 2014; Spence et al., 2021), indicating that public-facing organizations may have a significant role to play in shaping public narratives of NETPs. Indeed, SLO will rely on ongoing, participatory engagement with social actors, exceeding the requirements of acceptability alone (Batel et al., 2013; Bellamy et al., 2019). If NETPs fail to secure SLO across a wide range of stakeholder groups, their success may be compromised (Cox et al., 2020). It is thus important that climate policies involving negative emissions targets, like the European Green Deal, be rooted in a comprehensive understanding the perceptions of NETPs of key stakeholder active in different sectors, geographies, and time. In particular, politically active organizations such as NGO and industry actors will influence the wider political discourse and may ultimately affect the eventual success or failure of NETPs. While previous work has examined SLO indirectly, by comparing NETPs to possible analogues such as REDD+ (Buck, 2016), nuclear power (Lock et al., 2014), renewable energy (Buck, 2018; Rai et al., 2010) or CCS and biofuels (Honegger and Reiner, 2018), we address the topic using primary data sources, enabled by the growing number of documents related to NETPs produced by different organisations. This novel approach allows us to evaluate SLO as it develops, and with greater specificity to both individual NETPs and broader categories of NETPs.

Unstructured text is estimated to represent approximately 80% of organizations' data, and thus holds a wealth of knowledge on organizations' perceptions, policies, and strategies (Kobayashi et al., 2018). Text mining (TM) refers to "the discovery and extraction of interesting, non-trivial knowledge from free or unstructured text" (Kao & Poteet, 2007). Drawing on natural language processing, machine learning, corpus linguistics, computational linguistics, and statistics, TM can be a useful tool in understanding organizational positions that might otherwise be difficult to collect data on (Kobayashi et al., 2018). In the fields of environment and energy, TM has primarily been used to assess interactions on social media platforms (Dahal et al., 2019; Jiang et al., 2016) and decision-making processes (Arcari, 2017; Comyns, 2014).

Given the wealth of knowledge contained in unstructured text, we use TM to analyse stakeholder perceptions of NETPs across sector, geography, and time. Specifically, we collected 188 documents among reports, white papers, blog posts, and other text-based organizational data on NETPs produced by private sector, NGO groups, or a partnership between different stakeholders. These data are analysed using existing TM and sentiment analysis libraries in R to identify stakeholder sentiments towards various NETPs in order to help assess NETPs' social license to operate among stakeholders and the messages they are conveying to the public.

2. Methods

In order to identify organisational texts, we first relied on Google searches for stakeholder reports on NETPs, i.e. "Greenpeace report on carbon dioxide removal". In the first iteration, the search focused on organisations included in the stakeholder database we compiled for Deliverable 5.3 (on stakeholder perceptions of NETPs), which includes 298 environmental NGOs and 279 private sector organisations present in Europe (even in case of organisations with headquarters located on other continents) and having an interest in European Union policies for climate change mitigation. Apart from considerations about the nature of the organisation and the sector, stakeholders were identified based on whether they had existing sustainability targets that include carbon dioxide removal (CDR), using the database of corporate net-negative emissions targets compiled by the American University Carbon Removal Law & Policy Center. This initial stage of exploratory data collection allowed us to identify key search words for a systematized web search as well as the search patterns that successfully yielded texts relevant to our analysis. Relevant documents were defined as those that included one or more terms related to NETPs, either as a broad category or individual approaches, in the main text of the document.

Based on the qualitative findings of this first stage of data collection, we structured our Google search queries by combining terms from each of five categories (I + II + III + IV). We utilised advanced Google search operators AND & OR to indicate that search results should include at least one term from each category. We further took advantage of Google's stemming operator to access results that contained versions of the search terms even if not the exact terms themselves (i.e., "afforesting" or "afforested" in addition to "afforestation"). Duplicate search results were removed. While news articles themselves were not included as organizational documents, organizational reports mentioned by media in the first pages of Google results were. We did not find non-duplicate reports after page 5 of the Google search.

The search keywords are listed below:

I. NETPs (OR): {'carbon removal', 'CO2 removal', 'carbon dioxide removal', 'negative emissions', 'net negative', 'carbon sink', 'carbon sequestration', 'greenhouse gas removal', 'GHG removal', 'direct air capture', 'bioenergy with carbon capture and storage', 'biomass with carbon capture and storage', 'BECCS', 'bio-CCS', 'enhanced weathering', 'afforestation', 'biochar', 'remove carbon', 'remove emissions', 'geologic storage', 'carbon capture', 'CCS', 'CCUS', 'carbon storage', 'carbon sink', 'artificial sink', 'blue carbon', 'carbon cycle sink'}

AND

II. Subsectors: {'environmental', 'energy', 'multinational', 'agriculture', 'forestry'}

AND

III. Sectors (OR): {'non-profit', 'NGO', 'non-governmental organisation', 'company', 'industry', 'business', 'government', 'government agency'}

AND

IV. Documents (OR): {'report', 'blog', 'press release', 'white paper', 'position paper', 'letter'}

Initially, we included an explicit search category for geography; however, this led us to exceed Google's search queries limit of 32 words. We therefore used the advanced Google search option to specify geography from a drop-down menu, and thus manually conducted searches for each of the following regions:

{"Austria" OR "Belgium" OR "Bulgaria" OR "Croatia" OR "Cyprus" OR "Czechia" OR "Denmark" OR "Estonia" OR "Finland" OR "France" OR "Germany" OR "Greece" OR "Hungary" OR "Ireland" OR "Italy" OR "Latvia" OR "Lithuania" OR "Luxembourg" OR "Malta" OR "Netherlands" OR "Poland" OR "Portugal" OR "Romania" OR "Slovakia" OR "Slovenia" OR "Spain" OR "Sweden" OR "Iceland" OR "Liechtenstein" OR "Norway" OR "Switzerland" OR "United Kingdom" OR "Russia" OR "Ukraine" OR "Belarus" OR "Moldova" OR "Serbia" OR "Bosnia and Herzegovina" OR "Albania" OR "North Macedonia" OR "Montenegro" OR "Andorra" OR "San Marino" OR Holy See" OR "Monaco" OR "European Union" OR "Europe"}

In addition to the inclusion criteria described above, documents were manually skimmed to ensure relevance. Documents were discarded if they failed to provide organizations' perceptions on NETPs; our inclusion criteria mandated that at least one sentence engaged directly with the topic of NETPs (i.e., "Direct air capture is a necessary solution…"), rather than simply mentioning it (i.e. "Experts have studied wind energy, solar energy, carbon sequestration, and geothermal energy. This report will cover our company's views on solar energy"). Search results were limited to publication during the period from 2001 to 15 November 2021. Although direct discussion of negative emissions did not emerge until more recently, negotiations over the Kyoto Protocol did elevate the idea of "carbon sink enhancement" to broader discussion. This conversation, according to Carton et al. (2020) was largely a precursor to the discussion on negative emissions being had today, and thus provides useful insights for the study of NETPs. To capture these insights, we included "carbon sink" in our keyword list and organisational documents from the early 2000s.

