From polarization to reluctant acceptance–bioenergy with carbon capture and storage (BECCS) and the post-normalization of the climate debate

Simon Haikola, Anders Hansson & Jonas Anshelm

To cite this article: Simon Haikola, Anders Hansson & Jonas Anshelm (2019) From polarization to reluctant acceptance–bioenergy with carbon capture and storage (BECCS) and the post-normalization of the climate debate, Journal of Integrative Environmental Sciences, 16:1, 45-69, DOI: 10.1080/1943815X.2019.1579740

To link to this article: https://doi.org/10.1080/1943815X.2019.1579740

© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

Published online: 18 Mar 2019.

Submit your article to this journal

Article views: 532

View related articles

View Crossmark data
From polarization to reluctant acceptance—bioenergy with carbon capture and storage (BECCS) and the post-normalization of the climate debate

Simon Haikola, Anders Hansson, and Jonas Anshelm

ABSTRACT
The paper covers the public debate on BECCS (bioenergy with carbon capture and storage) between 2008 and 2018. Through a qualitative analysis of around 800 feature articles, editorials, and opinion pieces published in English, German, Swedish, Danish, and Norwegian in news media and debates sections of scientific media, we highlight conspicuous aspects of the debate and relate them to the theoretical concept of post-normal science. We find that the debate is characterized by an emphasis on values, scientific uncertainty and the integrity of science, premised on a pervading sense of urgency. To a significant extent, the debate can be understood as a “normal” view of science questioning what it perceives to be unscientific model-based climate scenarios, and the scenarios, in turn, can be seen as a response to post-normal circumstances. The urgency permeating the debate provides conditions for open debate about ethical and epistemological uncertainty. The debate goes through a period of polarization—corroborating findings from previous studies on the climate science debate after COP21—between an intense critique of BECCS inclusion in climate scenarios and reluctant acceptance thereof. Towards the end of the studied period, emphasis shifts towards reluctant acceptance, indicating that post-normal debate may only occur as a temporary state always tending towards new consensus.

Article history
Received 14 February 2018
Accepted 31 January 2019

Keywords
BECCS; the IPCC; climate science debate; Paris agreement; climate politics; post-normal science

Introduction
Since the 2015 United Nations Climate Change Conference in Paris (“Paris Conference”), the united front presented by the scientific community regarding how to deal with anthropogenic climate change has dissolved. The reason seems to be that a growing consensus that the time horizon for ordered and gradual decarbonization is rapidly shrinking (see, e.g., Figueres et al. 2017), has brought into the open disagreements among scientists as to the precise methods for achieving such societal transformation (Beck and Mahony 2017; Guillemot 2017; Livingstone 2018). At the centre of this debate is bioenergy with carbon capture and storage (BECCS),1 a controversial technology mentioned in the periphery of the mitigation discourse since the mid-1990s (Hickman...
Economic models of climate change, so-called integrated assessment models (IAM), used to evaluate different sociotechnical development trajectories, have begun deploying large amounts of technologies for removing carbon from the air, among them direct air capture, enhanced weathering of minerals and re/afforestation. The vast majority of mitigation scenarios referenced in the Intergovernmental Panel of Climate Change’s (IPCC) Fifth Assessment Report and in the more recent IPCC special report on the 1.5°C target that are considered likely to limit global warming to 2°C, include significant deployment of BECCS, which is preferred by models due to its relative (theoretical) cheapness (Lehtveer 2018; IPCC 2018a). With some time lag, governments and agencies in a few countries, e.g., Sweden, Denmark, the UK and also the European Academies’ Science Advisory Council (EASAC), have responded to this fact by initiating investigations into different negative emissions technologies (Mortensen et al. 2017; BEIS 2018; EASAC 2018; Swedish government 2018). Before the debate that followed from the Paris 2015 meeting, several scientific studies had already pointed to net negative emission technologies (NETs) being warranted, crucial, or cost-effective for ambitious emissions targets (e.g. Azar et al. 2006; Edenhofer et al. 2010). As BECCS have started to move from the theoretical world of modelling to that of policy-making, several researchers have begun to speak out against what they perceive as an illegitimate use of science. In their view, the uncertain scientific foundation of BECCS means that scientists should advise against it being considered an important mitigation technology in policy-making since it risks leading to further fossil fuel lock-in and severe negative impacts on food security and biodiversity conservation (e.g. Anderson and Peters 2016).

In this paper, we describe and analyse the public debate on BECCS from 2008 to the spring of 2018. We argue that this debate can be understood in relation to the concept of “post-normal science”, i.e., science in which both decision-stakes and uncertainties – of methodological, technical, as well as epistemological kinds – are high (Funtowicz and Ravetz 1992, 1993; see also Hulme 2007; Saloranta 2001). We pose the following research questions:

- What views on BECCS as a mitigation technology has figured in the mitigation public debate during the period?
- How has the climate-economic science informing the IPCC’s fifth assessment report been described in the public debate about BECCS?
- What is a legitimate role for climate science in relation to policy-making, according to protagonists in the public BECCS debate?

The analysis is guided by our aim to first outline the main features of the public BECCS debate as regards arguments and rhetoric, and then to analyse what characterises the debate in terms of views on the role of science in relation to policy-making. The analysis thus has two parts: one more descriptive, and one analytically driven in which we relate to the concept of post-normal science. We find that this concept is applicable in two ways. First, in terms of how climate science is conceived of descriptively within the debate. Some lament and criticise what they regard as a loss of scientific rigour and legitimacy in the climate-economic modelling science that underpins the IPCC’s reports, while others describe policy-relevant climate science as a necessary adoption to unique
circumstances. Secondly, the concept is applicable because of the way protagonists argue *prescriptively* about how science should be conducted at the interface with policy, with issues of morality and values given pride of place within the debate. We further posit that these post-normal aspects foster a special kind of debate, characterized by polarization but little substantive difference between argumentative positions.

The paper can be seen both as an empirical contribution to the literature on post-normal science, and as illuminating the main perspectives within the scientific community on the most frequently debated NET in recent years.

*Post-normal science and the climate science debate*

In this paper, we adhere to the definition of post-normal science proposed by Funtowicz and Ravetz (1992, 1993), i.e. science in which 1) decision-stakes are perceived as high while decisions are urgent and stakeholders hold conflicting interests, leading to significant value-commitments, and 2) there are high uncertainties as regards the behaviour and characteristics of the systems being studied, uncertainties that are not only of a limited technical kind but also of a more complex methodological kind and, furthermore, epistemological in nature. Such deep-seated uncertainties about the ability of science to deliver definite answers foster ethical uncertainties and may lead to fundamental and reflexive questions about science’s role in decision-making under high uncertainty (see further Craye 2006; Ravetz 2010). Whereas “normal science” is characterized by certain key assumptions shared by its practitioners, for example, its value-free nature, post-normal science is characterized by open discussions about the values and uncertainties underpinning scientific knowledge production (e.g. Saloranta, 2001; Turnpenny et al. 2011).

Obviously, this theoretical distinction invites critical questions as to where the line should be drawn between supposedly normal science and a post-normal one. After all, most, if not all, scientific fields would seem to harbour uncertainties that could be deemed significant, and decision-stakes are without doubt a highly relative concept. As Turnpenny et al. (2011) noted, the concept post-normal science is often used normatively, as a prescribed method for the scientific community to deal with the special demands forced on it by post-normal conditions (e.g. Hulme 2007). The focus is then often on the need to broaden the peer community allowed to have a say in the process of making political decisions based on science, based on the assumption that the high stakes and uncertainties involved increase the need for democracy and transparency. This is indeed how Funtowicz and Ravetz proposed the term in their original papers (1992, 1993), and with the onus thus placed on what the authors deem to be needed rather than on certain characteristics of the object of study, there is less need for a rigorous definition.

