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Article

Social Science Insights for the BioCCS Industry

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Abstract: BioCCS is a technology gaining support as a possible emissions reduction policy option to address climate change. The process entails the capture, transport and storage of carbon dioxide produced during energy production from biomass. Globally, the most optimistic energy efficiency scenarios cannot avoid an average temperature increase of +2 °C without bioCCS. Although very much at the commencement stage, bioCCS demonstration projects can provide opportunity to garner knowledge, achieve consensus and build support around the technology's properties. Yet many challenges face the bioCCS industry, including no guarantee biomass will always be from sustainable sources or potentially result in carbon stock losses. The operating environment also has no or limited policies, regulations and legal frameworks, and risk and safety concerns abound. Some state the key problem for bioCCS is cultural, lacking in a 'community of support', awareness and credibility amongst its own key stakeholders and the wider public. Therefore, the industry can benefit from the growing social science literature, drawing upon other energy and resource based industries with regard to social choice for future energy options. To this end, the following scoping review was conducted in order to ascertain gaps in existing public perception and acceptance research focusing on bioCCS.

Keywords: bioCCS; bioenergy; biomass; social choice; public acceptance; social license to operate

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1. Introduction

Controlling the Earth's climate and weather has tantalised scientific endeavours for many centuries. This idea may no longer be merely visionary as today's scientists have begun to develop a series of geoengineering options towards this goal [1]. Geoengineering has the ability to provide significant social and ecological benefit to communities, with ecosystem-based carbon dioxide (CO_2) removal approaches seen as the most effective [2]. The Royal Society [3] identifies two classes of geoengineering, both of which aim to reduce Earth's global temperature: (1) Carbon Dioxide Removal (CDR), and (2) Solar Radiation Management (SRM) techniques. The former removes CO_2 from the atmosphere, the latter seeks to redirect part of the Sun's light and heat back into space. Considered to address the root cause of climate change, CRDs remove greenhouse gas (GHG) emissions from the atmosphere, whereas SRM techniques seek to offset GHG levels by reducing Earth's solar radiation absorption. CDRs may include large scale engineering approaches that remove GHG via physical or chemical processes, or biological methods that aim to improve natural carbon storage processes. Continued global reliance on fossil fuels for energy production and slow transition toward renewable based energy systems has resulted in public and private investigation and investment into energy production systems that permit ongoing fossil fuel use whilst simultaneously reducing CO_2 emissions [4]. Carbon dioxide capture and storage (CCS) technologies is one such technology and, whether coupled with fossil fuel or bioenergy sources, falls under the CDR techniques identified for addressing climate change by the Royal Society [3]. Geoengineering raises many questions with regards to the social, legal and political implications which are likely to significantly impact future acceptability. Of these, socio-political and ethical factors, associated with geoengineering technologies and their deployment, are considered of central importance [1,3].

The ability for improved carbon emission reductions through the development of new and promising technologies, such as CCS, is seen to have a critical role to play in reducing fossil fuel power generation and industry related GHG emissions [5,6]. The past 10 to 15 years has seen an expansion of the scientific and technical knowledge required to advance investigation and development of CCS [7,8]. During this time it has become apparent that the technology's advancement requires large-scale demonstration projects to test its application under a variety of circumstances. Globally, development has advanced but large-scale, commercial progression of the technology has slowed due to a multitude of economic, environmental, social, legal and political reasons [9,10]. According to the Global CCS Institute's Status Report, of the world's 22 large-scale CCS projects, Canada's Boundary Dam Integrated CCS Demonstration Project was the first large-scale CCS project to begin deployment in October 2014 [9]. This slow progression reflects the complexity of the technology's development, the many and varied processes leading to deployment, and ongoing reticence both privately and politically to support low carbon technology strategies [11]. Yet these demonstration projects also provide opportunity to garner knowledge, achieve consensus and build support around the technology's properties [7,12].