The systematic Google search yielded 313 documents that met the initial inclusion criteria. Of these, 188 documents were retained; the others either had geographic focus clearly outside of Europe (e.g, a report from a Brussels-based NGO on a soil carbon sequestration project in Malawi) or did not include among the authors any NGO or private sector organisation (for instance if the report was produced solely by a governmental agency or a multilateral organisation such as the IPCC, IEA, or FAO). Once documents were selected, they were read into R using the tidytext package (Silge & Robinson, 2016). Text was then transformed to a matrix structure using the quanteda text analysis package (Benoit et al., 2018). Using standard textual data cleaning practices (Kobayashi et al., 2018; Mäntylä, 2018), documents were tokenized by word, making each word a unit of analysis. Words were stemmed to reduce them to their semantic roots. For example, "exploring" and "explored" would be changed to "explore". Text was converted to lower case for homogeneity, and punctuation, symbols, separators, numbers, and URLs were all removed. Stop words

- those that do not contribute information to the text, i.e. words like “is”, “the”, and “which” - were removed using an existing dictionary of common stop words in the quanteda package.

A customized dictionary of NETP-related keywords was developed using the authors’ own knowledge and through the initial stage of exploratory data collection. These included all terms used for the web search in addition to many others that could not be included because of word limitations. Keywords used can be found in Appendix A grouped by categories. This dictionary indicated to the code which terms to search for and pull out of each of the documents. A window of 5 words (excluding stop words) pre- and post-keyword were also extracted, which provided the basis for the sentiment analysis. The size of the window was selected based on past research that identified a window size of 5 words before and after each keyword as ideal for the analysis of long texts, such as organisational reports (Ito et al., 2020; Ri & Tsuruoka, 2020; Shuang et al., 2018). Inverse document frequency (IDF) was also used, a common procedure for identifying words that do not contribute substantively to text, assigning low weights to words shared by most or all texts. The TF-IDF method extends this to account for both the importance of a word in a text as well as its specificity (the R TM library has a function to create document-by-term matrices). Kobayashi et al. (2018) note that functions that disregard word order information tend to perform better than those that do not. Words identified by TF-IDF were assigned low weights for the sentiment analysis.

After a second round of data cleaning, sentiment analysis was conducted using quanteda’s built-in Lexicoder Sentiment Dictionary (LSD), which contains over 3,000 sentiment-associated words. Each word in in the LSD is assigned “negative” or “positive” and a corresponding score from 1 to 8 to represent sentiment polarity (i.e. “negative” 8 is more strongly negative than “negative” 1). Words that are neutral are assigned a score of 0. Final scores for each of the following categories were determined by taking the group mean by document for each keyword category: afforestation/reforestation, bioenergy with carbon capture and storage (BECCS), direct air capture (DAC), soil carbon sequestration, ocean-based removal, biochar, enhanced weathering, carbon dioxide removal. For comparison, we also analysed the sentiments for concepts related to carbon dioxide removals, and specifically net-zero, carbon credit, carbon capture and storage, climate change adaptation and climate change mitigation. Final sentiment scores by keyword group and document were collated with document metadata, including organisation(s), year published, length, whether the document was a product of multistakeholder and/or cross-stakeholder collaboration, location of publishing organisation(s), geographic scope of the organisation’s/s’ work, geographic scope of the report, organisation type, and document type. The number of times each keyword appeared was also counted for each document.

3. Key findings and policy relevant messages

3.1 Descriptive Statistics

As shown in figure 1, we found a marked increase in document publications from 2001 to mid-November 2021, with most documents published in 2020 or 2021. This finding aligns with interviews our research team has been conducting in parallel, which aims to understand how individuals in private sector and NGO groups conceive of NETPs. In these interviews, stakeholders have noted the recent swell of discussion on NETPs, and its peer effect—as more organisations present their opinions on NETPs publicly, other organisations feel increasingly compelled to shape and present their own opinions. Indeed, this study’s findings underscore how steep this trend is: each of the past two years has seen approximately the same number of NETP-related documents published as the years between 2001 and 2019 combined. This indicates that organisations across Europe have begun in past years to focus on NETPs, and to publish opinions on them.

It is likely that, as emerged in our interviews, there is a snowballing effect: as more organisations work on NETPs, the more likely others are to follow. This insight has important policy implications, as it means that stakeholders are increasingly interested in being involved in discussions on NETPs and their role in policymaking. Opportunities to capitalise on this growing appetite for stakeholder engagement will be important to realizing the cross-stakeholder discussions we identify as important in deliverable 5.3.

Approximately one-third of the organisations that authored one of the documents was based in western Europe, as shown in figure 2. The fewest organisations focus on southern Europe alone. Indeed, documents focusing on western Europe exceed those on southern Europe by more than tenfold, indicating significant variation in the level of stakeholder interest in NETPs across Europe. The heterogeneity of geographic focus among documents that discuss NETPs also has policy implications, namely that stakeholders in some regions of Europe are more likely to be informed and have shaped an opinion on NETPs as compared with others. Policymakers should take these differences into account when considering siting potential NETP development and deployment projects. The relative lower engagement of Southern European stakeholders is a key finding emerging from Deliverable 5.3 as well.

Regarding the type of documents included in our sample, the largest number of documents fell into the "report" category, as compared with blog posts, white papers, letters, etc., as shown in figure 3. This suggests that organisations are presenting informed, institutionalised opinions on NETPs, as opposed to relying solely on more text-sparse communication tools like blogs. We did not analyse other sources of opinion they might present such as social media posts. Further, many large organisations, especially in the private sector, have begun to include discussion of CDR in their annual sustainability reports, which indicates that removals may be playing a more important role in organisation-scale sustainability decision-making. Finally, the prominence of longer, detailed reports indicates that organisations are investing time and resources into shaping and presenting their opinions on NETPs. Indeed, many of the reports were based on original research conducted by the organisation itself or a third-party contractor. As policymakers gain expertise on the opportunities and risks of various NETPs, this non-academic grey literature will be important to take into consideration alongside more traditional academic studies.

