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Attitudes on Carbon Capture and Storage (CCS) as a Mitigation Technology within the UNFCCC

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Abstract: Carbon Capture and Storage (CCS) is a technology for mitigating emissions from large point-source industries. In addition to the primary role of reducing carbon dioxide (CO_2) in the atmosphere, CCS forms the basis for two large-scale negative emissions technologies by coupling geologic CO_2 storage with bioenergy (BECCS) and direct air carbon capture (DACCS). Despite its inclusion within the United Nations Framework Convention on Climate Change (UNFCCC), CCS has been largely unsupported by UNFCCC delegates because of its association with fossil fuels. We evaluate data from surveys given since 2015 to UNFCCC delegates at the Conference of the Parties (COPs) to ascertain how attitudes about bioenergy, BECCS, and CCS may be changing within the UNFCCC. The results show a positive change in attitudes over time for both fossil CCS and BECCS. Using a unique data analysis method, we ascertain that, in some instances, popularity of BECCS increased due to an increased acceptance of CCS despite lower opinions of bioenergy. Business and research NGOs have the most positive views of CCS, and environmental NGOs the most negative views. Delegates that attend CCS side-events have more positive attitudes towards CCS than non-attendees. Developing countries have a larger need and a greater appetite for information on BECCS than developed countries, but a need for information exists in both.

Keywords: CCS; CCUS; carbon capture; UNFCCC; negative emissions; NETs; side-events; mitigation; BECCS; DACCS; DAC

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1. Introduction

The UN Framework Convention on Climate Change (UNFCCC) is the most central and prominent international agreement to address climate change. It holds annual meetings of 197 contracting parties who participate in the Conference of the Parties (COP), and these focus on facilitating the formal negotiations that lead to and operationalize agreements such as the Kyoto Protocol and more recently the Paris Agreement. In addition to parties, non-state actors (NSA) also attend the COPs as "observers", and their influence in climate action has been steadily increasing over the years [1]. This influence was encouraged when NSAs' involvement was formally operationalized within the text of the Paris Agreement [2]. These groups include cities, states, indigenous peoples, women, youth, environmentalists, academic institutions, and businesses.

Whereas the role of parties is straightforward in that they directly negotiate and set policy, the significance and impact of NSAs at the COPs has been a subject of much research [3–8]. NSA groups have been found to materially impact climate change in their own right in addition to indirectly impacting the international climate negotiation process [3]. NSAs use the COPs to network, debate and discuss cutting-edge ideas and approaches. In so doing, these groups can affect global agendas by facilitating wider discussions and providing leadership for national and local governments. They attend these COPs for many different reasons, such as providing information, influencing states,

representing excluded groups, and acting as watchdogs. Thus, this sector of COP attendees represents an important component of influence on the implementation of climate policy within the UNFCCC [1,9–11].

CCS is a recognized mitigation technology within the UNFCCC and plays an essential role in Intergovernmental Panel on Climate Change's (IPCC) climate scenarios [12,13]. Yet, as of the writing of this manuscript, CCS deployment is drastically behind schedule for reaching Paris Agreement objectives. The low rate of deployment of CCS is not primarily related to technical issues but mostly due to policy- and financial-related factors, fueled in large part by a lack of public acceptance of the technology. Public perception of CCS has been a rich subject of research [14–18] and indicates that low levels of awareness and misperceptions around CCS are the main barriers to public acceptance. Most of these studies are targeted to specific groups and/or countries, and few compare attitudes across both developed and developing countries [17,19]. One large-scale international study [18] recommends targeting CCS information to the specific values of stakeholder groups. Thus, it is important to understand the attitudes of COP attendees (both parties and observers) with regard to CCS so that information can be targeted to the needs of stakeholders. It is also clear from these studies that inputting technical information into the COPs to address an overall lack of understanding about CCS is of great importance towards enabling the technology.

The UNFCCC-hosted side-event is one of the main avenues by which all attendees can access technical information at the COPs. These events are selected from a large pool of submissions and hosted by the UNFCCC alongside the negotiations, allowing organizations to present the latest work and results relating to climate change mitigation and adaptation. There are typically between 100–200 official side-events at any COP, and they are much in demand such that applications exceed the opportunities, typically 600–800 applications per COP. Recommendations [20,21], based on the survey research program reported herein on the function of side-events were used by the UNFCCC to maximize the benefit of official side-events. The conclusions showed that the role of side-events in capacity-building is significant. Side-events bring together a wide range of highly qualified people that it would be very costly to gather elsewhere or at other times. Consequently, side-events provide an efficient way of gaining exposure to pressing issues in climate policy and science" [20].

Since 2013, The University of Texas at Austin (UT) with the IEA Greenhouse Gas R&D Programme (IEAGHG) have partnered with the Carbon Capture and Storage Association (CCSA), Bellona Foundation, and the International CCS Knowledge Centre to conduct several official UNFCCC side-events to input technical information on CCS into the COPs. For six COPs these were the only official side-events on CCS (note there were still other unofficial events on CCS held at the COPs). Since 2007, Linköping University has distributed surveys to delegates at the COPs. From 2015 onwards, the survey has included questions on the respondents' preferred targets for investments in low-carbon energy technology distributed to the attendees at the UT CCS side-events, at other UNFCCC Official side-events, and to delegates attending the COPs in general.

The original focus of the questions targeting investment preferences was to assess the degree to which public preferences align with mitigation activities used in global energy systems modelling, specifically preferences for BECCS [22,23]; however, we identified that an expanded assessment of the data could provide additional insights. This paper is the outcome of a collaboration among these entities in order to further the use of the data to assess broader opinions on CCS in the COPs, i.e., both on biomass-based and fossil fuels, and to attempt to gain information on the impact of CCS side-events on UNFCCC attendee views.

More specifically, the data enables us to investigate whether stakeholder's views are changing over time and how different countries (developed and developing) and different groups (country negotiators and business, environmental and research non-governmental organizations) view CCS. We can also view any differences that might exist between those who were surveyed within the official side-events and those who had not been to the CCS

side-event but were questioned in the general COP environment. Given the importance of CCS to mitigating emissions in developing countries, it is also of interest to compare the responses from delegates residing in Annex 1 (broadly equaling developed countries, including economies in transition) and non-Annex 1 (broadly equaling developing countries) to assess any differences in awareness and/or the perceived importance of the technology in their countries. Such information can help in defining the audiences that are in need of information on CCS and enable information presented in the side-events to be more tailored to these groups. Finally, we were able to indirectly assess the degree to which opinions on BECCS are driven by biomass supply versus the use of CCS in bioenergy production, thereby gaining another layer of information on CCS attitudes.