In this paper, however, we have no such normative ambitions but use the concept analytically to describe how parties to the BECCS debate reflect on, argue about, and make recommendations for policy-relevant climate science. We should, therefore, establish some key points in our understanding of post-normality.

First, it should be stressed that what we are analysing is not the climate science itself, but rather how scientists and other public interpreters of science are debating it and its relationship to policy-making. Thus, when we claim that the BECCS debate is post-normal, this claim pertains specifically to how the science of BECCS is construed and
represented by practitioners and interpreters of climate science in the public debate, not to the actual practice of scientific investigation of BECCS (although, of course, the debate about science could and should be understood as integral to the “construction” of scientific knowledge). Furthermore, we do not posit post-normal aspects as absolute qualities that differentiate the BECCS debate from normal scientific debates in any definitive sense. Rather, post-normality, as understood here, is a matter of the degree to which the debate’s protagonists construe climate science about BECCS as crucial for urgent decisions with ramifications for future generations worldwide and suffused with uncertainties in the ethical and epistemological dimensions of the science–policy interface. We, therefore, suggest that post-normality can be used to describe a scientific debate that openly grapples with such issues, rather than focusing on more narrowly defined questions about technical uncertainties.

Departing from Funtowicz and Ravetz (1993) original call for a post-normal science in which “uncertainty is not banished but managed, and values are not presupposed but made explicit” (p. 740), we argue that “post-normal” can be used to describe a scientific debate in which protagonists advocate employing some form of post-normal methodology to manage uncertainty in the science in question, and in which the debate itself advances issues of epistemological uncertainty and value deliberation. We further posit that in the case of BECCS, the post-normal aspects produce certain effects as regards the tone and structure of the debate, which we reflect on in the concluding discussion. Finally, we argue that the BECCS debate has moved from polarization towards a state where BECCS is normalized, and we take this as a basis for hypothesizing that post-normal scientific debate may only occur as a strictly limited temporal phase.

Several authors have analysed climate science, especially the work of the IPCC, in terms of post-normal science over the last two decades. Some have argued that climate science has begun to adopt post-normal traits in different institutional fora over the last two decades (e.g. Bray and von Storch 1999; Etkin and Ho 2007), while others (e.g. Asayama & Ishii, 2014; van der Sluijs 2012) have instead highlighted how climate scientists attempt to reconstruct a form of normalcy in the face of post-normal conditions.

Two trends in the climate science debate deserve emphasis as important for understanding what we here describe as the post-normal aspects of the BECCS debate. First is a series of external pressures on the scientific community in the form of political imperatives and highly publicized controversies related to climate science (e.g. Berkhout 2010; van der Sluijs 2012; Guillemot 2017). These pressures have to some extent lowered the barrier between the scientific community and the wider community of stakeholders, as the former has been forced to engage in public discussion about the uncertainties inherent to climate science and to a certain extent about differing opinions regarding what should be done to address the climate threat. Second, the BECCS debate has been preceded by a more general geoengineering debate characterized by a highly value-laden and morally tinged rhetoric, as a more or less unanimous scientific establishment has warned against what they have described as ethically questionable methods for managing the climate (Asayama 2015; Nehrlich and Jaspal 2012; Loukkanen et al. 2013; Porter and Hulme 2013; Scholte et al. 2013; Anshelm and Hansson 2014a & 2014b).

As Guillemot (2017; see also Beck & Mahony, 2017) has noted, the formulation of the 1.5°C aim in Paris, and the framing of NETs and BECCS as key to achieving this, meant
that the established climate science community became openly divided for the first time about the role science should play in the construction of alternative futures featuring uncertain and controversial mitigation technologies. BECCS thus became a focal point for fundamental questions regarding science, politics, and morality heretofore not displayed in the public debate.

**Note on method**

In the first step we read through approximately 800 feature articles, editorials, and opinion pieces published in English, German, Swedish, Danish, and Norwegian in larger (e.g. BBC, The Washington Post, The Guardian, and Der Spiegel) and smaller (e.g. MSN South Africa and Slate Magazine) news media and in the debate sections of scientific media such as Nature and Science, as well as reports in popular science media such as Science Daily. Articles that were duplicated in the sample or merely reproduced press releases or notes on specific events were not selected for further analysis. From the original texts identified as relevant to this paper, we have cited approximately 120 to substantiate our claims. Note that the texts cited are chosen as representative of the dominant patterns within the discourse, and because they aptly capture certain main lines of argumentation or rhetorical figures that we have identified as significant carriers of meaning within the discourse. This means that they could, in most cases, have been added to or substituted from the pool of 800 relevant texts. When we cite texts that constitute rare or even singular examples of a claim within the debate, we clarify that this is the case.

Not all the texts analysed in the paper deal with explicitly scientific aspects, but they all deal in one way or another with how to justify (or not) the inclusion of large-scale BECCS in climate policy-making on the basis of uncertain science. Because BECCS is still a largely theoretical concept and there are very few facilities in operation, the debate is characterized by a high degree of abstractness, with little in the way of precise numbers or technical detail. Science, and the lack thereof is still ever-present in the debate, however, as the ground upon which decisions in the present are to be made.

The period covered is 2008 to March 2018, and most pieces were published from 2013 onwards. Our focus has been on argumentative texts expressing opinions, although some more descriptive pieces have also been included. To gather the empirical material, we conducted truncated searches in the Retriever database, which includes 12,000 newspapers globally, using the search terms “BECCS”/“NETS” and equivalents, both on their own and in conjunction with additional search terms such as “climate policy”, “COP21”, “IPCC”, and “climate scenario”. Though the coverage of the database is not exhaustive, it is sufficiently wide-ranging that we are unlikely to have missed important aspects of the debate that would significantly alter our analysis. We read through the 800 texts identified as relevant to our study inductively with the purpose of identifying patterns of meaning and of creating categories for recurring and central themes.[1] Through the first reading, we noted that the debate was intensified in connection with certain “focusing events”, for example, the leaking of information about the IPCC’s Fifth Assessment Report in April 2014, the observation that was made public in the spring of 2015 – before the Paris negotiations – that IPCC relied heavily on BECCS in its new report, the observation after Paris that the climate agreement presupposed large-scale BECCS implementation, and the publication of the
European Academies’ Science Advisory Council’s report in February 2018. The significance of such focusing events for how the debate evolved made a chronological presentation of our analysis seem necessary. Presenting the debate in that manner did not prevent us from highlighting certain recurring categories of meaning, such as the prevalence of religious, mythical and pop-cultural metaphors, the importance of modeling, the trust or lack of trust in the IPCC, the dilemma of moral hazard, the inability of international policy-making regimes to implement necessary mitigation measures, unrestrained belief in technological progress, and the influence of technocrats, economists and natural scientists in climate policy. We found that the prevalence of these specific categories testified to the relevance of the concept of post-normal science. In the concluding discussion, we, therefore, relate these central categories to certain aspects of the post-normal science theoretical frame and reflect on their meaning in a wider context of climate politics. First, in the following, we present a descriptive analysis of the public BECCS debate.