Finally, our search yielded approximately equal numbers of documents published by NGOs and private sector actors. Private sector organisations are mostly (around 60%) in the energy and agroforestry sector or are start-ups developing carbon removal technologies. Moreover, few documents were produced by cross-sector collaboration such as joint efforts between the private sector and NGOs (figure 4), suggesting that cross-sectoral initiatives are still sparse, despite dialogue between different stakeholder groups having been found to have an important role on stakeholder perceptions (Deliverable 5.3).

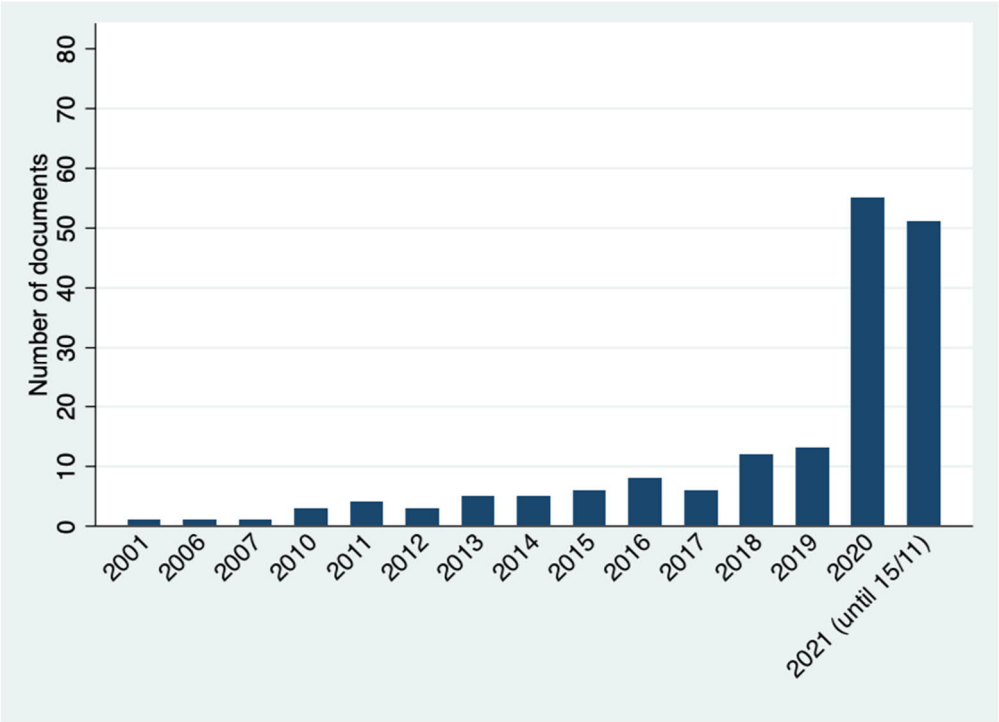

Figure 1 - Distribution of document publication dates.