Thus, we seek to answer the following research questions: (1) how have views on CCS (e.g., BECCS and CCS on fossil fuel) changed over time, (2) is there evidence that the technical information being provided on CCS through UNFCCC official UT and IEAGHG CCS side-events is having an impact on delegate views, (3) what are the views of the different actor types (governmental, business, environmental, researcher and others), and (4) how do the needs and appetites for information differ between developed and developing countries? In answering these questions, the information provided about CCS at the COPS can be more directed to stakeholders' views as recommended by [18].

1.1. CCS Technology

CCS is a technology for reducing emissions from large-scale industrial point sources of CO_2. These sources comprise all types of industry, including fossil fuel and biomass power and heat generation, synthesis of petrochemical products, and production of cement, iron and steel [24]. During the process of CCS, CO_2 emissions are captured before entering the atmosphere, compressed into a liquid-like state, transported and injected deep into subsurface geological formations for permanent storage. In this way, it is possible to avoid billions of tonnes (Gt) of CO_2 from entering the atmosphere and to securely and permanently (e.g., on the order of thousands of years) store the CO_2 in the deep subsurface (Figure 1) [24].

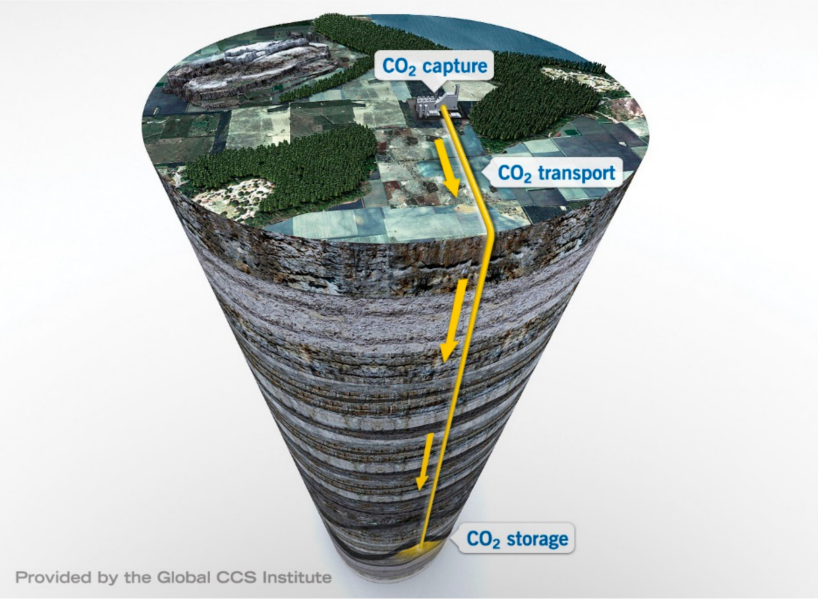

Figure 1. Schematic showing the process of carbon capture, transport and storage. Figure courtesy of the Global CCS Institute.

According to the International Energy Agency (IEA), deployment of CCS will substantially reduce the cost of reaching global climate ambitions. In IEA's Sustainable Development Scenario to meet the well-below 2 °C and net-zero goals that were agreed in the Paris

Agreement, CCS reduces the cost of emission reductions in the power sector and is deemed necessary to decarbonize industry. In this scenario, CCS is used to deliver 15% of emissions reductions (e.g., over 165 $GtCO_2$) in the period 2020–2070 [25]. For a more ambitious target of 1.5 °C, the modeled importance of CCS for mitigation increases, because of its potential as a negative emissions technology [13]. Even though 19 current projects can potentially store 40 million tonnes (Mt) CO_2 per year [26], IEA models indicate that we need to be currently storing closer to 1–3 $GtCO_2$ per year to stay on track by 2050 to reach the 2100 climate goal [25]. In addition, technology-cost optimized models project CCS to supply negative emissions by coupling geologic CO_2 storage with bioenergy (BECCS) and direct air carbon capture (DACCS).

1.2. History of CCS in the UNFCCC

The potential for CCS as a mitigation technology within the UNFCCC was introduced in a special report on CCS written by the IPCC (2005), which outlined the capabilities for the technology to deliver significant emission reductions. The report stimulated discussion and debate within the UNFCCC regarding whether the technology could be eligible under the Clean Development Mechanism (CDM), the main policy tool under the UNFCCC's Kyoto Protocol for encouraging low-carbon projects in developing countries. Years of discussion and information-sharing ensued within the UNFCCC to address the main issues of concern surrounding CCS; namely, permanence of CO_2 storage, monitoring and verification, environmental impacts, project boundaries and transboundary issues, liability, perverse outcomes (i.e., stimulating use of fossil fuels), and safety. A work program to address these important issues was enacted in 2010 at COP 16 consisting of written information and views submitted formally, a technical and legal workshop in Abu Dhabi in September 2011, and the production of draft modalities and procedures by the UNFCCC for negotiation at COP 17. The work program was completed, the issues were addressed, and the modalities and procedures were formally negotiated and accepted in Durban at COP 17 in 2011 [27].

Subsequent to its formal inclusion in the CDM in 2011, CCS was featured within the 2014 UNFCCC Technical Expert Meetings (TEMs) as an important technology with high mitigation potential for climate action alongside renewable energy, energy efficiency, transport, non-CO_2 greenhouse gases, land use, and urban environments. The importance of CCS for mitigation was further emphasized in UNFCCC technical papers on enhanced mitigation [25,28] and also noted in the "Climate Action Now Summary for Policymakers" [29], which outlined key recommendations from the TEMs.

Within the 2005 IPCC Special Report on CCS, bioenergy with CCS (BECCS) was men-tioned as a potential negative emissions technology. In BECCS, plants (and/or plant wastes and residues) which draw CO_2 from the atmosphere via photosynthesis are burned or otherwise processed for energy and emissions are captured and stored using CCS. Whereas BECCS was first thought of as only a potential backstop technology [30], it was increasingly added into the IPCC integrated assessment climate models (IAMs) starting in 2005 [31]. After this, BECCS was included in a 2007 IPCC TEM report [32], in the IPCC's fifth assessment report [12], and further elevated in importance in the IPCC special report on 1.5 °C warming (SR1.5) as negative emissions technologies (NETs) were becoming increasingly important within these scenarios [13].