The public BECCS debate

The concept of BECCS has been known among researchers since the 1990s, but it was not until 2013 that the mitigation potential of this novel method started to draw the attention of the international mass media.1 (1) With reference to research reports, BECCS was pinpointed as the most promising of the so-called carbon dioxide removal (CDR) technologies. (2) In some contexts, BECCS was framed as “the climate’s saviour” and contrasted with the ineffectual international climate negotiations. (3) However, amidst the optimism about BECCS, other voices raised the risk of “moral hazard”, i.e., that the promise of a technological solution would reduce the pressure on policy-makers to take drastic mitigation action. Hence, at this early stage of the debate, BECCS was presented as part of a dual strategy also including ambitious emission reductions. (4)

Before Paris: formation of the critique

In March 2014, Reuters revealed that leaked information hinted that the forthcoming IPCC Fifth Assessment Report (AR5) would ascribe an important role to a relatively unknown technology called BECCS. Various experts were interviewed in relation to the news that virtually all long-term climate scenarios for stabilizing the temperature at acceptable levels included BECCS. While some saw this as a clear sign that BECCS was becoming a real policy option, others emphasized its significant and unresolved problems, most notably its high cost, unproven functionality on a larger scale, and demand for vast land areas, with territory larger than India being mentioned as required in the more ambitious scenarios. For several experts, these uncertainties and problems meant that BECCS could at best be considered a partial solution. (5) Several major international newspapers picked up the Reuters story. In a few contexts, the news was welcomed as a sign that more alternatives were now available in the struggle against global climate change, with reservations about the challenges the technology faced. (6) Other sources noted that the EU, China, Japan, Russia, and other countries called attention to the need for AR5 to emphasize the major uncertainties linked to BECCS, such as land-use trade-offs, water shortage, and impact on biodiversity.
However, the strongest objections came from environmental nongovernmental organizations (ENGOs) such as Greenpeace and Biofuelwatch. They stressed their belief that BECCS was a totally unproven and “very risky” technology that could, in fact, aggravate climate change while exacerbating existing agricultural and water shortage problems; accordingly, BECCS was framed as a “false solution”. Meanwhile, criticism of BECCS was also growing in the scientific literature. Here, the main argument was that the IPCC would be irresponsible to assign an important role to BECCS at a time when many countries were already too reliant on technological solutions rather than focusing on ambitious emissions reductions by other means. Betting on BECCS would be a high-stakes gamble, according to these ENGOs, leading to soaring food prices and intensified land grabbing. It was further claimed that the method would not be commercially available in time and that it risked leading to eventual CO₂ leakage and increased fossil fuel production through enhanced oil recovery. In this critique, BECCS was considered a “dangerous distraction” from the urgent imperative to reconfigure global energy systems, allowing for the risky dream of emissions overshoot followed by subsequent remediation. Biofuelwatch’s spokesperson Rachel Smolker stated that the IPCC should not support such unsustainable dreams of “business as usual”. (8)

In April 2014, as information from the forthcoming AR5 became publicly known, many newspapers noticed that most of the 2°C scenarios underpinning the IPCC’s analyses required BECCS. AR5’s implicit support of the idea of negative emissions, with BECCS playing an important role, was highlighted as controversial. According to these news reports, AR5 showed the IPCC to be convinced that the urgency of the climate threat meant that BECCS would be needed as a temporary solution, even though the method was unproven and linked to significant uncertainties. Some articles added that the mere possibility of future negative emissions could induce politicians to reduce their ambitions to mitigate climate change. However, the general message delivered by mass media at the time was that BECCS would be necessary for climate change mitigation (9) and that scientific efforts to develop this option had to be intensified. (10)

However, a few voices were sceptical of the reliance on BECCS in the IPCC scenarios. They argued that allowing for a temperature overshoot in the hope of future remediation through unproven technologies was unethical, as they stressed the techno–economic uncertainties associated with large-scale BECCS. Arguing that the IPCC should instead immediately increase pressure on policy-makers to pursue mitigation by conventional means, these critics also questioned the legitimacy of transferring a large share of the mitigation burden to future generations and less-developed countries. (11)

At its most polemical, the critique dismissed the notion of negative emissions as a “myth”. From this perspective, the IPCC was perceived to have made an irresponsible reorientation from zero- to net negative emissions, neglecting the risks of large-scale land grabbing affecting the poor and of climate-warming emissions actually increasing due to enhanced oil recovery and increased use of chemical fertilizers. Accordingly, it was claimed that no form of CDR could lead to decarbonization, which was increasingly being demanded by ENGOs, the general public, politicians, and scientists in 2014. The message was that dangerous, obscure, and “pie-in-the-sky” technologies such as BECCS could not co-exist alongside the real options. (12)

Before the COP meeting in Paris in December 2015, the number of voices questioning the large-scale deployment of BECCS in scenarios increased significantly, and influential
scientists engaged in the public debate by writing or signing critical commentaries in the daily press and in scientific journals. Between May and December 2015, the critical discussion intensified and scientists such as Kevin Anderson, Professor of Energy and Climate Change and deputy director of the Tyndall Centre for Climate Change Research, and social scientists such as Oliver Geden, head of the EU division at the German Institute for International and Security Affairs, featured prominently. Half a year before the meeting, Geden published articles in both Nature and The Guardian claiming that the politically feasible rather than the environmentally necessary was determining target setting. According to Geden, NETs in general, and BECCS in particular, enabled politicians to postpone ambitious emission reductions by noting that the IPCC had concluded that it was possible to restore balance using BECCS during the second half of this century. That would lead to considerable carbon debts being handed over to future generations. Geden’s conclusion was that climate researchers had to re-evaluate their roles before Paris, maintain their integrity, and refrain from the “temptation to become political entrepreneurs”, instead critically analysing various measures’ pros and cons. (13)

From a similar perspective, Anderson argued that climate scientists were unwilling to accept and communicate “the revolutionary implications” of their scientific results. (14)

These rather controversial statements by Geden and Anderson attracted attention and were echoed by The Washington Post a few weeks before the Paris Conference. (15) On the same grounds, 40 scientists signed an opinion piece arguing it would be extremely risky to rely on the possibility of being able to remove emissions from the atmosphere in the future, and that the enormous ecological footprints of large-scale BECCS would be unacceptable. (16) German scientists claimed that BECCS would demand 75% of the arable land globally if the 1.5°C warming target including NETS was to be seriously considered, a daunting figure in light of a world population approaching 10 billion people. As trade-offs between food and biomass production would be inevitable, these scientists deemed the estimated potential for BECCS to be unreasonable, arguing for a revision of the scenarios underpinning AR5. (17)

Similar but more polemically worded criticism came from spokespersons of ETC Group, an ENGO that accused the governments meeting in Paris of subsidizing the root causes of climate change more than they supported measures to deal with them. The assumed strategy was to bury carbon dioxide “out of sight and out of mind”. Exceeding carbon budgets, legitimized by referring to untested and uncertain NETs, could result in other, even more radical geoengineering methods being forced on societies as desperate last alternatives, when BECCS and other NETs failed to materialize as large-scale solutions, according to ETC Group. (18)