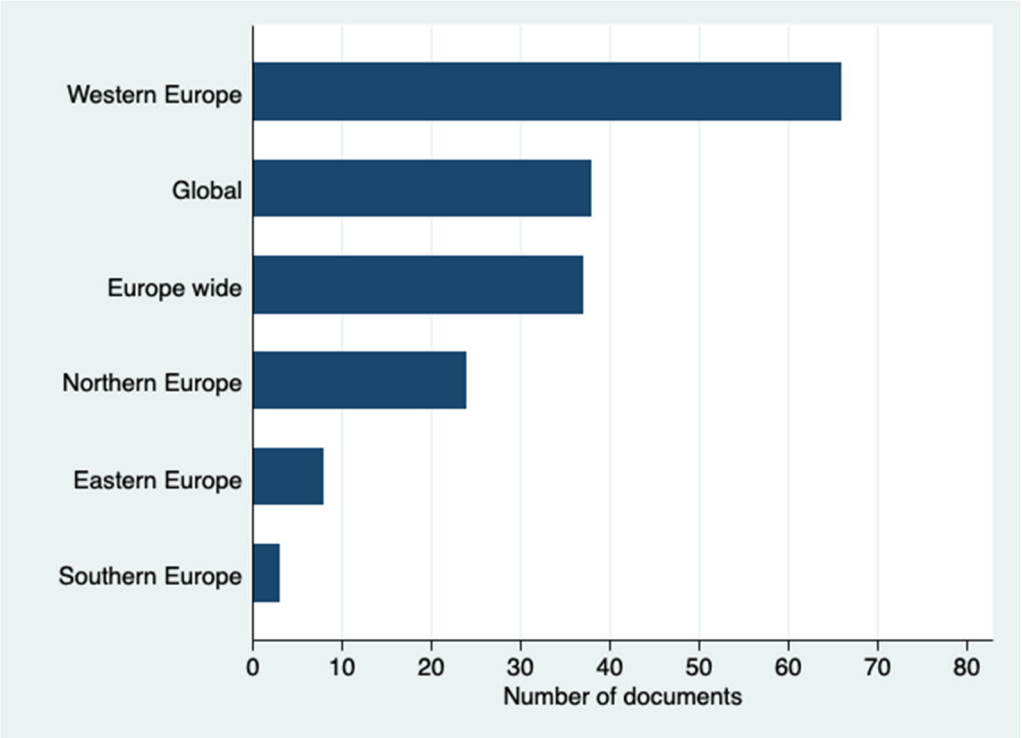

Figure 2 - Distribution of document geographic scope

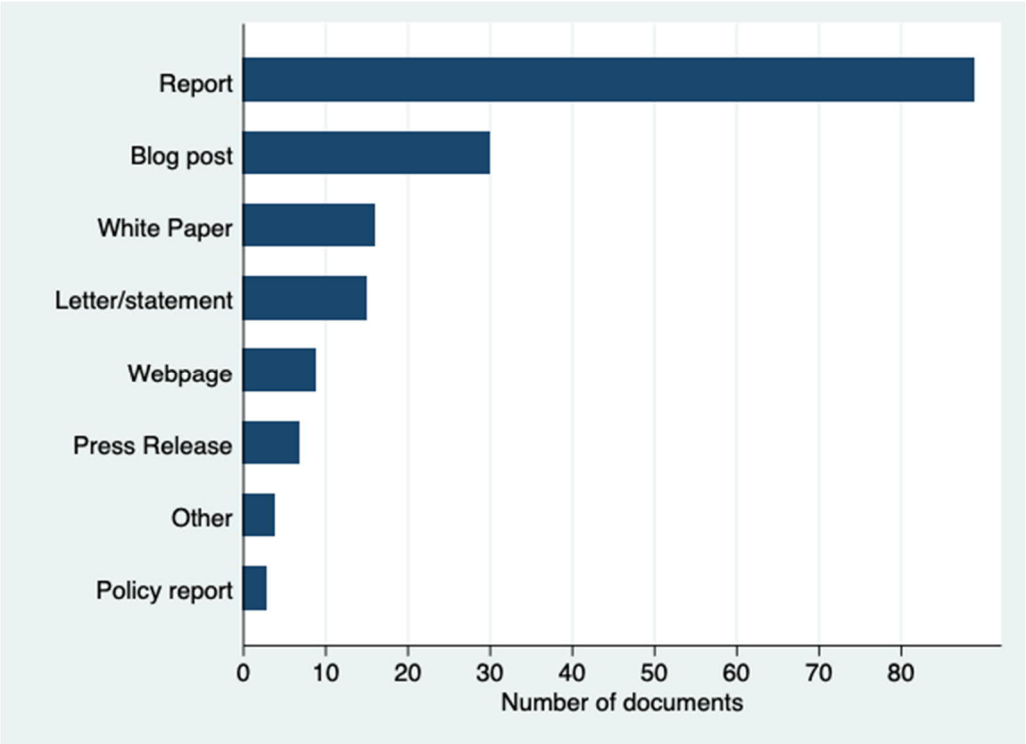

Figure 3 - Distribution of document types

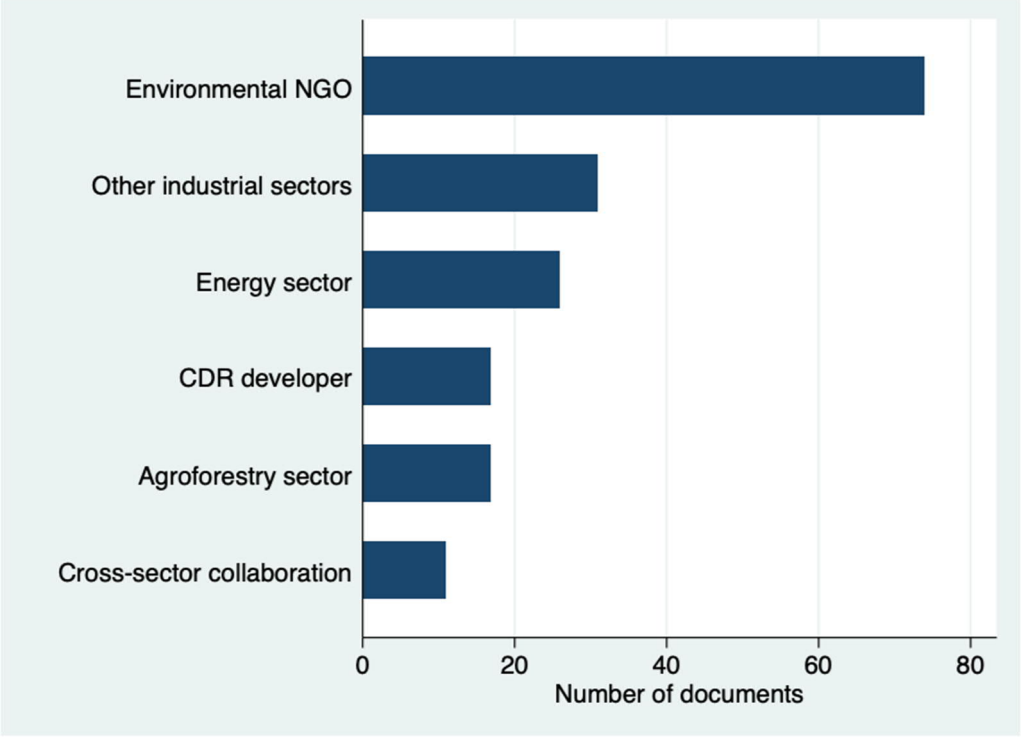

Figure 4 - Distribution of organisation types

3.2 Sentiment towards NETPs

Before analysing the sentiment towards each of the NETPs included in our analysis, we compared the overall sentiments associated with the keywords included in the broader category of carbon dioxide removal (see Appendix A for the complete list) and the ones associated with other key concepts that are often included in the debate about NETPs. This comparison supports data interpretation as it gives us a better understanding of the sentiment towards carbon dioxide removal not just in absolute terms, but also in relative terms. Figure 5 illustrates that, while all keyword categories had a net positive score on average, suggesting that all these concepts are perceived positively overall across organisational documents, carbon dioxide removal is associated with significantly more negative sentiments than net-zero emissions or climate change adaptation and resilience. The sentiments associated with carbon dioxide removal are in line with the ones associated to carbon credit and climate change mitigation as well. Finally, carbon dioxide removal is associated with more positive sentiments than carbon capture and storage (CCS), a precursor to and component of net-negative system such as BECCS.

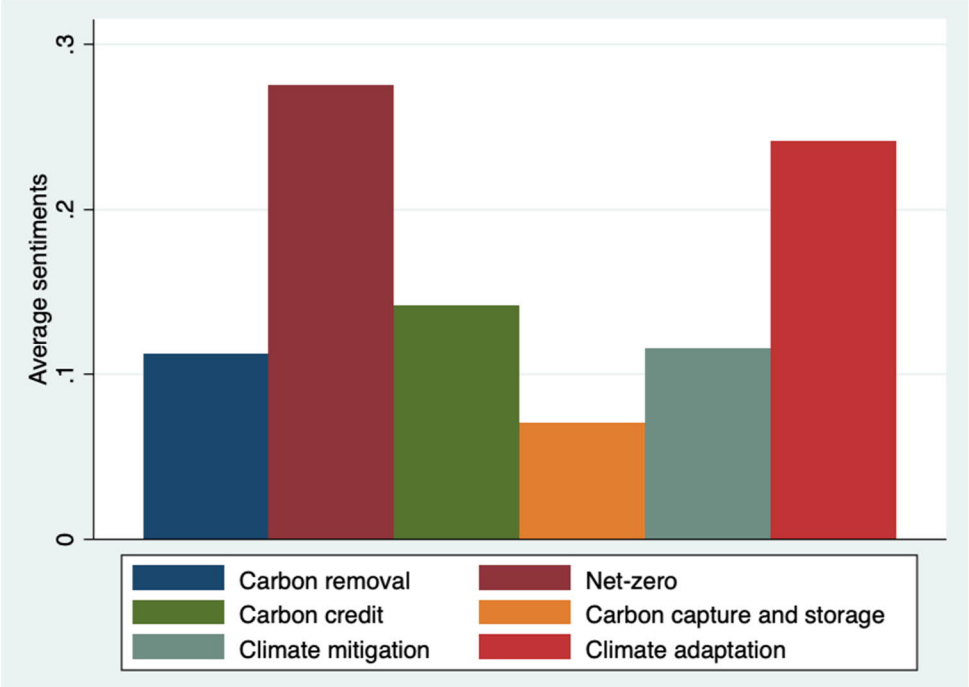

Figure 5 – Average sentiment score for carbon dioxide removal and related concepts

Scores are calculated by averaging, within documents, the sum of the "negative" and "positive" scores of the 5 words pre and post each keyword occurrence. Each word in this window is assigned "negative" or "positive" and a corresponding score from 1 to 8 to represent sentiment polarity (i.e. "negative" -8 is more strongly negative than "negative" -1). Words that are neutral are assigned a score of 0. We further averaged the scores for the keywords included in each of the 6 categories represented in the figure (see Appendix A for the full list).