In fact, a greater sense of urgency to aggressively limit emissions was communicated within the SR1.5, which focused on the dire outcomes of temperature rise past 1.5 °C. The importance of negative emissions became more evident with BECCS and AFOLU (agriculture, forestry and other land use) NETs taking the forefront. However, also in the SR1.5, a relatively new CCS-related NET known as direct air carbon capture (DACCS) was used in a few of the IAMs for the first time. DACCS is a process by which CO_2 is stripped directly from the atmosphere, concentrated, compressed, transported and injected in deep geological formations for permanent storage.

CCS-related NETs such as BECCS and DACCS are seen by many to provide the largest-scale and most permanent solutions [33,34], which may be indispensable as climate change outpaces our mitigation efforts. As previously stated, the IEA projects that CCS should be used to mitigate a total over 165 $GtCO_2$ between 2020 and 2070. Furthermore, 15% of the emissions reductions using CCS should be in the form of CCS-related NETs. Thus, it is clear that CCS is needed to play a crucial role in achieving climate goals but has fallen behind in both deployment and public acceptance, for policy-related rather than technology-related reasons. Additional influences may include the financial commitment required for CCS projects as they are larger in scale than other low-carbon energy technologies (which could be built at smaller scale), the relationship of CCS to decarbonizing fossil fuels, and the difficulty of the public to understand how CO_2 could be injected into the subsurface. There has been an increasing opinion moving against the use of fossil fuels because of their significant contribution to climate change, in both the wider society and reflected by environmental and youth NGOs inside the UNFCCC COPs. Agreements by countries and states such as "Powering Past Coal" reflect this, although noting that this agreement is against "unabated" coal use for power, i.e., not coal with CCS, but such details are lost in the popular narrative [35]. It is common to have anti-fossil protests by environmental and youth NGOs inside and outside recent COPs, with some fossil-related side-events even being disrupted by protestors. However, as IPCC recognizes, CCS applies to all large point sources of CO_2 such as bioenergy and biorefineries and hard-to-abate sectors such as cement and iron and steel, and not just for the use of fossil fuels for power generation.

Thus, opinion on CCS is mixed. On one end of the spectrum of opinion, CCS is seen as a way for fossil fuel companies to continue business as usual while appearing to mitigate their emissions. This opinion tends to result in resistance towards the technology and negative messaging that CCS is not viable. On the other end of the spectrum, CCS is major technology for achieving significant negative emissions through BECCS and possibly now DACCS. Whereas other storage methods are also potential negative emissions such as reforestation and improved land use practices, the permanence of CCS is superior, with storage lifetimes of tens to hundreds of thousands of years.

2. Methods

The International Negotiations Survey platform has been ongoing since 2007, led by the Centre for Climate Science and Policy Research at Linköping University. The project gathers data from the wide variety of participants at UNFCCC events such as the annual COPs. Survey questions cover a range of topics relevant to the UNFCCC negotiations both inside and outside of the official UNFCCC CCS side-events.

The original purpose for a subset of the surveys that were distributed throughout the COPs in 2015–2019, including at The University of Texas side-event on CCS, was to understand the degree to which public preferences align with mitigation activities used in global energy systems modelling, specifically preferences for BECCS versus fossil CCS [22,23]. At the time of the surveys, BECCS was the main negative emissions technology option within the COPs. Since then, DACCS has become another potential negative emissions technology. The questions were designed to assess; (1) preferences for investing in BECCS compared to other low-carbon technologies, (2) views of the role of BECCS as a mitigation technology, globally and domestically, and (3) assessment of possible domestic barriers to BECCS deployment. However, we make use of these surveys to glean additional insights into attitudes on CCS at the COPs.

Building on questionnaire data from five UNFCCC COPs (21–25), respondents (Table 1) were asked to rate various technologies with respect to long-term (specified as 25–50 years) investment by their countries to achieve a transition to low-carbon electricity generation with 1 being "disagree strongly" and 7 being "agree strongly". Technologies mentioned were; bioenergy without CCS, BECCS, fossil CCS, hydropower, nuclear power, ocean power, solar power, wind power, and other forms of power that were specified by the respondents. Aside from general questions designed to categorize the type of respondent;

e.g., the country of residence, expertise, gender and goals in attending the COP, additional questions were asked that were not assessed for this study.

Table 1. Number of respondents surveyed inside and outside the CCS side-event at each COP by primary role and country of residence. Note that the questionnaire was only given at the official UNFCCC side-event at COPs 22, 24, and 25.

Role	Respondent	COP				
		21	**22**	**23**	**24**	**25**
Governmental	Side-event participant	–	11	–	14	3
	All other	242	377	390	398	276
Business	Side-event participant	–	5	–	10	4
	All other	41	83	45	112	79
Environmental	Side-event participant	–	7	–	18	6
	All other	136	150	168	121	127
Researcher	Side-event participant	–	3	–	20	8
	All other	140	142	108	140	89
Other	Side-event participant	–	5	–	12	4
	All other	151	109	233	151	167
Total	Side-event participant	–	31	–	74	25
	All other	710	861	944	922	738
Country of residence	**Respondent**	**COP**				
		21	**22**	**23**	**24**	**25**
Annex 1	Side-event participant	–	14	–	46	17
	All other	368	379	439	476	339
Non-Annex 1	Side-event participant	–	11	–	11	3
	All other	225	336	327	321	335
Unspecified	Side-event participant	–	6	–	17	5
	All other	117	146	178	125	64
Total	Side-event participant	–	31	–	74	25
	All other	710	861	944	922	738

The inclusion of bioenergy, BECCS, and fossil energy with CCS within the questionnaires presents a unique research opportunity to assess an additional layer of information on attitudes about CCS. As previously discussed, we see attitudes against CCS because of its association with fossil fuels. What are attitudes about CCS when it is coupled with bioenergy, i.e., BECCS, which is a NET? With information supplied on both bioenergy and BECCS, any decoupling of attitudes between these two mitigation options could indicate whether attitudes about BECCS are due to the CCS component or the biomass component. According to [23], objections regarding the biomass component can include a range of issues including biomass availability, conflicts with biodiversity and food security goals, or competition for land. Thus, comparing the answers from each respondent could tell us if the biomass or the CCS component is the reason for the attitude.