2. Method

To better determine existing knowledge surrounding public perceptions of bioCCS, the authors undertook a scoping review of the current literature spanning the past decade. Comprehensively reviewing peer reviewed journal articles sourced via online search engine 'Google Scholar', direct access of known ‘open to the public’ journals and via access to online membership based journal databases. From this process, key journals were identified and individually reviewed. Search terms applied included: ‘bioCCS’, ‘bioenergy’, ‘biomass’, ‘biofuel’, ‘public perception’, ‘public attitudes and carbon capture and storage’, ‘bioenergy with CCS’, ‘bioenergy with carbon capture and storage’ and ‘BECCS’. It soon became apparent that little was known in the literature regarding public perceptions of bioCCS although several studies were identified focusing on bioenergy and/or biomass. In addition, a number of the articles that were located centered on the current debate into bioenergy with CCS (BECCS) (for example, see [13–17]). All bioenergy articles sourced were reviewed to develop a better understanding of the industry’s existing public perception research. While a scan of the ‘social licence to operate’ literature, primarily pertaining to the mining industry, identified pertinent articles which were introduced to the review in order to broaden how the term ‘public perception’ is conceptualised. The review was undertaken by utilising a tabulated annotated review (provided in the supplementary material). Information sourced in this manner was then considered in line with existing knowledge gleaned by the authors as a result of past research surrounding public perceptions of CCS with fossil fuel. The information sourced as a result of the scoping review was then distilled and summarised.

3. Public Acceptance and Opposition to Fossil Fuel with CCS

Low emission energy technologies have the potential to reduce GHG emissions over the coming decades. CO_2 emissions from fossil fuel combustion (such as coal and gas) for electricity production are a major contributor to global warming [18]. The International Energy Agency (IEA) [19] has indicated that in order to restrain average global temperature change to +2 °C by 2050, CO_2 emissions need to be substantially reduced and would require the capture and storage of 120 $GtCO_2$ by 2050. Long term the least costly climate change mitigation scenario estimates derived by the IEA indicate that CCS could capture and store in excess of 7 $GtCO_2$/yr by 2050 [19]. When coupled with fossil fuel energy production CCS has potential to remove large amounts of CO_2 [20] captured from significant production sources, such as coal-fired power stations. Once captured, CO_2 can be piped or transported to storage locations before being injected into deep geological structures. Continued reliance on fossil fuel with CCS for energy production, though not sustainable per say, does however, provide one option toward significant CO_2 emissions avoidance [18,21]. The IEA’s 2010 Energy Technology Perspectives indicates that CCS has the potential to account for up to 19% of global CO_2 emission reductions by 2050 [18,22]. The opportunity exists therefore for CCS to play a crucial role in the long-term global goals for sustainable energy production.

Defining policy to determine which low carbon sustainable energy technology to support is complex and difficult [7]. Such decisions must account for carbon allocations and offsets [23] as well as what is ethically, morally and socially acceptable [24]. Politicians and decision-makers, regularly in receipt of briefings and updates on innovative and emerging technologies to assist their decision-making processes, nonetheless continue to debate this issue worldwide [25], not least due to the social choice nature of the decision. Social choice navigates “a variety of continually branching alternative pathways for change” [26,27]. Innovative advancements in technology, whether deliberate or inadvertent, reflect social choices involving uncertainty, legitimacy, and competitiveness within the decision-making process [20]. Often the ‘precautionary principle’ is heavily debated around such complex decisions [26,28]. Stirling notes one such precaution as “scientific uncertainty is not a reason for inaction in preventing serious damage to human health or the environment” [26]. Indeed, decisions focused on uncertainty rather than risk are not value-free or exact ‘technical risk assessments’ but rather involve far broader issues and seek alternatives that require value-based political deliberation [26,29]. Such complex and politically fraught decisions, including energy technology advancements such as CCS, require knowledge and understanding in order to ensure informed decision-making is reflective of society’s values and levels of acceptance.

Globally awareness of CCS is low [20], albeit with some pockets of increased awareness due to higher exposure of the technology in certain locations. For example, L’Orange and colleagues [21] highlight a survey conducted by Reiner and colleagues [30] in the United States, noting less than 10% of American citizens as being aware of CCS. Whereas, an online representative survey conducted in Canada found approximately 14% of participants were aware of the technology [31]. In locations where members of the public are directly or indirectly exposed to similar project experiences, such as enhanced oil production, there appears to be greater knowledge and understanding of the technology (Saskatchewan 40%, Alberta 27%) [21,31]. Further, a European Commission [32] study notes approximately 28% of Europeans surveyed as being aware of CCS while approximately 10% were knowledgeable about the technology. The exception being The Netherlands, where 52% purported to be knowledgeable regarding CCS while a further 30% indicated awareness of the technology [32]. Overall, public perception and acceptance of CCS research indicates a general lack of enthusiasm toward the technology [5], yet not all public opinion is against CCS. Though energy efficiency options and renewable energy technologies would appear to be preferred, people nonetheless recognise the need for trade-offs [33,34].