After Paris: the critique reaches its peak

When the Paris Agreement was signed in December 2015, the mass media referred to the 40 scientists who highlighted that the deal implicitly assumed that NETs, and especially BECCS, would deliver large quantities of negative emissions after 2050. The message was that such a strategy would be “extremely risky” and that the preferred alternative was drastic emission reductions. (19) While Geden categorized NETs as “science fiction”, Hans Joachim Schellnhuber, founding director of the Potsdam Institute for Climate Impact Research, argued in more moderate terms that BECCS and
afforestation could play significant roles in compensating for hard-to-achieve emissions reductions. (20) Glen Peters, senior researcher at the Center for International Climate and Environmental Research in Oslo, claimed that because CCS should not be considered an option, BECCS must be regarded as even more farfetched, as it can basically be understood as CCS with the added dimension of land-use problems. (21) Other actors raised concerns regarding uncertainties in the lifecycle analysis of BECCS, arguing that throughout the chain of biomass production and processing, altered land-use could ultimately render BECCS counterproductive. (22) ENGOs such as Biofuelwatch repeated their previous warning that BECCS would postpone real emissions reductions. (23)

The post-Paris criticism of BECCS’ role in the agreement was reinforced by Kevin Anderson in *Nature*. He claimed that NETs – “exotic Dr Strangelove options” – had now been re-categorized as part of Plan A instead of being considered last resort. Even though BECCS was not explicitly mentioned in the agreement, it was framed as necessary for its fulfilment, an assumption he found “breathtaking” given the land area needed for energy crops in a world with increasing demand for food and for biofuel for shipping and aviation. To Anderson, the reliance on BECCS was evidence of a bizarre dilemma at the centre of global climate policy and science, namely, that the dogma of “green growth” was not allowed to be questioned. The “mathematically nebulous green-growth and win–win rhetoric” developed by politicians set the conditions for both the actions on climate change and the climate scenarios, and Anderson questioned the way climate scientists had participated in this “pantomime”. He concluded that the Paris Agreement was worse than its predecessor signed in Copenhagen in 2009 and that “the world ha[d] just gambled its future on the appearance in a puff of smoke of a carbon-sucking fairy godmother.” (24)

Six weeks later, the climate change researcher Phillip Williamson, science coordinator of the Natural Environment Research Council in the UK, published a commentary in *Nature* under the title “Scrutinize CO2 removal methods”. According to Williamson, physicists and modellers rather than ecologists had dominated the IPCC since its inception in 1988, which was mirrored in the fact that nowhere in AR5’s 5000 pages were the environmental consequences of large-scale carbon removal analysed. When issues of biodiversity were taken into consideration, claimed Williamson, the promise of BECCS looked vastly different, and he suggested that large-scale BECCS could actually jeopardize more species than a global mean temperature increase of 2.8°C. Moreover, as a consequence of “land clearance, soil disturbance” and increased use of chemical fertilizers, large plantations of biomass would initially lead to net emissions and not net reductions. He also found the uncertainties concerning the impacts of climate change on future energy crop harvests, water supply, and food security to be worrying. (25)

Anderson’s and Williamson’s commentaries had a large impact on the public debate. An editorial paper in *Nature* and articles in *The Guardian* and *National Geographic* shared the two scientists’ viewpoints: that many questions remained to be resolved before conclusions could be drawn as to whether or not BECCS was just “another one-hit climate wonder”, and that the time had come to see whether the politically palatable could stand the test against the scientifically reliable. According to these texts, more or less all questions about BECCS concerning feasibility, environmental impacts, and costs remained to be answered. (26)
A few months later, Tim Krüger and Steve Rayner, the two leaders of the Oxford Geoengineering Programme, together with Oliver Geden publicly urged that the “BECCS hype” be abandoned in the IPCC climate models. They argued that the models underpinning the AR5 that included massive BECCS deployment rested on faith and were thus not compatible with “scientific rigor”, as evidence was lacking of the technical, economic, and political feasibility of BECCS. Further complicating the issue, claimed the three researchers, was that it was inherently impossible to obtain the necessary answers about the feasibility of large-scale BECCS through experiments or modelling. Local and small-scale deployment of BECCS would not provide sufficient answers about the consequences of the kind of “gargantuan-scale implementation that was presupposed in the IPCC scenarios. Echoing Anderson’s previous description of BECCS, they referred to BECCS as “science fiction” and its deployment in policy-informing scenarios as “reckless”, arguing that NETs should be discarded from the IPCC scenarios until satisfactory scientific knowledge was available. Decision-makers ought not to be given the opportunity to “hide behind” the vague formulations of the Paris Agreement, and at a time of high uncertainty, it was crucial to cleanse “magical thinking” from the models. In a call for scientific rigor, the researchers concluded: “Only by undertaking research will it be possible to determine whether today’s science fiction could be transformed into tomorrow’s science reality.” (27)

The criticism voiced by these three researchers was indicative of the polemical turn the debate had taken after Paris, while it rearticulated the same basic message that other researchers and ENGOs had expressed previously. Actors from the global south then added a further angle to the criticism. On the final day of the Paris Conference, more than 20 African social movements publicly demanded that the 1.5°C target must not be allowed to lead to land grabs. Referring to the widely held notion that the ambitious climate target represented capitulation to pressures from the most vulnerable nations, this group now voiced a fear that the global south would suffer the most if BECCS failed to deliver according to the models. Instead of changed production and consumption patterns in the rich parts of the world, the African countries claimed that they would have to sacrifice their arable land and food production capacities, based on the assumption that BECCS would work. (28)

The critical discussions intensified when Kevin Anderson and Glen Peters published a new article in Science later in 2016. They repeated their previous criticism of BECCS and concluded that even though BECCS might prove deployable at a limited and local scale, portraying it as an option to mitigate climate change was nevertheless “highly speculative”. Describing the climate scenarios as permeated by technical utopian thinking, they went on to echo the African social movements warning that poor countries in the global south would suffer the most if BECCS failed to deliver according to the models. Arguing against viewing BECCS as an “insurance policy”, they claimed that it should instead be seen as “an unjust and high-stakes gamble”, “a moral hazard par excellence”. Anderson and Peters further claimed that if the problems BECCS faced were realized, this would rapidly lead to a 4°C temperature increase by 2100, a degree of warming equalling that anticipated at Paris if no substantial measures at all were taken, and the risk of passing on such a terrible burden to future generations could not be justified. (29) Anderson and Peters’ article in Science can be viewed as representative of the perspective on BECCS that gathered strength among scientists and journalists in the public
debate after the Paris Agreement. Articles questioning BECCS increased dramatically in number in 2016, becoming overwhelmingly more numerous than those supportive of or neutral towards BECCS. Only Norway deviated clearly from this pattern, for reasons that could be easily explained by the country’s unique industrial configuration and geographical conditions. The Norwegian ENGO Bellona had already identified BECCS as an important mitigation measure in 2011, and Norway’s forestry industry, energy researchers, energy agencies, economists, and politicians have since voiced their support.

The polemical tone, dramatic metaphors, and conflict-oriented argumentation characterizing the debate in the year following the Paris Conference were very reminiscent of the rhetoric employed by critical NGOs such as Biofuelwatch, ETC Group, and Greenpeace as early as 2014. Several researchers took on a critical, political role outside the traditional role of the professional expert, sometimes explicitly arguing that under the extreme circumstances of the climate threat, a supposedly neutral stance would be equally political. The orientation towards the political was also mirrored in the metaphors that critical researchers and journalists articulated when depicting BECCS. The technology was often described in terms inspired by myths, religious beliefs, folklore, and contemporary popular culture, similar to what has previously been observed in the public debate on geoengineering and the far more controversial options for solar radiation management (Anshelm and Hansson 2014a, 2014b, 2016).