Statistical analysis of the survey data show they are ordered and non-normally distributed, i.e., suitable for non-parametric statistical tests. To detect and confirm statistically significant differences among groups of respondents (such as different groups of actors and respondents at different COPs), the Kruskal–Wallis H test has been performed. Statistical differences are confirmed at the 0.01 significance level, and all significance levels in the post-hoc pairwise comparisons have been adjusted by the Bonferroni correction for multiple tests. We use this method because it is a conservative approach designed to eliminate false positive hypotheses (e.g., Type I errors), yet with the risk of not identifying other relevant differences (i.e., a risk of false negatives, so called Type II errors). However, it is often performed to avoid detecting false differences.

3. Results and Discussion on Participant Data

3.1. COP Delegate Views over Time

Answering the question of whether opinions have changed over time is slightly complicated from a statistical perspective because we do not keep track of individual respondents, i.e., we cannot return to the same respondent and gauge if he or she has changed viewpoints since they were last surveyed. However, we can see if, in general, the views of the sample at the different COPs are different as a proxy for changes in views over time, but it is not a direct measurement of the same. We view the data as cross-sectional in that different people in the same population are surveyed at multiple points in time, and we infer changes in views of UNFCCC delegates based on the sample.

Figure 2 shows the views of the general population randomly surveyed at different areas within the COP from COPs 21–25. This assessment is designed to give information on the general overall opinions of CCS over time. For all surveys, the responses span the entire range from strongly agree to strongly disagree. The Bonferroni-corrected Kruskal-Wallis test detects only small statistically significant differences in views of bioenergy (without CCS) compared to views on BECCS. These technologies both have medians of 4 over all COPs meaning "neither agree nor disagree" and lower quartiles of 2, which signal a consistent middle-of the road viewpoint. The upper quartile for BECCS, however, shows a statistically significant increase from about 5 to 6, indicating slightly more positive views of BECCS from COP 23 onwards. In contrast, the upper quartile for bioenergy is variable and could be seen to decrease from 6 to 5. Thus, it could be surmised that the increase in the popularity of BECCS in this case is due to an increased acceptance of CCS despite slightly lower opinions of bioenergy.

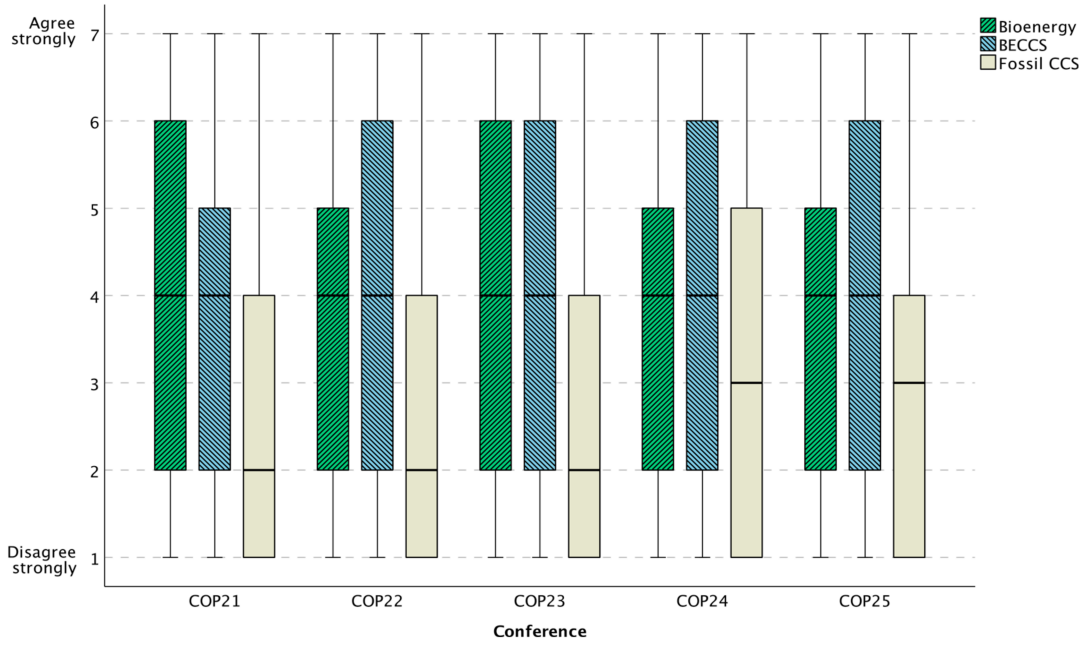

Figure 2. Survey data from general attendees at the COPs indicates an overall more positive response to BECCS than fossil CCS, and to BECCS than bioenergy without CCS.

For fossil CCS, we see a low and static approval rating until COP 24 (the COP where the IPCC SR 1.5 was launched) where we see a slightly higher approval with an increase in the median response for fossil CCS, although there is still mostly disagreement that fossil CCS should attract investment. Although the question is about investment, which could be slightly off point for our purposes, we still see the outcome as an indication of pervasive non-acceptance of fossil CCS, especially when compared to BECCS. At COP 24, we also see the median for fossil CCS increase for the first time in all our years at COP, even though

there is a large anti-fossil fuel movement with many delegates protesting to divest from fossil fuels within the COPs. This outcome could potentially be due in part to the SR1.5 (even if it cannot be proven), which put an urgency on mitigation and seemed to bring some delegates to an understanding of the need for CCS in general. We also perceived this shift in attitudes in our conversations in the margins of the COPs.

To further illustrate these conclusions, we include a line chart (Figure 3) of the percentage of all respondents that have marked "agree slightly" to "strongly agree" that investments should target BECCS or fossil CCS, (i.e., all respondents that have answered 5, 6 or 7). This is perhaps a more visual representation of how views have become more positive over time, although at a very low level overall for fossil CCS. We include the data for bioenergy to shed light on whether any change in views on BECCS are more likely related to CCS or to other issues around bioenergy as a whole. As previously stated, objections to bioenergy are usually related to biomass availability and potential conflicts with biodiversity and food security [23]. However, it is also possible that objections to BECCS could originate from a lack of faith in CCS technology. For example, Anderson and Peters [36] state "The idea behind BECCS is to combine bio-energy production with CCS, but both face major and perhaps insurmountable obstacles". The data indicate that the increased acceptance of BECCS is most likely the result of an increase in acceptance in CCS overall rather than an increase in the acceptance of the use of bioenergy for fuel. This is because we see bioenergy acceptance decrease as BECCS acceptance increases. Alternatively, it is possible that these trends reflect the opinion that NETs are of such great importance, that bioenergy would only be acceptable as a fuel when coupled with CCS to deliver the greatly needed NETs. In this scenario we could surmise that attitudes on CCS may be increasing with an increasing awareness of the need for long-term NETs.