Many complex factors impact the future deployment of CCS projects, with public acceptance identified as a significant barrier [6,9]. The CCS debate, seemingly driven by a lack of knowledge and awareness about the technology, reinforces Not In My Back Yard (NIMBY)-like opinions that extensively impact the technology’s appeal [7,15,35]. Yet with demonstrations of CCS only at the commencement stage and opposition remaining an ‘in principle’ response [36], it may be too early to predict how a full commercial scale CCS plant will ultimately be received. In the United Kingdom for example, evidence suggests there may be public support for CCS deployment, albeit with reservations [37,38]. Where public opposition has been experienced, the most prominent concerns have focused on perceptions of risks associated with deep underground geological storage of CO_2, with underground and surface leakage [39–41] and associated health and safety issues [32,42–44]. This opposition is further enhanced by concerns about the technology’s role in assisting the continued use of GHG emitting fossil fuels in energy generation [36]. Kaiser *et al.* [45] note risk concerns surrounding CO_2 leakage and groundwater contamination (among others) as key points in focus group discussions relating to the Polish EU-funded SiteChar project. Many other studies also indicate that the most frequently raised and influential issue regarding CO_2 storage is the perception of risk associated with leakage [18,21,46,47]. Though research undertaken to date into public perceptions of CCS with fossil fuel has been insightful in understanding risk perceptions influencing public acceptance (or otherwise) of the technology, the extent to which risk perceptions of bioCCS may impact the technology’s uptake or raise other issues of acceptability, is yet to be determined [13].

Mitigation and low emission technologies are an integral component of any emissions reduction strategy where reliance on fossil fuel is high [48]. CCS presents one potential solution amongst a suite of possible solutions [21,49,50]. Early research into public perceptions of CCS [40,41,51] note that when CCS is presented as a standalone technology to address climate change acceptance is unlikely.

Yet, if approached from a social choice perspective and presented as one of a portfolio of low carbon energy technologies with capability for addressing climate change, greater appreciation of CCS as a mitigation option is likely [6]. Other potential low carbon energy options which may be included in a suite of options with coal, natural gas and CCS include: geothermal, wave and tidal, nuclear, wind, hydroelectric, solar and bioenergy [5].

4. What Is BioCCS and Its Potential?

With 2020 GHG targets appearing less and less attainable [14], achievement of low carbon, globally sustainable energy warrants the further evaluation of CCS beyond fossil fuel energy production to also include other low-carbon energy technology options [52,53]. One alternative, which is gaining support as a possible emissions reduction policy option, is carbon sequestration achieved through CCS during energy production from biomass and bio-fuels (bioCCS, also known as BECCS) [53,54]. In addition to fossil fuel generated power, electricity and heating can be produced from converting biomass into bioenergy. Biomass is a near CO_2 neutral substitute for fossil fuels and a means for sequestering carbon [55]. For example, biomass may include agricultural residues (post-harvest pruning and animal manure), forest biomass (post stem wood harvest residues–branches, foliage, roots) and energy cereal crops including specific biomass cultivars (cereals such as sugar cane, corn/maize, wheat and sorghum) and municipal solid waste [56–59]. Biomass helps to draw carbon from the atmosphere by binding carbon as it grows. In Europe, forest biomass is the largest biomass raw material stream on the continent [60].