BECCS was repeatedly described as a “saviour”, but with questionable virtues. Parallels to religious myths were drawn to illustrate that promises about BECCS rested on irrational foundations rather than on scientific knowledge. For example, Krüger, Rayner, and Geden described BECCS as based on “magical thinking”, while Lili Fuhr, head of the Ecology and Sustainable Development Department at the Heinrich Böll Foundation, argued that BECCS was a quest for “the holy grail” and that NETs belonged to the world of myth. (33) Scientist Robert Jackson described NETs as “somewhere between a godsend and voodoo”, while Anderson, as mentioned, argued that the Paris Agreement constituted a gamble “on the appearance in a puff of smoke of a carbon-sucking fairy godmother”. (35) A BBC environmental reporter meanwhile labelled BECCS “a Cinderella technology”.

To conclude, this terminology can be considered as a pattern at the time and was widespread across both a variety of sources and actors. These metaphors, of course, illustrated that the calculations and estimates of the potential of BECCS underpinning the IPCC scenarios did not rest on a scientifically sound foundation, but rather on what was perceived to be politically palatable. According to critics, the IPCC premised its policy recommendations on a “dogma” of maintained economic growth and expectations of future technological breakthroughs. The
metaphors were not used to question the IPCC’s legitimacy or authority or climate modelling as such, but rather to make the claim that non-scientific concerns had contaminated the climate models. Consequently, the call was made for scientific re-evaluation and revision of the scenarios. With recourse to a language laden with metaphors, critical researchers and journalists contested the trust in NETs in a manner that would hardly have been possible if they had relied exclusively on scrutinizing and pinpointing scientific flaws in calculations. From 2015 and onwards, the voices critical of BECCS acquired more and more space in influential journals and papers and their criticism increasingly found its way into the daily press, while the voices backing up BECCS as a substantial contributor to climate mitigation became marginalized to a corresponding degree.

Reorientation and normalization of BECCS?

However, some influential researchers did not agree with the critical message that dominated after the Paris Conference, although they were considerably less vocal in the public debate. Anderson and Peter’s article in Science received a polemical response from physicist Klaus Lackner, director of the Center for Negative Carbon Emissions, together with 45 co-signers, in the same journal. In their commentary, they took issue with the characterization of NETs as an “unjust and high-stakes gamble”, arguing instead that real gamble would be taking such technologies off the negotiating table. (42) The fact that Lackner himself professed scepticism towards large-scale BECCS, and regarded other NETs as having greater potential, (43) is indicative of a wider tendency towards disillusioned fatalism that would come to dominate the debate in 2017 and 2018. This fatalism entailed a cautious acceptance of BECCS as a necessary part of any mitigation strategy, on the premise that time was running out for reliance on conventional mitigation strategies. This could be taken as indicating that, following several years of intense criticism, BECCS was now reaching a stage of normalization in the debate. By normalization, we mean that BECCS moves from being a topic of polarization (see more below, under “polarization without poles”) to being adopted as a given aspect of the mitigation discourse.

Beginning in 2017, a common line of reasoning was that political plans must imminently be made for the introduction and deployment of BECCS, both because this was presupposed by climate scenarios and because inaction, as regards mitigation by other means now, necessitated such a solution. (49) Glen Peters, for example, maintained that while scale remained a key problem regarding CCS both with and without bioenergy, implementation of CCS should be prepared immediately, because “love it or hate it, we need carbon capture and storage to keep below 2 C”. (50) Meanwhile, Oliver Geden and Andreas Löschel, professor in Energy and Resource Economics at Münster University, claimed that if such plans were not made, the IPCC must discard all overshoot scenarios. (51) Geden and Peters also published a paper in Nature in which they argued that a system for reporting, verification, and burden-sharing in relation to CO₂ removal must be put in place as soon as possible. (52) Thus, while the issue of moral hazard was still presented as relevant, for example, by Peters, (53) there was a now a tendency to shift the focus of the argumentation towards the absolute necessity, given the urgency, of trying technological avenues that were relatively well researched. (54)
However, consistent, but now less vocal, criticism was still expressed in the debate. In early 2018, a paper in *Nature* by Vera Heck, of the Potsdam Institute for Climate Impact Research, et al. received widespread attention. It argued that the pressures on water and land from irrigation and fertilizers in a large-scale BECCS system would lead to ecological disaster. (55) Around the same time, the European Academies Science Advisory Council published a report (EASAC 2018) concluding that NETs had “limited realistic potential” to reduce CO₂ levels in the atmosphere to the levels envisioned by the IPCC scenarios. Reliance on BECCS would, therefore, have dangerous consequences, and all efforts should instead be devoted to emissions reductions. (56) Phil Williamson referred to the report in arguing that the confidence in NETs should be scaled down to more realistic levels, and that efforts to mitigate emissions should be scaled up to a corresponding degree, while professor John Shepherd at the University of Southampton claimed that NETs, although “interesting”, were “not an alternative to deep and rapid emissions reduction.” (57)

As the public debate entered a more moderate phase and researchers began to weigh the pros and cons of BECCS in the context of a rapidly shrinking carbon budget, the previous polemical tone was maintained and even ratcheted up by ENGOs. Barbara Unmußig, president of the Heinrich Böll Foundation, claimed that the whole debate had been framed and determined by people holding technocratic and undemocratic world-views, to the detriment of indigenous and local people, (58) while her colleague Lily Fuhr argued that “magical technofixes” such as BECCS signified a “shift in the broader denialism and prevention strategy of the fossil fuel industry.” (59) Critical voices like these found support in the arguments of Kevin Anderson, who maintained his criticism of what he perceived as irrational trust in “magical technologies” due to an incapacity to acknowledge the “elephant in the room”, namely, the irreconcilability of endless economic growth and effective climate measures. (60) In line with this framing of the problem, some critics concluded that “climate science recognizes a clear de-growth imperative.” (61)

**Discussion**

The BECCS debate has been untraditional in the sense that even while it goes through a period of intense polarization, there is not one side supporting BECCS and one side arguing against it. Rather, the cautious acceptance of BECCS indicates serious misgivings and reservations, while even the most vocal critics acknowledge the need for some kind of carbon dioxide removal technology and research into BECCS. This means that, when crystallized, the arguments put forward from either side of the debate are in fact similar. The acceptance of BECCS has, with minor exceptions, always been restrained and implicit rather than explicit, being included in most of the IPCC climate scenarios. Over time, this cautious acceptance of BECCS increases, on the assumption that time is running out for conventional mitigation strategies, something which we take to indicate that BECCS is becoming normalized in the debate.

We would argue that this distinctive feature – intense polarization in the absence of clear-cut differences – can be explained as a result of the debate’s post-normal aspects. In the following concluding the discussion, we will explain in more detail how we see
the notion of post-normal science as important to understand the characteristics of the BECCS debate.