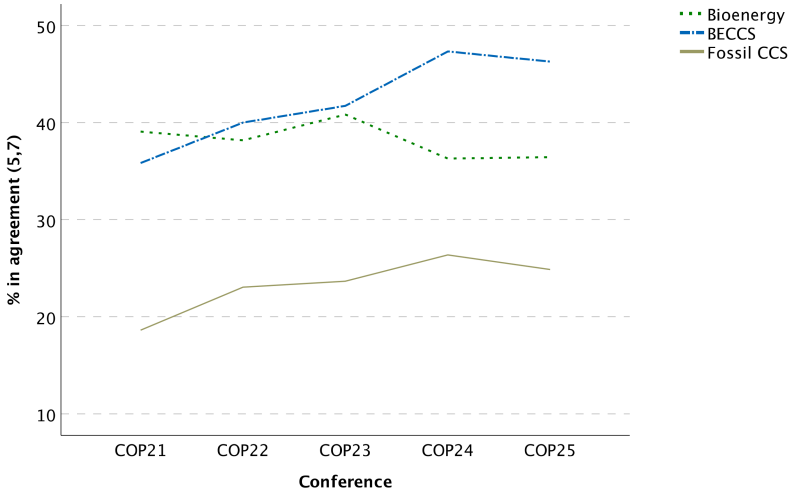

Figure 3. Line graph comparing responses of 5 (agree slightly) or above for bioenergy, BECCS, and fossil CCS. The graph indicates more positive attitudes over time for BECCS and fossil CCS and more negative attitudes for bioenergy without CCS.

3.2. Attendees of Official UT and IEAGHG CCS Side-Events versus Other Delegates

We now turn to a cross-sectional analysis of attitudes around bioenergy, BECCS, and fossil CCS from delegates within the CCS side-event compared to those within the general COPs as a way to gain insights into the impact of these side-events. Attitudes of participants attending the UT and IEAGHG side-event at COP 22, COP 24 and COP 25 are compared to the rest of the delegates attending COP 21–25 (Figure 4). The Bonferroni corrected Kruskal–Wallis test indicates that there are no statistically significant differences between views of bioenergy or BECCS among delegates within the general COPs. Both technologies have medians of 4, lower quartiles of 2 and upper quartiles of 6. These delegates also have a low opinion of fossil CCS indicated by a median of 2 with lower

and upper quartiles of 1 and 4, respectively. These attitudes are in stark difference to those of the participants of the UT and IEAGHG side-event where we see significantly more positive views of both BECCS and fossil CCS compared to the rest of the delegates. Interestingly, views on bioenergy are significantly lower (median = 3.5) for attendees of the CCS side-event than for the delegates of the general COP (median = 4) and they are lower than for BECCS and fossil CCS, suggesting that for this population, CCS improves views of bioenergy. BECCS is also seen as more favorable than fossil CCS. Taken together, all of these relationships indicate a significantly higher view of CCS for attendees of the UT and IEAGHG side-event versus those who were not at the side-event.

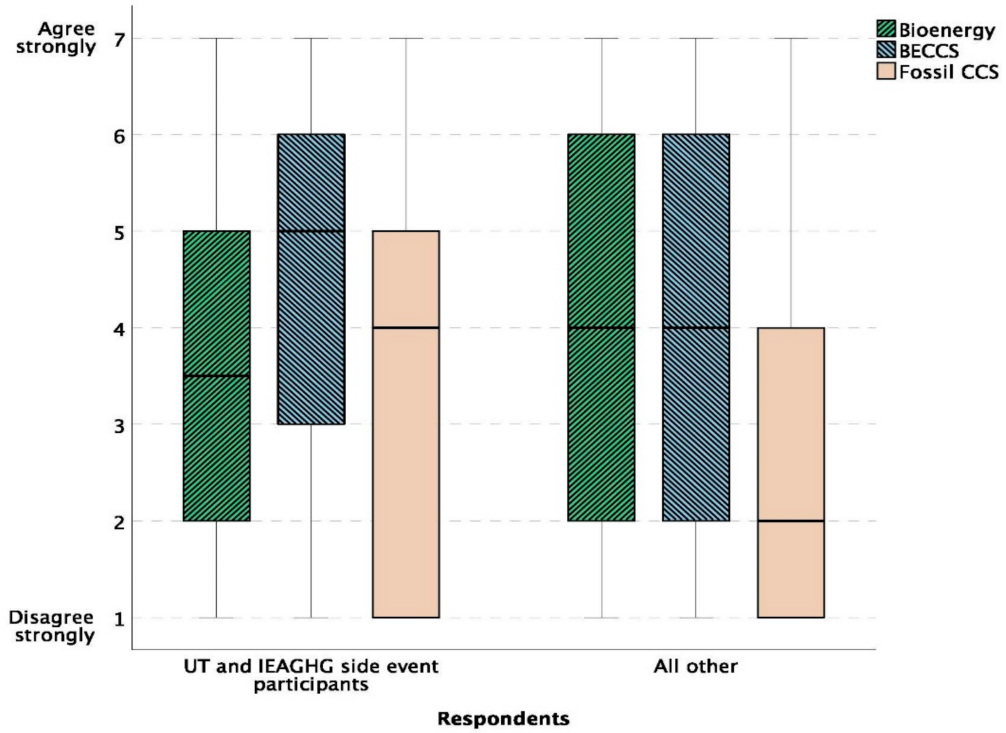

Figure 4. Views of the importance of bioenergy, BECCS and fossil CCS from participants who were surveyed within the UNFCCC side-event on CCS versus those who were sampled within the general delegate population. Side-event data are from COP 22, 24, and 25.

We note that side-event attendance is self-selecting; that is, only the people who have some type of interest in CCS and have no other scheduling conflicts will attend. It is also important to check if UT and IEAGHG side-event participants are generally more positive in their response patterns than other participants because they perceive greater needs in the energy system of their countries of residence. Therefore, we tested respondents' views of their current electricity production system and beliefs about the need for investment into low-carbon electricity production. Such differences cannot be detected. The same goes for their views on bioenergy (as reported in Figure 3) as well as solar, wind and ocean power. Hence, there is no generally positive response bias among UT and IEAGHG side-event participants that can explain their generally more positive views towards directing investments into BECCS and fossil CCS compared to the other COP delegates.