Bioenergy's diverse and wide ranging technologies include: conventional biomass-fuelled power plants and heating systems [61] such as co-fired biomass and coal, direct combustion cogeneration electricity and heat with conventional boiler, and biomass integrated gasification combined cycle; gas recovery and anaerobic digestion for biogas production; and hydrolysis, fermentation and distillation, as well as pyrolysis (biochar) and gasification for the production of biofuels (bioethanol and bio-oil) [56–58]. With the conversion of the biomass into bioenergy, the carbon stored in the biomass is released back into the atmosphere as CO_2; this results in a net atmospheric carbon emissions outcome [62]. Though biogenic storage on its own may greatly reduce atmospheric CO_2 [63,64], there is concern that as climate change continues, the biosphere may cease to be a net sink and instead become a net source of atmospheric carbon [65]. The capture of CO_2 produced by bioenergy combustion for electricity generation (at the point of conversion) can potentially be addressed through advances in CCS technologies for the capture of CO_2 and storage in underground geological formations (as in CCS demonstration plants with fossil fuel combustion power stations). By coupling CCS with biogenic sequestration, carbon is removed from the natural carbon cycle (in which carbon is photosynthesised) and permanently stored deep underground [8]. The integration of these systems, known as bioCCS, results in a negative net atmospheric carbon emissions outcome [59,66]. As greater recognition of the value of CCS for storing carbon as an alternative to releasing it into the atmosphere increases, the potential for bioCCS to sequester carbon from bioenergy production becomes an attractive, minimally engineered approach with potential for achieving co-benefits through enhanced biomass growth [8]. This ability "could have important implications for mitigating anthropogenic climate change" [66].

However, there are many issues that should be considered in relation to bioCCS, beyond localised public acceptance of bioenergy as a fossil fuel replacement renewable energy alternative [23]. In addition to the maelstrom of complexities attached to CCS [7], the uptake of renewable energy sourced from biological materials carries GHG implications that extend past regional, state and national boundaries to encompass the greater global community [23]. Consideration of bioenergy, from biologically sourced feedstock, by-products and natural waste, as a renewable energy alternative involves an understanding of the full carbon life cycle of the energy source, environmental allocations (inputs and outputs) and extent of burden ("air pollution, acidification, eutrophication, ozone depletion, land use, *etc*.") [23,67,68], society's social values and choices, and the sustainability trade-offs these impose [23,57,69]. Where sustainability is defined as "capacity to achieve a balance between economic stability, social equity and ecological balance" [69]. Life Cycle Assessment (LCA) takes account of the environmental and energy performances of a bioenergy source, such as biomass, in order to gain a better understanding of the renewables' validity for reducing GHG emissions and society's dependence on fossil fuels for energy production. Validity that should account for: competing uses of biological resources for food or feed (such as corn production for consumption verses ethanol production), by-product yields and values (for example, fodder), deforestation and afforestation and their effects (reduced biogenic carbon storage, and ecological impacts due to monoculture practices such as soil nutrition depletion), the ecological and environmental sustainability of the harvesting of the bioenergy resource, economic considerations of alternate land use options, ongoing accessibility to natural reserves and/or cultivated resources [23], and fair trade practices (morals, localised impacts and trade-offs), and ethical behaviours (production, consumption, corporations, governance) [24,70].

Nonetheless, as a climate mitigation method, bioCCS has the capability to permanently remove CO_2 from the atmosphere [59], and in doing so adds new dimensions to the CCS debate. Though not expected to mitigate global warming in isolation, as a negative CO_2 emissions energy source, the importance of the technology in climate change mitigation modeling cannot be ignored. It is considered a practical cost effective approach for reducing GHG emissions, across a wide range of biomass related technologies [71]. When included in a suite of mitigation options, bioCCS provides a glimpse of the possibility of decreasing overall atmospheric CO_2 levels [15], and goes some way towards prevention of a 'lock-in' of fossil fuels as the primary source of power generation for future global energy needs [16,72]. These benefits may well be critical elements that can lead to the social acceptability of bioCCS [14]. Though as previously indicated, overall public awareness of CCS is low [16], of the two technology combinations, carbon reduction through conventional CCS (with fossil fuels) is more widely known, while bioCCS appears to have a far less public profile regardless of its optimistic GHG emissions reductions potential. A workshop hosted by the University of Oxford in October 2014, attended by key UK national and international experts and stakeholders of climate geoengineering governance included bioCCS (identified as BECCS) as one of a number of geoengineering options for discussion. A summary of the workshops findings note an overall general lack of support evident for the technology, with CCS perceived as experiencing greater support, albeit limited and likely to be linked to local political circumstances (for example, enhanced oil recovery) [73].