**Values and facts under uncertainty**

As Guillemot (2017) has noted, the post-Paris debate about the science underpinning the Paris Agreement has largely played out on the opinion pages of influential scientific journals, rather than through the publication and discussion of standard research papers. The formulation of such a highly ambitious climate target seems to have taken the scientific community, or at least a large part of it, by surprise. This has left very limited time for the scientific community to accumulate both theoretical and empirical knowledge of large-scale BECCS. This rather sudden imposition into the climate science debate of BECCS as a key measure for achieving decarbonization is an important explanation for the stress put on ethical and epistemological uncertainties. While a minor part of the debate is couched in terms of narrowly defined technical and methodological uncertainties in current knowledge of BECCS, such arguments are overshadowed by the ethically grounded arguments for or against the deployment of BECCS – both in real-world practice and in the IPCC scenarios – that are put forward against the background of an acknowledged systemic uncertainty of an epistemological nature. Thus, just as described by Funtowicz and Ravetz (1993) in their discussion of post-normal science, the classical distinction and preordained order between facts and values, as understood in normal science, has become inverted. Rather than appealing to hard facts to justify a proposition having secondary ethical consequences, the protagonists of the BECCS debate make value-based appeals to justify or criticize a proposition made under deep uncertainty. It is not a matter of prioritizing values over facts, however, but of acknowledging the impossibility of distinguishing between them under preconditions understood as post-normal. As Funtowicz and Ravetz (1993) wrote about such circumstances, “the traditional fact/value distinction has not merely been inverted; in post-normal science, the two categories cannot be realistically separated” (p.751).

**The values of “gambling”**

While the post-Paris debate about BECCS is characterized by disagreement and criticism, it is framed by a consensus on the need to make radical changes to the global socio-economic system in a situation of deep scientific uncertainty as to the efficacy of various technologies and measures. There is accordingly also a general consensus that any decision will by necessity involve an important value dimension, as one uncertainty must be traded for another. In the debate following Paris, the forceful critical claim that unrealistic modelling results had supposedly come to influence policy-makers quickly established BECCS in the policy-making context as a matter of “gambling”. The debate has therefore become polarized between two different valuations of gambling stakes: the risk in hoping that technologies will materialize, versus the risk in disregarding the prospect of admittedly uncertain technological solutions in policy-making.

The major thrust of the criticism of how policy-makers have come to “gamble” on BECCS is that there is no valid scientific backing for the prospect of large-scale BECCS.
From this perspective, IAMs have made a scientifically illegitimate jump of scales, taking the scientifically plausible idea of applying CCS to bioenergy production and deploying it on massive scales amounting to over 10 gigatonnes of CO$_2$ removal/year. Appealing to a classical notion of science as the deliverer of hard, indisputable facts, these critics argue that scientists have breached the compact of what constitutes legitimate scientific advice. This criticism could be understood as a symptom of the form of crisis of scientific legitimacy likely to arise under post-normal circumstances, as envisioned by Funtowicz and Ravetz (1993): “A new form of legitimation crisis could emerge; for if the authorities try to base their appeals for sacrifice on the traditional certainties of applied science … this will surely fail” (p. 751).

Interestingly, this line of argumentation also has the effect of forcing those employing it into a similar rhetorical position as that of climate sceptics (see also van der Sluijs 2010; van der Sluijs 2012; Boykoff 2013; Anshelm and Hultman 2015). There are striking similarities in both the language employed – laden with metaphors of myth and popular culture to reveal the irrationality of the supposedly scientific claims – and in the criticism of the IPCC as driven by political considerations rather than purely scientific ones. As Guillemot (2014) has argued, this rhetorical position was considered taboo for anyone outside the climate sceptic community before the Paris Conference, after which the polarization of the debate altered the previous configuration.

The defence of a scientifically authorized push for BECCS in policy-making is not, however, anchored in an appeal to firm scientific findings about its large-scale feasibility, but instead in the lack of technological alternatives and, most of all, in the lack of political ability to deliver forceful mitigation through more conventional means. From this perspective, not to enforce sustained research and development efforts to make large-scale BECCS functional would constitute a greater gamble than waiting for it to materialize through a more classical procedure of scientifically driven technological development. The debate thus entails not only a post-normal inversion of the classical fact–value distinction and order, but also an inversion of the linear model of technological development: a vision of technology guiding science rather than the reverse (Bensaude-Vincent 2016; see also Boettcher and Schäfer 2017, regarding geoengineering).

**Integrated assessment models as “professional consultancy”**

To understand this inversion, and the criticism of how BECCS has come to feature so prominently in policy-making, it is necessary to look to the centrality of integrated assessment models in the IPCC analyses and policy recommendations. These models are highly theoretical and generalized constructions intended to broadly illustrate different future socio–technical development paths. According to those who construct them, they should not be seen as scientific verdicts on feasibility but hypothetical “talking points” for policy discussions (Haikola et al. 2018).

The scenarios incorporating large-scale deployment of BECCS can be seen as the response of integrated assessment modellers to inquiries from policy-makers for a 1.5°C option. This is a form of risk and uncertainty management that responds to the high uncertainty and urgency inherent in the climate science–policy interface in a way that can be understood as the kind of “client-serving, professional consultancy” that
Funtowicz and Ravetz (1993) described as one strategy for scientific problem solving, the client in this context being the policy-making community. In professional consultancy, uncertainty, urgency, and high stakes mean that the specific expert–client relationship determines the scientific outcome to a much larger extent than is the case in either curiosity-driven or applied science. Such consultancy abandons the quest for pure scientific truth as an unworkable ideal, instead focusing on what is contextually relevant (see also Hulme 2007). This transition into a post-normal mode of science production explains much of the critique against BECCS, which is based on a “normal” understanding how of science should inform policy.

However, the critique is equally strong against integrated assessment modellers for not being post-normal enough, in the normative definition proposed by Funtowicz and Ravetz (1993). In this definition, post-normal science should be characterized by open deliberation with an extended peer community beyond the expert–client relationship, and engage with issues of valuation and epistemological uncertainty. In Figure 1, Funtowicz and Ravetz position curiosity-driven, “pure” science at the intersection of two axes. Here, no external stakes are involved and uncertainties are generally low. At the other extreme, in the sphere of post-normal science, are various external stakeholders with often conflicting purposes, and processes involving open deliberation between these purposes ideally generate democratically valid, science-informed, but fundamentally uncertain policy decisions.

A recurring theme in the BECCS debate is that BECCS has surreptitiously entered the policy-making domain through models that are black-boxed and impossible for policymakers to decipher. From the perspective of Funtowicz and Ravetz’ illustration, then, we can understand the critique of integrated assessment models in the BECCS debate as a critique of a scientifically illegitimate middle ground. In the eyes of critics, integrated

---

**Figure 1.** Illustration of how scientific problem-solving approaches changes in relation to decision stakes and systems uncertainty (from Funtowicz and Ravetz 1993, p. 745)
assessment models are neither sufficiently grounded in the normal paradigm of applied science, nor sufficiently open about their uncertainties and assumptions to merit the title of post-normal science.

**Polarization without poles: reflexivity and stalemate**

Consistent with the debate’s framing of the issue as one of gambling, BECCS is argued by those who claim it should be considered a genuine policy option to be the safer of two bets, the worse bet being to rely on policy-makers to adopt radical mitigation measures by other means. It follows that the promotion of BECCS, which was largely tacit and implicit for a long period in the debate, is presented as a last resort, a necessity under dire circumstances. The fact that this disillusioned stance, quite different from the visions of a “climate saviour” evident in the early days of the debate, constitutes the positive pole in the debate has the effect of fostering a polarized debate without definite poles. The debate does involve a decisive polarization, in the sense that two distinct argumentative positions are formed in relation to the issue of large-scale BECCS. However, a closer analysis of the arguments put forward reveals that both poles are in fact quite similar. Furthermore, as already noted, the debate tends to move from polarization towards a state where BECCS becomes discursively normalized.