Next, we explore the sentiments associated with each of the NETPs included in our analysis (afforestation/reforestation, soil carbon sequestration, biochar, BECCS, DACCS, enhanced weathering and ocean-based removals). Figure 6 illustrates the number of documents in our sample mentioning each of these NETPs. The most commonly discussed NETPs is, expectedly, afforestation/reforestation and related keywords (see Appendix A), consistent with the higher stakeholder awareness of this NETPs discussed in

Deliverable 5.3. Despite their relative nascence compared with ecological-storage removals, geological-storage removals were the second most common category across documents (BECCS and DACCS, see Deliverable 2.2 for a discussion of ecological and geological storage removals). Fewer than 20 documents mention enhanced weathering and ocean-based removals, confirming the results discussed in Deliverable 5.3 pointing to the lower stakeholder awareness of these NETPs.

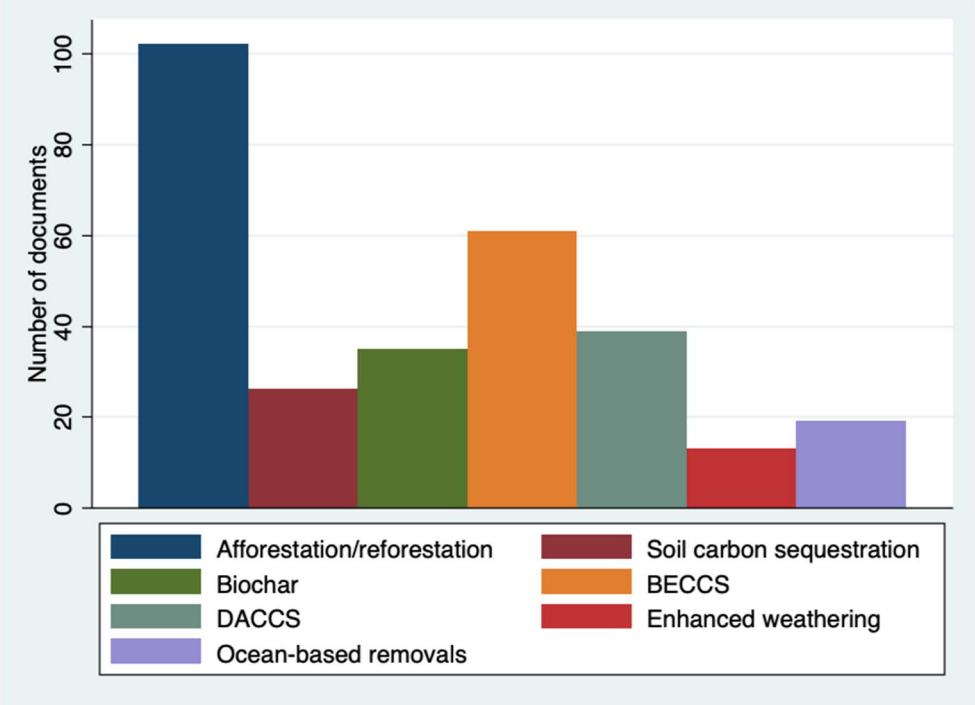

Figure 6 – Number of documents including each NETP

Figure 7 shows average sentiment scores calculated for each NETP. In addition to being the most frequent NETP category across documents, AR also showed the one of the highest average sentiment (favourability) score, exceeding even broader categories under which it might fall, like carbon removal and climate mitigation (scores in figure 5). This is in line with previous research that shows public favourability skewed toward removals perceived to be more "natural" than "technological" (Cox et al., 2020; Shrum et al., 2020; Buck, 2019). Biochar, soil carbon sequestration, and DACCS are also associated with positive average sentiment across reports, even if lower than for afforestation and reforestation. BECCS, by comparison, has significantly lower sentiment, suggesting greater stakeholder scepticism towards this NETP. Interestingly, all NETP keyword categories yielded positive average sentiment scores across documents except for enhanced weathering. Given the limited number of documents mentioning this NETP, however, one should be cautious in interpreting this result. However, our analysis does reveal that the few reports mentioning this NETP are sceptical about it. The opposite is true for the equally less mentioned ocean-based removals. In this case, the few reports mentioning this NETP seems to come from strong proponents of this solution and thus receives the highest average score.