According to the Zero Emissions Platform (ZEP) [59] the technical potential for bioCCS moving toward 2030 to 2050 is significant [59]. However, its technological potential is constrained by several factors, *i.e.*, sustainable biomass availability, capacity for CO_2 storage, and the future capability of technological biomass conversion and CO_2 capture technologies. The ZEP [59] note that "the net energy conversion efficiency (including the energy penalty) and the carbon removal efficiency of the bioCCS technology determine the technical potential for bioCCS in terms of primary energy converted, final energy and net (negative) GHG emissions". Globally, the most optimistic energy efficiency scenarios cannot avoid +2 °C without bioCCS; the technology seen as necessary for achieving the stabilisation of atmospheric CO_2 [72]. Indeed, the ZEP [59] suggest that bioCCS's global technical potential is significant and, should the technology be deployed, has the possibility to effect some 10 Gt of CO_2 equivalent negative emissions on an annual basis. Though conjecture surrounds the long term viability of large scale bioenergy in some countries due to the constraints of competing land use, water shortages, and energy requirements for irrigation and water drainage, such as in Australia for example [57]. By 2050, bioCCS in Australia could potentially remove and displace 65 $MtCO_2$-e annually, or around 1.5 times the nation's current car emissions. Thus, by 2050 bioCCS has the potential to contribute in reducing Australia's CO_2 emissions by as much as 780 $MtCO_2$-e [17]. While in Europe, bioCCS has the capacity to remove some 800 Mt/yr of atmospheric CO_2 by 2050, which comparatively represents over 50% of Europe's existing energy-related emissions [59].

BioCCS is not without the potential for pitfalls, as there is no guarantee that the sourcing of biomass will always be from sustainable sources. Any carbon benefit bioCCS might bring could be negated by the use of unsustainable biomass, resulting in possible net positive CO_2 emissions outcomes instead of emissions reductions. In addition, bioCCS could potentially result in carbon stock loss and decrease or neutralise net positive GHG mitigation outcomes due to direct and indirect land-use changes [74]. Though, impact assessments of land-use changes may redefine our understanding of absolute CO_2 emissions avoided, and should therefore be treated as case and circumstance specific. The pros and cons of activity boundaries are therefore critical, thus bioCCS should not be taken as a simple solution [75].

Whilst investigating whether CCS could help to avoid reinforcing fossil fuel lock-in, Vergragt *et al.* [16] found that the situation for bioCCS seemed rather poor. At best the processes' strongest functions were thought to be its ability for knowledge creation and entrepreneurial activity through demonstration. Furthermore, this was noted to be most often framed in terms of CCS alone. Indeed, in some instances where bioCCS was central, participants in a project were apparently unaware of this focus. As a result, Vergragt and colleagues [16] concluded that the key problem for bioCCS was culturally imbedded, lacking in a 'community of support', and awareness and credibility amongst its own key stakeholders. Identifying specific key interventions as essential to advance the technology, including: a roadmap for development; establishment of research groups with a bioCCS focus; bioCCS specific centres and networks; the hosting of seminars and workshops for the benefit of scientists; the public and potential stakeholders; the directing of dedicated bioCCS research and development; and, the arrangement of demonstration support programs along with specific incentive programs [16]. The recommended activities may well benefit the several bioenergy with CCS projects planned across the world, for example the White Rose CCS Project in the UK, the Aemetis' Keyes ethanol plant project in California, and three other large-scale projects in Illinois [17,76–78]. The benefits from these activities can assist in fast-tracking awareness and knowledge building as identified by Vergragt *et al.* [16].

Vergragt and colleagues [16] further noted bioCCS to be seriously lacking in legitimacy, guidance and market creation dynamics, implying that a stronger link in these areas has been established between CCS and fossil fuels sources than between CCS and biomass. It was further suggested that "ambiguity in the relationship between bioCCS and CCS" [16], as well as institutional factors (for example, lack of awareness of the technology, limited knowledge creation and diffusion, entrepreneurial activity tending to be as ‘an aside’ to CCS, and no direct market incentives to encourage uptake), may further prevent the applicability of CCS specific knowledge being developed and applied to bioCCS. As a result, a strong orientation of CCS for fossil fuels has been supported yet the application of this technology for bioCCS would appear to have been neglected. Furthermore, existing funding rules tend to exclude biomass, therefore a risk exists that application of the CCS technology to only one particular energy source may prevent the development of the bioCCS option [16]. In addition, some nations, such as Australia, which have the resources necessary to develop bio-CSS, are experiencing a slow progression of CCS due to policy environments and local public opposition [17].