Since Paris, there have been no passionate speeches in defence of the viability of BECCS. Instead, the words of Glen Peters, formerly a critic of how BECCS came to feature in policy-making contexts, aptly capture both the fatalistic and disillusioned spirit of the side advocating the necessity of CCS: “Love it or hate it, we need carbon capture and storage to keep below 2°C.” (62) At the same time, those criticizing how BECCS has come to feature in the policy-making sphere acknowledge the inadequacy of conventional mitigation policies that are likely to be enforced, and the need for sustained research into and development of BECCS and other NETs. Despite the often-forceful rhetoric employed in the post-Paris BECCS debate, there is little discernible difference between different perspectives on the need for or the functionality of the technology itself. No one professes to regard the more ambitious deployment scenarios of BECCS as feasible, and only a few regard BECCS as an idea that can or should be dismissed.

Instead, the core of the post-Paris debate around which the polarization is configured is the issue of whether or not “gambling” on BECCS constitutes a moral hazard. This is not something that lends itself easily to debating, both because it is inherently impossible to prove either way, and because of the disillusioned framing of the debate: it is difficult to argue something to be a moral hazard that may or may not postpone measures that are acknowledged to be unlikely to materialize in any case.

We can discern two consequences of this “polarization without poles” for the debate’s form and substance. First, the focus on moral hazard, uncertainty, and meta-scientific issues regarding science’s relationship to policy-making – rather than intra-scientific issues about varying degrees of certainty of specific variables or claims – leads to far-reaching reflexivity and transparent discussion not only of the high uncertainties involved in the climate science behind much of the Paris Agreement, but also of the performative role of science (see also Boettcher and Schäfer 2017, about reflexivity in geoengineering research). Second, there is little room for the debate to evolve in the same direction once the issue of moral hazard has been established, as the arguments
reach a kind of saturation point. Instead, towards the end of the period analysed here, we already see a tendency for the debate to move from the issue of moral hazard to focus instead on the need for policy-makers to deal with the consequences of the Paris Agreement and its reliance on NETs.

Concluding remarks

While there is no way to evaluate the effects the BECCS debate has had and will have in terms of concrete policies based on the preceding discussion, the analysis does hint at a tension that seems to lie at the centre of the notion of post-normal science. In its more normative thrust, the post-normal science literature assumes – or hopes – that open discussion of methodological, epistemological, and ethical uncertainties will facilitate better decision-making under uncertainty. As Saloranta (2001) put it, “this enhances the quality of the information and thus reduces the danger of misunderstanding in decision-making” (p. 399). What we see in the BECCS debate, however, is that while the post-normal circumstances – high uncertainty, high stakes, and urgency – involved do foster open discussion of ethical and epistemological uncertainties, there is a tendency for the discussion to reach something of an impasse. This concerns not only the difficulty of debating moral hazard, as mentioned above, but also the urgency that frames the debate: it is easy to argue that the ship has sailed for discussions of intangible values and risk. Thus, while the urgency in play in policy-relevant climate science does invite transparency concerning ethical and epistemological uncertainties, it arguably also limits the time available to debate such issues. In this sense, it would seem that a post-normal scientific debate is only possible as a temporary state brought on by a perceived crisis or dramatic event – in this case, the perceived radicalism of the Paris agreement – to be followed by a new normalized state. However, even if BECCS does become normalized as part of the mitigation discourse and the polarized language subsides, the post-normal debate about the philosophical underpinnings of scientific knowledge production may well have some institutional effects in the way climate science is performed. For example, the production of the IPCC special report on the 1,5°C target (IPCC 2018a) is an indication that the IPCC has responded to some of the critique voiced after Paris (see Livingstone 2018).

Notes

1. CCS: “A process in which a relatively pure stream of carbon dioxide (CO₂) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere.” BECCS: “Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, CO₂ can be removed from the atmosphere.” (IPCC 2018b).
2. For more information about the database’s coverage: https://www.retriever-info.com/product/monitoring-and-analysis/
3. See Appendix A for the empirical references. See Appendix B for tables displaying the countries of origin for the publications used in the analysis and the distribution over time for the total sample (n = 120).
4. While being outside the temporal scope of our investigation, the most recent public debate around the IPCC special report on the 1.5°C target (IPCC 2018a), seems to support this observation. Our complementary reading of debate pieces and more argumentative articles (~200 international articles published between 8 October and 7 November 2018 with the same search strings, data base and methods for analysis as applied in the core sample) about BECCS in relation to climate politics indicates that it has become a more accepted part of the discussion, which is now more about what levels of BECCS are reasonable to assume than the moral hazard implied by its inclusion in model scenarios. While most of the critique that was voiced until the spring 2018 still dominates, the support for research into BECCS has become stronger. However, many ENGOs have become more critical towards BECCS and instead favour afforestation and enhanced agricultural methods.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Svenska Forskningsrådet Formas [2016-00958]; Vetenskapsrådet [2016-06359];

ORCID

Simon Haikola http://orcid.org/0000-0002-2874-4146
Anders Hansson http://orcid.org/0000-0002-1156-8748

References

Hickman L. 2016. The history of BECCS. Carbon Brief. 16 April 2013.
IPCC. 2018a. Strengthening and implementing the global response.. In: de Coninck, H, et al., editor. Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.


**Appendix 1: Articles**

(1) Carbon Capture vs Biomass, *Chemicals Technology*, 10–09-14


(3) E.g. Aus für CO₂-Abscheidung als Klimaretter? *Deutsche Welle*, 13–08-02; Engineering climate: from pariah to saviour, *MSN South Africa*, 15–12-14

(4) Dangerous global warming could be reversed, say scientists, Guardian, 13–07-11; Negative emissions technologies – a positive step? *Source the engineer*. 13–06-13

(5) Extracting carbon from nature can aid climate but will be costly…., *Reuters*, 14–03-26

(6) Battle Plan for Climate Change, National Geographic, 14–04-09; Climate mitigation report: Key findings, *BBC*, 14–04-13; UN climate panel ponders Plan B, geengineering, considered mad science by opponents, *The Japan Times*, 14–04-11; What is climate change mitigation? *BBC*, 14–04-13

(7) Many nations wary of extracting carbon from air as climate fix, *Reuters*, 14–04-08; Nations wary of extracting CO₂ from the air, *Independent Online*, 14–04-09; UN dilemma over “Cinderella” technology, *BBC*, 14–04-12


Carbon Capture and Storage: scaling up to a viable model, Ferret.com.au, 14–05-01; CO2-lagring blir aldrig virkelighet, Teknik Ukeblad, 15–02-05; Det handler om verdens fremtid, Norsk Skogbruk, 14–11-27; FN’s klimapanel: “Der er håb, et beskedent håb”, Information, 14–04-13; FN’s klimarapport: Toget er klart til avgang, NLLU, 14–04-16; Fossil fuel caps urged as scientist warn of climate woes, Business Week, 14–11-03; McCarthy: Clean power plan targets may change, National Geographic, 15–02-19; Plants the key to removing 63M tonnes of carbon dioxide a year, The Guardian, 14–04-16; År IPCC pessimister? Upsala Nya Tidning, 14–04-23

(11) IPCC: emissions cuts are about ethics as well as economics, Eco-Business, 14–04-14; c.f. How we could save the world from global warming before time is up, Gizmodo UK, 14–04-17