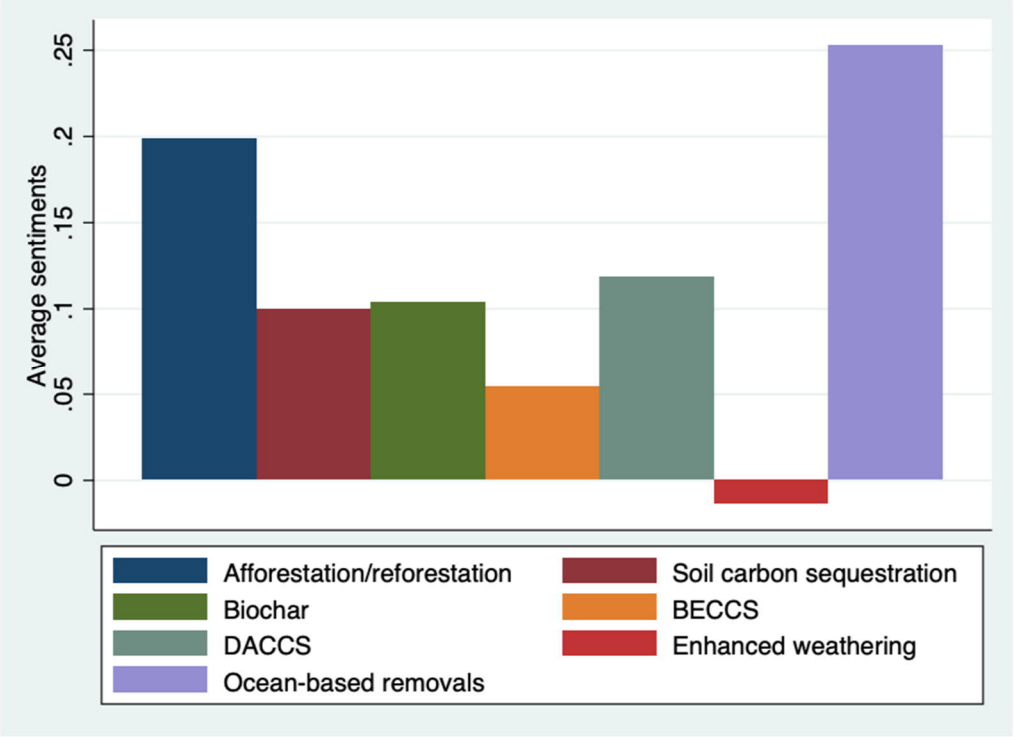

Figure 7 - Average sentiment scores by keyword categories across all documents

Scores are calculated by averaging, within documents, the sum of the "negative" and "positive" scores of the 5 words pre and post each keyword occurrence. Each word in this window is assigned "negative" or "positive" and a corresponding score from 1 to 8 to represent sentiment polarity (i.e. "negative" -8 is more strongly negative than "negative" -1). Words that are neutral are assigned a score of 0. We further averaged the scores for the keywords related to each of the 7 NETPs represented in the figure (see Appendix A for the full list).

Figures 8 and 9 show average scores in positive and negative directions respectively. Afforestation / reforestation shows the largest positive as well as negative values, suggesting it is the most polarizing category. This can be due to the fact that we included in this NETP keywords related to REDD+ that have a mixed record of effectiveness and have been contested by some stakeholders (Pasgaard et al., 2016). For enhance weathering, the total negative score is due to a high negative score (in absolute value) and a low positive one, while the opposite is true for ocean-based removal, characterized by low negativity score compared that left it with a higher average value. Both these cases indicate lower polarity among stakeholders (which can be explained also with the limited numbers of stakeholders discussing them).

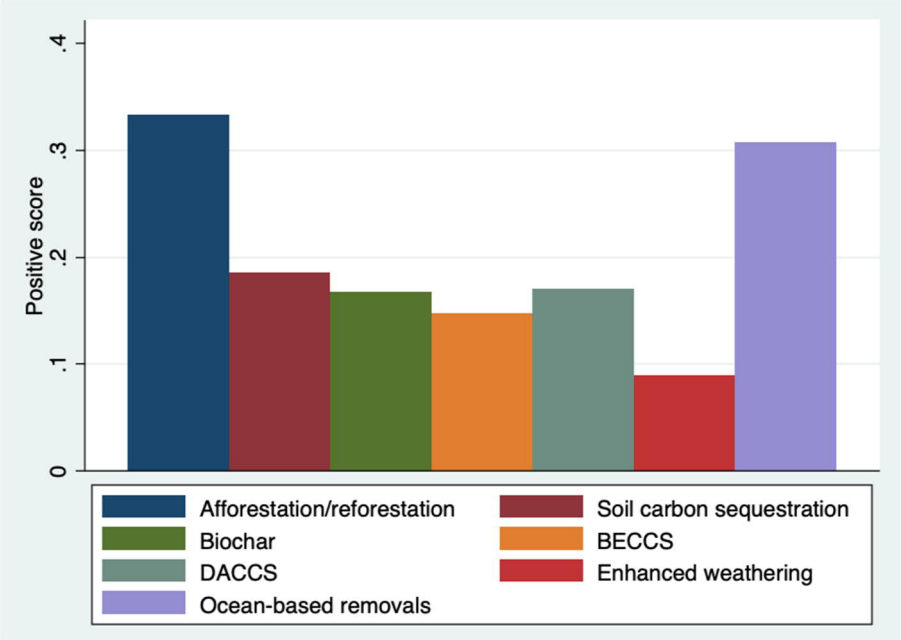

Figure 8 - Average positive sentiment scores by keyword categories across all documents

Scores are calculated by averaging, within documents, the "positive" scores of the 5 words pre and post each keyword occurrence. Each word in this window is assigned a corresponding score from 0 to 8 to represent sentiment polarity (0 being neutral and 8 being the highest positive score). We further averaged the scores for the keywords related to each of the 7 NETPs represented in the figure.

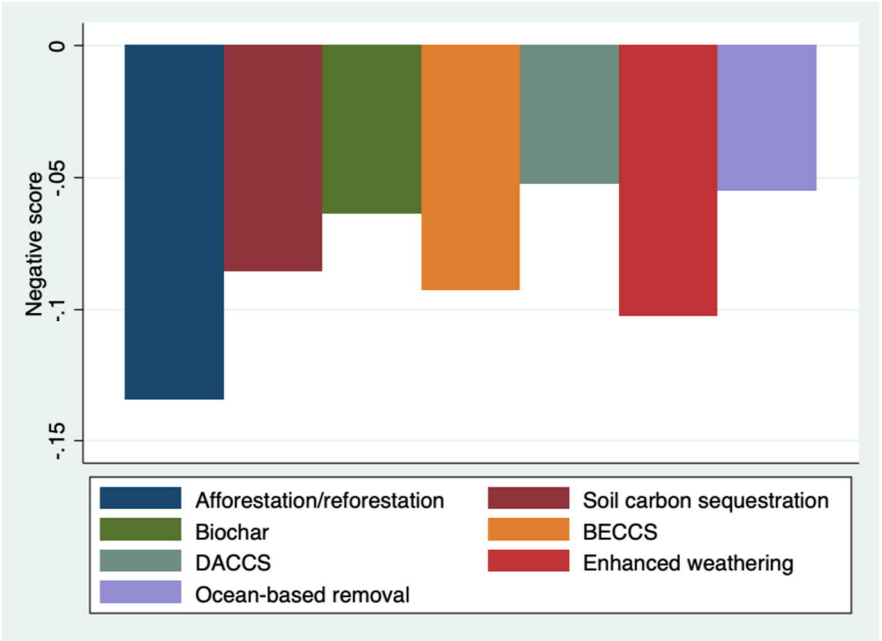

Figure 9 - Average negative sentiment scores by keyword categories across all documents

Scores are calculated by averaging, within documents, the "negative" scores of the 5 words pre and post each keyword occurrence. Each word in this window is assigned a corresponding score from 0 to -8 to represent sentiment polarity (0 being neutral and -8 being the highest negative score). We further averaged the scores for the keywords related to each of the 7 NETPs represented in the figure.