5. Social Science Insights and Future Areas of Research for BioCCS

Being concerned with the aggregation of individual preferences to reach collective decisions [79], social choice occurs at different levels, including at local, regional, national and global scales. Each individual preference draws upon past experiences, current context, levels of knowledge, access to information and the ability to prioritise one factor over others (trade-offs). Yet, social choice is concerned with group decision-making and the behaviour of collective actors; and the normative and logical aspects of information aggregation on the views, interests and preferences of individuals into group decisions [80]. From an energy perspective, there are wide and varied factors that each individual takes into account when making a decision about which energy options are acceptable to them. Those factors range from perceptions of risk, awareness and knowledge of the technologies, what social benefits will be provided and procedural processes are in place, what the current context is in which the decision needs to be made, the amount and availability of information and the framing of that communication, as well as the influence of other views and perspectives. The following section provides an overview on how these social choice factors can influence the perceptions and acceptance of bioCCS, drawing upon research conducted in other energy and resource industries, and highlights future areas of research.

Observing public acceptance is heavily driven by perceptions of risk, Singleton [81] set out to better understand risk perception and its influence on the public’s acceptance of CCS. Whilst investigating this phenomena, he noted the public to react negatively to worst case assessments and in order to avoid adverse potential outcomes, were more likely to reject the technology than bear the risk. And, where expert advice might view risk more realistically, the public was more inclined to consider risk from a socially constructed perspective. Thus, expert advice alone was seen to be ineffective in the quest for gaining public acceptance [81]. Interestingly, whilst reviewing CCS literature in 2011, Vergragt and colleagues [16] noted a scarcity in dedicated research efforts specific to bioCCS. To date these observations appear to remain valid, with limited available information and only minimal public opinion research in the area of bioCCS [61]. An exception, Upham and Roberts [36] studied public acceptance of CCS across a range of potential energy sources including coal, nuclear and bioenergy across six European countries. Their findings support Singletons’ [81] risk perception research around public acceptance of CCS, indicating general common opinions and concerns regarding CCS, with such concerns not allayed through information provision, tending to be more negative as a result [36].

On the whole, research into public perceptions associated with CCS has consistently reported findings supporting a general lack of public awareness of the technology [72,82]. Awareness of other climate mitigation options favouring energy efficiency and renewable energy appear to prevail over that of CCS.

Where limited knowledge of the technology is evident, it is overshadowed by concerns regarding risk and safety. Yet given sufficient information, reluctant acceptance for CCS has been evidenced, albeit tempered with an expectation that the technology will act as a "bridging technology away from fossil fuels" [36]. The question is whether or not public acceptance issues experienced to-date around the development and deployment of CCS for fossil fuel based energy sources and high CO_2 emitting industries are likely to replicate for bioCCS? If indeed this is the case, what impacts will these have on the bioenergy industry's ability to gain a social licence to operate (SLO), sufficient enough to enable the technology to gain traction where positive climatic mitigation outcomes are possible? There is a belief that public perceptions will indeed impact the success of bioCCS, with negative perceptions of CCS and/or biomass considered likely to stall the technology's uptake as well as increase transport and storage costs [83]. However, biomass and CCS in combination are expected to gain greater public support than the technologies might achieve individually [84]. Therefore, the bioCCS industry can benefit from the growing social science literature which reports on research in other energy and resources based contexts in regards to a SLO and public acceptance.

Over the course of time, the resource and energy industries have been increasingly asked to provide governments and communities with more detailed assessments, plans and reports on the economic, environmental and social impacts from their activities. The most recent of these, social impacts, has evolved from companies simplistically demonstrating 'corporate social responsibility' to a more engaged and holistic SLO model [85,86]. The SLO approach, with its beginnings in the mining sector [87], provides a framework that integrates corporate citizenship, social sustainability, reputation, legitimacy and stakeholder engagement in order for industries to develop an understanding of their relationship with communities and other stakeholders [86,88,89]. In other words, an SLO can be a measure of the ongoing approval or social acceptance of the activities being undertaken by a particular industry [87], as well as the dynamic and changing quality and strength of the relationship and engagement with its stakeholders [90,91]. To assist in maintaining a social licence, which is not a static concept [92], researchers state the importance of an industry being flexible, accommodating and responsive to "evolving social attitudes and expectations" [93].