(14) Duality in Climate Science, Nature Geoscience, 2015, 8, 898–890

(15) New U.N. report underscores the grim math behind the global carbon budget, Washington Post, 15–11-06; Scientists just undermined a key idea behind the Paris climate talks, Washington Post, 15–12-07; The magic number: Holding warming under 2 C is the goal. It may already be too late, Washington Post, 15–11-29; The radical idea that’s gaining momentum at the Paris climate talks, Washington Post, 15–12-08

(16) Scientists just undermined a key idea behind the Paris climate talks, Washington Post, 15–12-07

(17) Klimawandel Löst die Zwei-Grad-Fessel in der Klimapolitik, Tagesspiegel, 15–06-09; Negative CO2-emissionen mit schulden zum zwei-grad-ziel, Neue Züricher Zeitung, 15–11-13


(19) An unusual tech bet could slow climate change, Scientific American, 15–12–15; Climate deal agreed in Paris, Deutsche Welle, 15–12–12; Countries just adopted a historic climate change accord. Here’s what happens next, Washington Post, 15–12–12; Engineering climate: from pariah to saviour? MSN South Africa, 15–12–14; Scientists just undermined a key idea behind the Paris climate talks, Washington Post, 15–12–07; The radical idea that’s gaining momentum at the Paris climate talks, Washington Post, 15–12–08

(20) Climate deal agreed in Paris, Deutsche Welle 15–12–12; Countries just adopted a historic climate change accord. Here’s what happens next, Washington Post, 15–12–12

(21) Klimagipfel Die verflixten anderhalb Grad. Der Spiegel, 15–12–10; see also The trouble with negative emissions. Science, 16–10–14; We’re placing too much hope in pulling carbon dioxide out of the air, scientists warn, Washington Post, 16–10–13

(22) An unusual tech bet could slow climate change, Scientific American, 15–12–15

(23) Engineering climate: from pariah to saviour? MSN South Africa, 15–12–14


(26) How scared or hopeful should we be in a warming world? The Guardian, 16–05–12; Massive tree farms may be a really bad climate idea, National Geographic, 16–02–10; Outside the bubble, Nature, 16–02–10


The trouble with negative emissions, Science, 16–10-14; see also The promise of negative emissions, Science, 16–11-11; The promise of negative emissions – Response, Science, 16–11-11

Eine langsamer Gradewanderung, Die Tageszeitung, 16–05-26; Forskare varnar för övertro på koldioxidtvätt, Östgötacorrespondenten, 16–03-22; Gefährliche klimaschulden, Der Spiegel, 16–10-14; Geo-engineering unlikely to work, conservation group says, Eco-Business, 16–11-03; Klimaschutz – Basteln am Klima, Frankfurter Rundschau, 16–10-29; Klimavertrag: CO₂ sparen reicht nicht mehr, Frankfurter Rundschau, 16–04-22; Next year or the year after, the Arctic will be free of ice, The Guardian, 16–10-17; Nullutsipp haster – Norge har et stort ansvar, Eneregi og Klima, 16–12-20; Oansvarigt att välja oprövad teknik för att rädda klimatet, Dagens Nyheter, 16–10-21; Radical realism about climate change, Eco-Business, 16–11-03; Tax fossil fuels or risk kids’ future: US climate scientist, Times of India, 16–10-04; The Good, Bad, and Ugly Approaches to Geoengineering, Slate Magazine, 16–01-25; These charts show what the Paris agreement is up against, Huffington Post, 16–08-15; Today’s climate progress an tomorrow’s climate challenges, New York Times, 16–10-17; UN review says carbon plans fall well short of climate goals, BBC, 16–11-03; Using forests to curb climate change threatens human rights, Eco-Business, 16–11-03; We just got a glimpse of where Obama’s hugely ambitious climate policies were headed – before Trump, Washington Post, 16–11-16; We’re placing too much hope in pulling carbon dioxide out of the air, scientists warn, Washington Post, 16–10-13; What would a global warming increase of 1.5°C be like? The Guardian, 16–06-16; Will biggest danger from global warming be the change in diets? New Scientist, 16–03-03

Aus für CO₂-Abscheidung als Klimaretter?, Deutsche Welle, 13–08-02; How we could save the world from global warming before time is up, Gizmodo UK, 14–04-17; Radical realism about climate change, Eco-Business, 16–11-03; Engineering climate: from pariah to saviour, MSN South Africa, 15–12-14

Abandon hype in climate models, The Guardian, 16–04-26; The magic number: Holding warming under 2°C is the goal. It may already be too late, Washington Post, 15–11-29; see also Kulturwandel im Lebensstil, Neues Deutschland, 2017–11-07; 5 ting, der bør ske ved klimatopmødet COP23, Videnskab.dk, 2017–11-08; Climate’s magic rabbit: Pulling CO₂ out of thin air, BBC, 2017–11-15


The magic number: Holding warming under 2°C is the goal. It may already be too late, Washington Post, 15–11-29

Talks in the city of light generate more heat, Nature, 15–12-23

A dilemma over “Cinderella” technology, BBC, 14–02-12

Talks in the city of light generate more heat, Nature, 15–12-23


Climate Change, the movie, Spectator, 14–04-16

Outside the bubble, Nature, 14–02-10

Talks in the city of light generate more heat, Nature, 15–12-23

The promise of negative emissions, Science, 16–11-11

Dr. Klaus Lackner. The Carbon Catcher, New Zealand Herald, 16–03-10; The search is on for pulling carbon from the air, Scientific American, 2016–12-27; The quest for negative carbon emissions, Washington Post, 2016–03-05

CCS som klimatteknologi – et sentralt tema, Bellona, 11–12-02; Biomasse, galskap or reservenöklar, Teknisk Ukeblad, 12–03-22; Åpner for å manipulere klimatet, Dagens Næringsliv, 2013–10-03

CO₂-lagring blir aldri virkelighet, Teknisk Ukeblad, 15–02-05; Forskning: Fryktet klimatteknologi: Jeg er ikke tvil om at dette er et helt trygt konsept, Teknisk Ukeblad, 2016–02-12

Det handler om verdens fremtid, Norsk Skogbruk, 14–11-27; Energigården retter blikket ut og fram, Norsk Skogbruk, 16–08-31; La skogen redde verdens klima! Norsk Skogbruk, 15–11-30

(47) Fra plus til minus, *Stavanger Aftenblad*, 14–04-14


(50) Do we need carbon capture and storage? *Energi og Klima*, 2017–09-14

(51) How much CO2 will the world have to remove from the atmosphere? *Scientific American*, 2017–11-30

(52) Catalysing a political shift from low to negative carbon, *Nature*, 2017–08-14

(53) Er et klimamål et stykke under to grader en mulighet? *Videnskab.dk*, 2017–10-01

(54) Climate’s magic rabbit: Pulling CO2 out of thin air, *BBC*, 2017–11-15


(56) Negative emission technologies: What role in meeting Paris Agreement targets?, *EASAC policy report 35*, February 2018

(57) “Silver bullet” to suck CO2 from air and halt climate change ruled out, *The Guardian*, 2018–02-01


(59) Climate’s magic rabbit: Pulling CO2 out of thin air, *BBC*, 2017–11-15


Appendix 2

Figure 2. Distribution over time for the cited articles (n = 120). The dataset ends 2018–02-27.

Figure 3. The country of origin for the cited articles (n=120).