3.3 Predictors of sentiment towards NETPs

In this section we develop a series of regression models to understand what explain the variation in the average sentiment score for each NETP. Given the small number of documents discussing enhanced weathering and ocean-based NETPs, we are excluding these NETPs from the regression analysis, as the sample size is below the threshold for meaningful and interpretable results. Table 1 shows the results of the models for the included NETPs. Overall, the models are able to explain the variance in the sentiment for different NETPs from 10% to 55%, as per the R^2.

First, we found that the temporal dimension has no significant effect on the average sentiment score for each NETP. This is probably due to the fact that most documents are concentrated in the past two years, making it difficult to capture the longitudinal evolution of the debate. It is likely that temporal trends will start to be visible in the sentiments over the next few years.

When considering the different sectors, we find that companies in the agroforestry sector are significantly more positive than organisations in other sectors towards soil carbon sequestration ($p<0.05$), given that these actors are the most involved in the implementation of this NETP which is often perceived as an additional cost. More surprisingly, however, energy companies see soil carbon sequestration more favourably than organisations in other sectors ($p<0.05$), possibly as a relatively low-cost offsetting strategy. Finally, as expected, CDR developers have more positive sentiments towards BECCS ($p<0.1$) given their involvement in the development of such technologies.

The length of the document has a significant negative effect only for BECCS ($p<0.05$), suggesting that shorter documents tend to have a more positive view of this NETP. Moreover, we could not find a difference between reports and other types of documents in the average sentiment for each NETP, suggesting that organisations have consistent messages across documents.

Finally, we find some notable geographic differences across Europe (see also Deliverable 5.3). Northern and Western European actors are significantly more negative towards DACCS ($p<0.05$ and $p<0.1$ respectively), compared to other European regions and global organisations (the baseline variable).

Table 1 - Predictors of Sentiments for NETPs

The table illustrates the results of multiple regression analysis models developed to explain the variation in the average sentiment score associated with each of the NETPs included in our study with a sufficient sample size to lead to meaningful results (thus excluding enhanced weathering and ocean-based removal). In particular, we test the significance of predictors such as the year and type of publication (e.g., reports compared to other less-represented formats, such as blogs, letters, or press releases), the sector (NGOs, agroforestry, energy, CDR developer as well as cross-sector collaboration, compared to other less-represented industrial sectors), the region (Northern and Western Europe, as well as European-wide organisations, compared to other European regions and global organisations), as well as the number of document pages and the number of team each keyword is repeated in the document, as relevant controls.

Total Sentiment for Different NETPs					
	(1)	(2)	(3)	(4)	(5)
	Afforestation / Reforestation	Soil carbon sequestration	Biochar	BECCS	DACCS
Year	0.004	0.029	-0.002	0.019	-0.011
NGO	-0.041	-0.187	-0.069	-0.013	0.023
Agroforesty sector	-0.051	-2.026**	0.113	0.008	0.310
Energy Sector	-0.054	2.228**	-0.008	0.048	0.091
CDR developer	-0.160	-0.327	0.127*	0.144*	-0.217
Cross-sector collaboration	0.218	-0.296	0.200**	-0.114	0.200
Northern Europe	-0.062	0.042	-0.099	0.116	-0.407**
Western Europe	-0.037	0.067	0.104	-0.027	-0.244*
European wide	-0.036	0.736	0.063	0.043	-0.007
Doc Length (pages)	-0.001	0.001	-0.000	0.001**	-0.000
Report	-0.130	-0.056	0.010	-0.011	-0.180
Keyword count (per each NETPs)	-0.000	0.006	-0.000	0.001	0.000
_cons	0.325	-0.275	0.129	-0.371	0.592
N	97	23	32	58	37
R2	0.0993	0.5519	0.5003	0.4196	0.3367

*p<0.1; **p<0.05; ***p<0.01

4. Conclusions and further steps

Our work analysed documents produced by NGO and private sector stakeholders across Europe dating back to 2001. Specifically, we used text mining and sentiment analysis to identify the polarity of stakeholder opinions on carbon removal strategies as a whole, compared to other related concepts, as well as specific negative emissions technologies and practices: afforestation/reforestation, soil carbon sequestration, biochar, BECCS, DACCS, enhanced weathering and ocean-based removals. Average sentiments across Europe, as well as nuanced understandings of geographical, temporal, and sectoral variation, are important to inform policymaking as the European Union works to meet net-zero goals. Specifically, organisational

sentiments toward NETPs are important indicators of potential social license to operate (SLO), which has been demonstrated to be important in the long-term success of large-scale projects.

Our main findings are fourfold. First, we find that documents published by organisations on NETPs are heavily concentrated in the past two years compared with the preceding decade. This suggests a recent surge in interest among stakeholders in carbon removal as a whole and in specific approaches. Qualitative interviews conducted with stakeholders, many of whom members of the authoring organisations, confirm and clarify this finding. Stakeholders identify increased interest in NETPs in recent years, coinciding with policy events that highlight carbon removal as a potential tool for climate action. Indeed, these interviews highlight the importance of a peer effect—as a growing number of organisations put forward their views on carbon removal in general as well as on specific NETPs, other stakeholders learn and shape their own views, and feel more compelled to publish positions (accompanied by their rationale or extended justification and associated evidence) for their own organisation. As NETPs continue to pervade policy discussions at national, EU, and global scales, this trend is likely to persist. Therefore, as policymakers continue to consider the role of NETPs as part of broader climate policy agendas, ongoing engagement with key stakeholders from NGOs and private sector will be important to building lasting SLO.