Although it is recognised that a SLO can exist at multiple levels (local, regional, national and international), the dominant view is that a "SLO successfully maintained at a local project level may positively influence the industry, which can potentially result in a SLO for the industry as a whole. It is presumed that the reverse may also hold true; that the public loss of SLO at the project level would also have negative implications for how the industry is perceived more broadly" [94]. There are many perspectives on how best to secure, maintain and measure a SLO, which includes several engagement and communication methods, ideas on the frequency of interactions, perspectives on the fairness of the process, information provision and successful relationship strategies [86,95,96]. The underlying concept across all these approaches is trust [97,98].

6. Social Infrastructure and Procedural Fairness

How a community experiences the impacts of hosting new industry developments can differ significantly to what may have been expected in the initial development stage. The results of that experience can be both positive and negative and can significantly impact how a community accepts a new operation. Positive impacts can include employment and training opportunities and significant infrastructure investment. While negative impacts may for example involve a degree of stress on local social services and infrastructure (health, education, housing, civic and utilities, transport, and correctional and justice services) [99]. Some of the more onerous impacts associated with these issues can be addressed through regulation and policy mechanisms which may go some way towards minimising local community tensions and resentment [100]. CCS researchers have found that dimensions such as infrastructure, legal systems and regulatory processes and their impacts have the potential to significantly influence a project's advancement and long term outcomes. For example, site selection, project development and the imposition of legal and regulatory processes may cause those impacted to experience procedural and distributive justice issues [6].

A series of case studies undertaken in India [101] focusing on local acceptance of bioenergy plants (excluding CCS) in developing regions, notes that a SLO can be impacted by a failure to address community concerns and can result in legal and regulatory challenges for the company developing the technology. Their research highlights issues similar to those perceived by opponents of CCS, such as local air pollution issues, inappropriate storage of by-products and doubts about the credibility of bioenergy developers; each in their own right important concerns. When further unpacked, Eswarlal *et al*. [101] found these concerns were deeply influenced by perceptions of trust surrounding not just the company as an entity but in its capacity to relate to local energy needs and benefits beyond the company's own self-interest.

In their study, Moffat and Zhang [98] consider procedural fairness as an influencing factor in establishing a SLO for mining development acceptance by local communities. Specifically, individual desires for a voice, an active role in decision making processes, and to be treated with respect were all deemed as important for supporting expectations of procedural fairness. Mediated through trust, an ability to voice an opinion in decision making can lead to cooperation and a willingness to accept the decisions made by others. When engaging with local communities, perceptions of procedural justice were found to positively correlate with trust, and it was recommended that the mining industry needed to focus its efforts in ensuring contact is both high in quality and quantity. This supports previous research which found perceptions that others genuinely care for one's welfare and best interests were linked to a sense of security and confidence in the good intentions and behaviours of others. Developing and establishing positive intergroup relations trust was seen to be crucial [42,102,103]. Further, Ashworth and colleagues [6] found the need for transparency and procedural fairness was a common influencing factor in public acceptance around CCS technology. Conflict can arise when decisions imposed upon local communities result in impacts to the local context, creating a sense of disempowerment and exclusion from the decision-making process [43].

7. Knowledge, Context, Information and Framing

The influence that knowledge has on social acceptance is a reoccurring theme in the literature (for example, see [6,47,51]). A lack of knowledge can influence how people perceive the costs, risks and benefits associated with a new or emerging technology. These perceptions indirectly influence acceptability (judgement of and attitude towards technology) and acceptance (behavioural responses) and have the potential to modify people's opinions. Shifts in opinion can be predicated on trust (in those who manage the technology) and on an individual's perceptions of a technology's risk [104]. Risk perceptions differ across individuals. They can be influenced by factors such as social norms, values and feelings, collective and personal experiences and knowledge [105]. Perceptions of risk are very closely linked to trust, in terms both of the perceived integrity and competence of decision makers to act in the best interest of all stakeholders [98]. There is evidence that misconceptions are directly related to unstable and uninformed opinions that result from a lack of knowledge and understanding of CO_2 and CCS [33,106].