3.3. Different Groups

We also tested for differences among actor types both within the general COP assembly and at UT and IEAGHG CCS side-events (COPs 22, 24 and 25) in order to understand the general views of each audience. Of additional interest is to define the groups that are attending the UT and IEAGHG CCS side-events and thus being reached by the information provided. For the survey, the number of respondents (n = 4305) in each group are reported

in Table 1, with governmental respondents totaling 1711, respondents representing business (379), environmental (733) or research (650) NGOs totaling 1762, and other NGOs, media representatives and unspecified totaling 832 respondents. The same table reports the number of respondents at UT and IEAGHG CCS side-events and the calculated response rates of attendees. The response rates of 46% (COP 22), 74% (COP 24), and 40% (COP 25), were calculated by dividing the number of respondents by a headcount of people seated for a majority of the duration of the events. We view the diversity of respondents as a proxy for the composition of all delegates attending the events. In Figure 5, we lump these respondents together for the analysis.

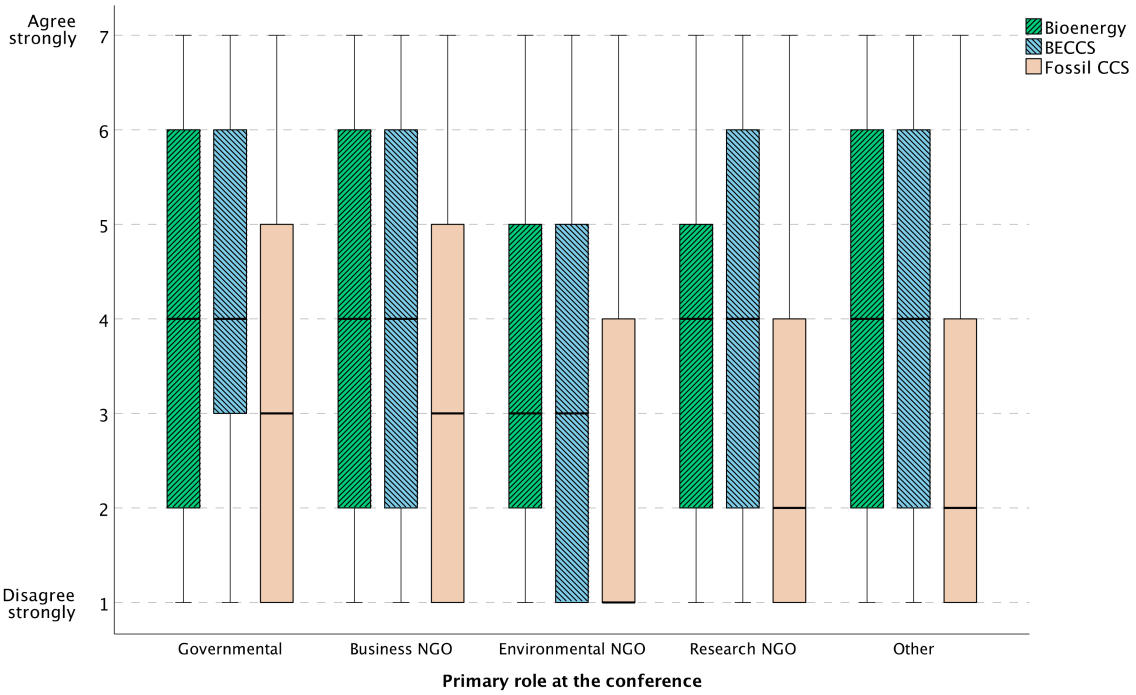

Figure 5. Responses on the importance of investing in bioenergy without CCS, BECCS or fossil CCS among different actor-types at the UNFCCC COPs" (including, but not limited to, delegates attending side-events).

The results show that across the board, environmental NGOs view all of the listed mitigation technologies as less desirable than other groups view them. For BECCS, statistically significant differences can be detected between researcher, governmental and business groups, which have the most positive views, and environmental NGOs, which have the least positive views. This trend is very similar for bioenergy with medians that consistently match BECCS in all groups. Looking at upper and lower quartiles of bioenergy versus those of BECCS, CCS appears to slightly improve the case for bioenergy for governmental and research NGOs whereas it generally decreases the opinions of environmental NGOs regarding bioenergy. Other respondents seem to be indifferent to the CCS component. Environmental NGOs are the only ones that break with this bioenergy trend, seeing bioenergy with CCS as slightly less positive than bioenergy alone.

For fossil CCS, business and governmental groups have the most positive views, with environmental, researcher and other NGOs having the least positive views. In fact, environmental NGOs display a median of 1 (disagree strongly). It is extremely rare to see a median around disagree strongly in this type of response format, which has been reported to have a slight positive bias overall (i.e., it does not influence comparison among groups). Environmental NGOs stand out as having an extremely strong negative position on fossil CCS. The contrast with solar and wind, for which we have medians of 7 for these groups in some regions, is stark. Fossil CCS competes with nuclear for the lowest score. We find this extremely interesting given the technical viability of CCS technology, its role within

mitigation scenarios assessed by the IPCC, and its inclusion within financial mechanisms such as the UNFCCC CDM.

Thus, it appears that overall, more discussion with environmental NGOs on the topic of CCS to resolve misunderstandings and mediate between conflicting views is needed. This is also the case with research and other groups which could also benefit from such discussion. Data from Table 1 indicate that UT and IEAGHG CCS side-events have roughly 24% environmental, 24% researcher, 21% governmental, 15% business, and 16% other groups in attendance over the years and is reaching a good mix of the groups that would benefit most from the information and discussion that is provided by the platform of an official side-event.

3.4. Annex 1 and Non-Annex 1 Countries

We use Annex 1 (A1) and non-annex 1 (NA1) designations as a proxy for developed and developing countries, respectively, and report the data from the general COP population, both within various side-events and from the general COP 22–25 population (n = 930). Figure 6 shows the level of agreement or disagreement by delegates residing in these two country-types regarding whether bioenergy without CCS, BECCS, and fossil CCS should be targeted for investments. Here, we see a statistically significant difference between respondents in the two types of countries for bioenergy without CCS, with delegates from NA1 countries being more agreeable (median = 4) compared to delegates from A1 countries (median = 3). For BECCS, there is no significant difference between the two country-types, but for fossil CCS we see significant difference, with NA1 countries more amenable to fossil with CCS (median = 2) compared to A1 countries (median = 3).Thus, overall, we see less negative assessments of all technologies in NA1 countries, suggesting that delegates from these countries are more open to bioenergy as a whole (with or without CCS) and also to fossil fuel investments relative to delegates from A1 countries. This outcome perhaps indicates greater needs in these countries for investment in energy production overall with advantage given to non-fossil energy sources (bioenergy and BECCS with median = 4, fossil CCS median = 3).