Second, we find positive sentiment scores overall for both carbon dioxide removals in general (and related concepts such as net-zero or climate change mitigation) as well as the individual NETPs assessed, except for enhanced weathering which presents a net negative score (possibly due to the low number of reports discussing it – indicating lower stakeholder awareness and interest). The highest sentiment is associated with ocean-based removals, even if the limited number of reports mentioning this NETP also reduces the interpretability of this result. A key limitation of our study is therefore the document sample size, especially for enhanced weathering and ocean-based removals. As more reports emerge on the topic, the more the sentiment scores will become more reliable. Moreover, while afforestation/reforestation has a high average sentiment score across documents, DACCS, which relies on geological storage, has a similar average score compared to soil carbon sequestration and biochar, which relies on ecological carbon storage. Therefore, while DAC performed less well than AR, its average score is in line with the score of carbon dioxide removals in general. This finding is a surprising one, as previous research on public perceptions (Cox et al., 2020; Shrum et al., 2020; Buck, 2019) suggests that the public prefers NETPs perceived as natural or working with nature as opposed to those with technological component(s). A potential explanation is that existing research has focused on general public perceptions, while are likely to be more informed about these NETPs, and therefore more likely to perceived them positively, in line with the relationship between stakeholder awareness and perception discussed in Deliverable 5.3. However, in line with prediction from the literature, BECCS was associated to the second lowest average score, following enhanced weathering. Moreover, when comparing carbon dioxide removals with related concepts, we found that it is perceived more positively than the precursor concept of CSS, recently applied to certain NETPs, but more negative than net-zero, despite the concept of net-zero, being net, implies the use of removals. This finding illustrates the importance of framing in shaping stakeholder perceptions. Net-zero is often presented as a bold, ambitious target we should aim for, and it is therefore perceived more favourably than the less-discussed concept of carbon dioxide removal, despite the two concepts being two faces of the same coin.

Third, in addition to the differences we found in overall scores for NETPs, we also found differences in the level of polarity. While afforestation/reforestation had the highest positive values, it also had the highest negative values, suggesting that this category is more strongly polarized than others. This evidence can be explained by the fact the afforestation/reforestation was also the most discussed NETP in our documents. Since this NETP has been discussed as a climate solution for decades, there is probably greater awareness of the associated pros and cons. Moreover, we included afforestation and reforestation in the same

category, which comes with different risks, on top of specific programs like REDD+, with mixed effectiveness record. We had expected this difference to be explained in part by the multiple regression analysis but the main explanatory variables (sector, year, geography, etc.) were not significantly correlated with the sentiments for this NETP. In contrast, the less discussed NETPs, enhanced weathering and ocean-based removal are also the less polarized as the sentiments are concentrated in the negative and positive side respectively. This further evidence seems to confirm that stakeholder discussion leads to polarization. This speculation is in line with the evidence reported in Deliverable 5.3 that indicates how, following workshops which include stakeholder discussions, the perception of NETPs became, in many cases, more polarized. Further research to better understand the dynamics that led to this result is necessary and could help policymakers better understand the contexts within which each NETP would be more likely to be granted social license to operate.

Finally, there was considerable geographic and sectoral variation in organisations' sentiments. Western European and Northern European reports showed the most negative sentiment overall and was significantly more likely to associate negative sentiments with DACCS. However, these actors are also the ones discussing NETPs more often in their documents, while other European regions had the fewest documents about NETPs – there were ten times as many documents from Western Europe as Southern Europe. As the European Union considers where and how to implement carbon removal policies, policymakers should carefully consider geography and its role in determining the likelihood of achieving local SLO. Similarly, while we did not find a difference between NGOs and private sector actors, in contrast with Deliverable 5.3 on perception of NETPs, we found that stakeholders in the agroforestry sector are more likely to perceived soil carbon sequestration as negative, possibly due to the cost associated with these practices, while the opposite is true for companies in the energy sector. Finally, CDR developers are more likely to see BECCS favourably, not surprisingly given that many of them are involved in CCS technologies.

Overall, we identified complex dynamics that are shaping social license to operate for NETPs among stakeholders. Understanding sentiments toward carbon removal more broadly, as well as individual approaches, will be especially important in shaping policy at national and EU scales. Moreover, the sentiment associated with each NETP can be integrated into models that can therefore take into account social enablers and barriers in the estimation of NETPs diffusion patterns.

To better understand the factors that influence stakeholder perceptions of NETPs, we plan to expand this research to include more documents and perspectives, and to identify specific linguistic structures being used to discuss NETPs in public discourse. As the number of reports and organisations expands, it may also be possible to identify a temporal evolution in the sentiment score, on top of more accurate predictors (especially for the less discussed NETPs, namely enhanced weathering and ocean-based removal). We will also further explore stakeholder perceptions through qualitative interviews and a pan-European survey to better understand how individuals within organisations are shaping their opinions, and to identify which factors they perceive to be important in helping them shape these positions.

For preparing this report, the following deliverable/s have been taken into consideration:

D#	Deliverable title	Lead Beneficiary	Type	Dissemination level	Due date (in MM)
2.2	Interactions and trade-offs between nature-based and engineered climate change solutions	UOXF	R	Public	17
5.3	Stakeholder perception of NETPs	UCAM	R	public	18
7.2	Extended MONET-EU	ICL	R	Public	17

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NEGEM

Appendix A

cdr_dictionary <-

DACCS= c("direct air capture", "DAC", "DACCS", "DACC", "direct carbon capture", "carbon capture from air"),

BECCS= c("BECC*", "BiCR*", "bio* with carbon", "bio* with carbon", "bio* with CO*", "bio* with CO*", "bio*CCS", "bioCCS"),

Enhanced Weathering= c("enhanc* weathering", "minerali*", "rock weathering", "weathering rock*"),

Ocean-Based= c("blue carbon", "ocean alkalin*", "direct ocean capture", "ocean* CDR", "enhanc* ocean sink", "ocean fertili*ation*", "ocean* carbon removal", "iron fertili*", "ocean* carbon*"),

Afforestation/Reforestation= c("LULUCF", "AFOLU", "afforest*", "aforest*", "reforest*", "forest* carbon", "forest* sequest*", "REDD*"),

Soil Carbon Sequestration= c("soil carbon sequest*", "enhanc* soil carbon", "increas* soil carbon", "no*till", "reduced*till"),

Biochar= c("biochar", "bio-char", "pyro* carbon"),

Carbon Dioxide Removal= c("carbon remov*", "negative emission*", "carbon dioxide remov*", "CO* removal", "GHG remov*", "greenhouse gas remov*", "CDR", "GGR", "net-negative", "removals", "net*negative", "remov* carbon", "remov* stor* carbon", "remov* stor* emission*", "capture* CO*", "draw*down", "emission* sink*", "carbon sink", "carbon sequestr*", "sequest* carbon", "carbon capture"),

CCS= c("carbon capture storage", "CCS", "CCUS"),

Carbon credit= c("carbon credit*", "carbon market*", "ETS", "emission* trad*", "carbon offset*", "CO* offset*", "emission* offset*", "carbon trad*", "CO* trad*", "emission* offset*", "emission* trad*", "CO* market*"),

Mitigation= c("mitig*", "energy efficiency", "emission* reduction", "GHG reduction", "CO2 reduction"),

Adaptation= c("adapt*", "resilien*"),