Personal experience increases knowledge which in turn informs opinion and impacts behavioural intentions [104]. In appreciating the limitations of a community's existing awareness and knowledge baseline, communication, engagement and education plans can be developed which may go some way towards addressing deficits in both personal and community experience and knowledge [6]. Knowing the aspects of the local context, including the social, cultural, economic and political characteristics of a community, is fundamental from a baseline measurement perspective [107]. Drawing upon CCS research, the importance of information in developing overall knowledge and understanding of the CCS technology, particularly with regards to accessibility, complexity, diversity, quality and tone, is indicated [48,106]. For ease of understanding, different audiences require information materials that are tailored to their needs, is user specific, credibly sourced, of high quality, relevant and factual [6,46,108]. Use of a range of methods that include formal, informal, technical and other less complicated processes is also key.

The way in which CCS is framed for different stakeholder groups has been acknowledged as a key consideration for successful communication. Discussions about CCS should encompass the broader context of climate change and the mitigation potential of low carbon energy technologies [42]. This is however mitigated by individual stakeholder beliefs in climate change [109]. Furthermore, positioning CCS as only one low carbon option within a range of available energy technologies reflects the technology's potential within a suite of options, whereas advocating for CCS as a standalone technology is less likely to be tolerated [6]. By extending the context in which CCS is framed beyond that of climate change, for example positioning CCS within the wider energy debate, broadens its potential application as an energy alternative across markets and industries and their associated cultural and political contexts.

8. The Role of the Media

In regards to increasing the awareness and profile of bioCCS with the general public, the industry is encouraged to actively engage with the media. Mainstream media can play a salient role in influencing and shaping the debate and has been shown to also increase knowledge on bioCCS's contribution to addressing climate change, the technology's implementation process and dialogue related to any associated risks [110–114]. Therefore, tracking and analysing media coverage can offer insights into public discourse regarding awareness, knowledge, understanding, and any perceived risks associated with bioCCS.

Previous media analyses of fossil fuel based CCS projects [51,115–117] have shown the majority of media coverage to be balanced or neutral in tone, lacking in technical detail, with a focus on reporting the progress of pilot and demonstration projects and funding issues. A link has been made between a general journalistic lack of understanding of the CCS technology itself and the number of questions and concerns raised [116]. This has led to journalists producing articles that are speculative in nature as to what CCS can actually achieve as opposed to providing factual and accurate descriptions of the technology's capability.

From our understanding there is no empirical research investigating bioCCS in the media, therefore it is uncertain how this technology in particular is perceived compared with fossil fuel based CCS projects. With risks associated with new technologies and the possibility of becoming the focus of public and political debate, it is essential for the bioCCS industry to monitor and engage the media in order to provide technical information as well as address any concerns or perceived risks. Media interaction can provide opportunities to engage with a larger cross-section of the population which can lead to further awareness of and discussions about bioCCS technology's wider application, use and impact.

9. Conclusions

The lack of public perceptions and acceptance research into bioCCS may need to be rectified in order to reflect the relatively recent attention CCS with bioenergy has been garnering in the policy and modeling spaces as a potential supplementary climate change mitigation mechanism to fossil fuel with CCS [16]. Where research has been undertaken for bioenergy projects (excluding CCS), community acceptance has been identified as a key requirement for a sustainable bioenergy project [101,118,119]. Similarly, public acceptance has been proven to considerably impact the successful development of CCS projects, in some cases causing projects to falter and eventually fail where public opposition has taken precedence [42]. Therefore, the bioCCS industry can leverage off research already conducted in similar industries in relation to informing social choice in regards to future energy options as well as gaining, monitoring and improving a SLO and public acceptance [90,94] and to pro-actively establish strong communities of support [16]. In taking on board lessons learnt from other energy and resource industries, fast-tracking of bioCCS technology to large-scale demonstration and commercial levels may considerably assist the potential for bioCCS to significantly contribute to addressing imminent climate change impacts.

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Conflicts of Interest

The authors declare no conflict of interest.

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