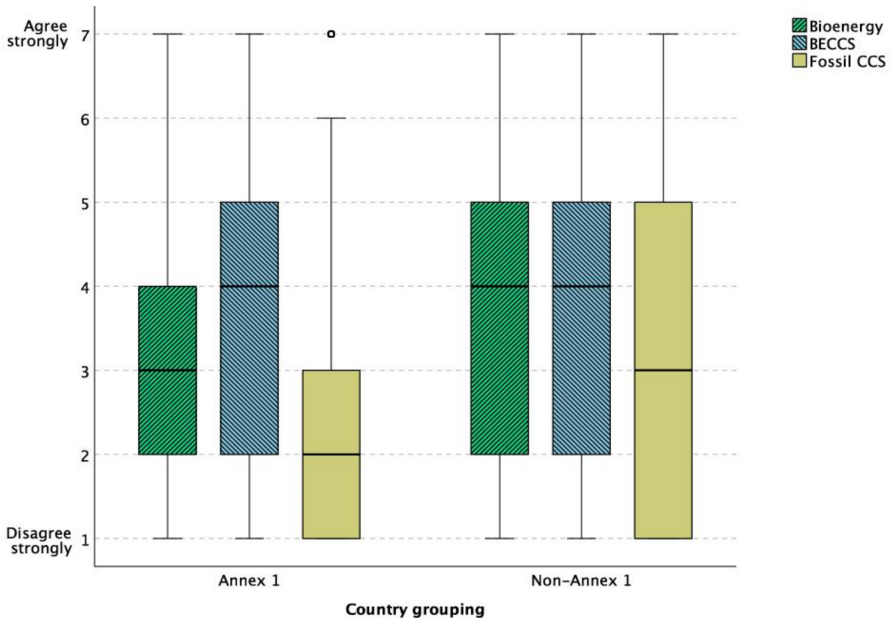

Figure 6. Level of agreement or disagreement by delegates residing in Annex 1 and non-Annex 1 countries that bioenergy, BECCS, and fossil CCS should receive investments in their country.

A significant result for A1 countries is the higher approval rating for BECCS (median = 4) than for bioenergy without CCS (median = 3). This result indicates that CCS actually en-

hances the approval for bioenergy. With this result in mind, it appears that the low results for fossil with CCS (median = 2) reflect anti-fossil sentiments even if fossil is mitigated by CCS. Higher support for BECCS versus bioenergy without CCS suggests that disbelief in CCS is not the reason for the low opinion of fossil CCS from A1 delegates but that the fossil component is the source of the disagreement. The data reflect a belief that fossil fuel companies should not receive investment even when mitigated with CCS.

To look deeper into these attitudes between A1 and NA1 countries, we look at the self-assessed level of acquaintance with the concept of BECCS, and views on the extent to which BECCS is likely to contribute to the global 2 °C goal as well as views on substantial mitigation in the respondents' countries of residence. Figure 7 shows data from respondents attending various official side-events at COP 22–25 (n = 930). A total of 775 respondents indicated country of residence allowing us to put them in A1 and NA1 country groupings. A1 = 520 respondents on this item, NA1 = 255. Although the samples size for this question is relatively small which affects significance levels, we consider this assessment to give insights into the interest and need for information on CCS from these types of countries.

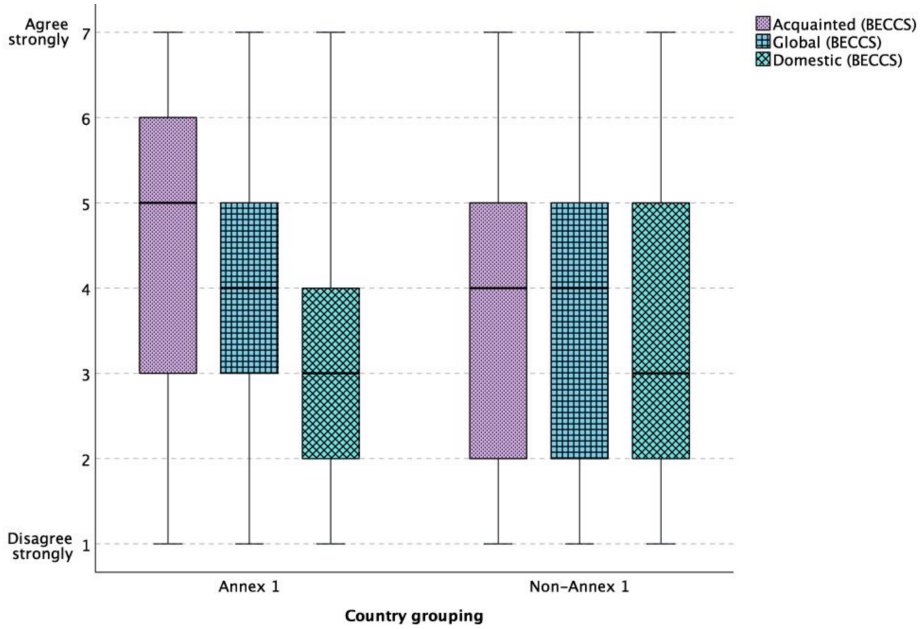

Figure 7. Self-assessed technical readiness and views on the deployment of BECCS to limit global temperature rise to 2 °C through global deployment or deployment of BECCS in respondents' country of residence.

The results suggest that A1 country delegates feel more educated on BECCS (median = 5) than NA1 country delegates (median = 4). A1 country delegates believe that there is a greater need for BECCS in other countries (median = 4) rather than their own (median = 3). In contrast, NA1 country delegates appear to feel a lesser technical readiness and greater need for information and have a greater belief that BECCS should receive investment both globally and in their own countries. With respect to views on BECCS being likely to contribute to the global 2 °C goal, we see no statistically significant difference between A1 and NA1 countries. These results support the notion that there is both a larger need and a greater appetite for information on BECCS in developing countries than in developed, but that a need still exists in both types of countries. Note that this question was not surveyed for the other discussed technologies.

4. Future Expectations and Challenges

Future deployments in CCS, including BECCS, remain uncertain. Our results indicate, for example, that UNFCCC delegates prioritize investments in CCS relatively low. The

share of delegates that prioritize CCS is, however, increasing over time. Whether this trend will continue into the future is an empirical question, yet, if it were, it would be in line with expectations. In the wake of new record high levels of atmospheric CO_2 concentrations year by year, the role of CCS in climate transition pathways is elevated. The growing awareness of the potential contributions that CCS can make to mitigate climate change is likely to lead to a continuously increasing support for directing investments towards CCS technology.

While CCS is far from a panacea for resolving the climate crisis, many industrial processes rely on CCS for the reduction of fossil CO_2. It is true that in some processes, CCS is one among several alternatives to achieve decarbonization. In steel production, for example, CCS competes with replacing coal by hydrogen [37]. Carbon-intensive goods can also be substituted, such as by switching from using concrete to wood in construction [38]. However, CCS remains an important—sometimes the only—option to decarbonize industrial processes. It is likely that it will have to be deployed to some degree in production of steel, cement, heat, power, and fuels to be able to limit global warming well below 2 °C. In addition, the ability to combine bioenergy with CCS (BECCS) to generate negative emissions is increasingly forwarded as a potential complement to emission reductions. The quickly diminishing carbon budget for the Paris Agreement's temperature objective means that the luxury of being able to choose between increased ambition in emission reductions or to effectuate CO_2 removals is no longer available. Fulfilling the Paris Agreement will require both drastic emission reductions and large amounts of removals [13].

The debate on the role that BECCS should play in producing negative emissions is relatively nascent but is becoming more and more vivid by the day, as is the research on negative emissions [39]. The potential of BECCS to produce negative emissions on large scales has meant that it has received a lot of attention in climate modelling, and increas-ingly also in politics [40,41], but it is also noted that modeling the global potential of a large set of highly context-dependent negative emission technologies is difficult [42,43]. In the near future, we will likely see an intensified debate also on other CO_2 removal options, and how these may supplement BECCS deployment. An increasing attention to alternative sources of negative emissions is already visible in how integrated assessment models recently have diversified their technology portfolios with more negative emission technologies, such as DACCS [44]. As yet, however, BECCS, alongside afforestation, remains a key technology in assessments of the potential for CO_2 removals. This is likely to remain the case in the near future (see for example [43]).

The challenge for CCS deployment at a scale sufficient to make a difference for the climate is marked by a persistent inability of governments to agree on conducive policy environments for CCS. The lack of policy support is particularly obvious for BECCS, but pricing mechanisms and other policy instruments intended to spur CCS have also failed to provide incentives that are both robust and sufficiently high for companies and inves-tors to engage with CCS at scale [45]. There is surely scope for further technology devel-opment, with new and promising pre-combustion technologies in development [46], but post-combustion technology is by large already well proven. The challenge is one of de-signing and agreeing on effective policy. New policy must be acceptable to policymakers and publics alike. Moving forward, it is obvious from history that lack of acceptance will undermine the effectiveness of policy instruments to spur CCS, including BECCS, de-ployment. Any policy to incentivize CCS, therefore, must be developed responsibly, in-volving a broad set of actors in the policy processes. It is at this juncture we stand today, one where we see an increasing need for expeditious CCS deployment to help mitigate climate change but also one marked by a need to tread carefully to build CCS policy re-sponsibly to ensure its robustness [47,48]. At this juncture, continued debate to under-stand conflicting perspectives on viable and advisable futures for CCS is much needed, one to which Official CCS side-events at UNFCCC COPs can contribute substantially.

5. Conclusions

We report on survey data collected by Linköping University within UNFCCC COPs 21–25 regarding attitudes on investing in bioenergy, BECCS, and fossil fuel with CCS. The data were collected from respondents within the general population attending the COPs and also within some specific UNFCCC official side-events. UT and IEAGHG official side-events on CCS have been held at six COPs and were some of the events surveyed. Whilst the data reported in this study were not intended to provide direct feedback to the CCS side-event organizers, they are unique and useful in providing evidence on the views of fossil CCS and on BECCS in the UNFCCC COP environment.

Although CCS is a proven technology and accepted within the UNFCCC, many UNFCCC delegates believe CCS technology is not viable. The information assessed in this study allows a more targeted approach to information input at the COPs, making CCS side-events more effective at providing technical information to the groups with the greatest need for information.

A unique method for drawing out information from these surveys on attitudes regarding CCS was to include bioenergy without CCS in our assessment. By looking at differences between attitudes on BECCS versus bioenergy without CCS we could access another layer of information on whether the CCS or the biomass supply component of BECCS was causing the reported opinions.

One unexpected conclusion is that there has been a positive change in attitudes over time for both fossil CCS and more so for BECCS. We saw a low and static approval rating for fossil fuels with CCS until COP 24 when more respondents gave a slightly higher approval, which we surmise may have been from the IPCC SR1.5 report that put an urgency on mitigation and brought more delegates to an understanding of the need for CCS in general. The data suggest that the increased acceptance of BECCS is the result of an increase in acceptance in CCS overall rather than an increase in the acceptance of the use of bioenergy for fuel.

The results also show that attendees to the CCS side-events are more positive towards CCS than non-attendees in the COPs, which cannot be explained by their country of origin. Along with other evidence on attendee numbers observed at the CCS side-events, the results and conclusions suggest that official CCS side-events are, along with other events and sources of information on CCS, worthwhile information-providing and capacity building activities to be provided at COPs.

Environmental NGOs stand out as having a strong negative position on fossil CCS and also on BECCS. We find this extremely interesting given the technical viability of CCS technology, its role within IPCC mitigation scenarios, and its inclusion within financial mechanisms such as the CDM. We conclude that more discussion and a deeper understanding of the issues surrounding CCS is needed, especially with many of the environmental and research NGOs. When looking at the makeup of the UT and IEAGHG CCS side-events, we find that as many as one fourth of the attendees are from environmental and research groups, illustrating the continued need for these events to reach the intended groups.

With respect to developed and developing countries, the data show that CCS actually enhances the approval for bioenergy. With this result in mind, it appears that the low results for fossil with CCS reflect anti-fossil sentiments even if fossil is mitigated by CCS. Higher support for BECCS versus bioenergy without CCS suggests that disbelief in CCS is not the reason for the low opinion of fossil CCS from developed country delegates but that the fossil component is the source of the disagreement. Furthermore, we see that there is both a larger need and a greater appetite for information on CCS in developing countries than in developed, but that a need still exists in both types of countries.

Regarding whether side-events on CCS are directly impacting delegates' views, a study design focusing on the same delegates' views on the same set of questions prior to and after a CCS side-event would be needed. The results suggest that CCS information at COPs should be targeted to environmental NGOs and to developing country delegates.

Overall, the main conclusion is that more information is needed on CCS in the UNFCCC COPs.

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