Project no. 723678

"The next Generation of Carbon for the Process Industry"

Coordination and Support Action

Theme [SPIRE 5] – Potential use of CO_2 and non-conventional fossil natural resources in Europe as feedstock for the process industry

Deliverable *5.2*:

Report on Findings on SME Survey

Due date of deliverable: December 2017

Actual submission date: January 2018

Start date of project: 1 September 2016 Duration: 24 months

Organisation name of lead contractor for this deliverable: The University of Sheffield

Project funded by the European Commission within the Horizon2020 Framework Programme		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents

1. Executive Summary

The role of small and medium sized enterprises (SMEs) in the introduction of alternative carbon feedstocks for the process industry sector is important and understanding issues that SMEs face is key to encouraging growth. By comparing issues from all sizes of business, conclusions can be drawn as to how best support SMEs. Barriers affecting the market development for SME's can be broad, from legislative hurdles to lack investment to lack of knowledge in specific areas. Developing an understanding of the factors preventing companies from deploying alternative carbon technologies via carbon capture and utilisation (CCU) can help remove these barriers though policy changes and industrial collaboration and this report seeks to identify these factors.

This report identifies that there is an observed lack of knowledge of how various policies and regulations have impacted decisions to implement alternative carbon feedstocks. No difference in knowledge of the impacts of policies/regulations was observed between SMEs and large companies indicating that it is a sector wide issue. In particular, increasing the ETS/carbon tax was perceived as having a positive impact on future decisions to engage with alternative carbon technologies, however there are a number of 'grey areas' within the ETS regarding the inclusion of CO_2 utilisation technologies and clarity is needed to understand possible implications for the process industry.

Chemicals sector respondents appear to be the most positive to the deployment of new carbon technologies and generally rated their knowledge of CO_2 utilisation as 'very familiar', with 45% of the companies saying they did not lack the technical knowledge to implement new carbon technologies. The chemical sector respondees rate inconsistent policies between countries as a having a highly negative effect on implementing new technologies and would like to see a higher carbon tax/ETS and a major governmental policy push to increase interest.

The highest level of familiarity was found to be with the production of fuels from CO/CO_2, although only 14% of respondents reported their organisation worked in this sector. Lower levels of familiarity were observed in the production of fine and bulk chemicals indicating that if alternative sources of carbon are to be introduced in these areas a greater level of knowledge and investment is required.

Differences were observed between micro-enterprises and SME's, particularly regarding scale-up of technologies with 71% of micro-enterprises reporting a lack of technical knowledge regarding scale up was an inhibiting factor to deploying technologies. Funding programmes for SMEs directed at this development stage (TRL5-8) could enable technology deployment to be expedited.

In general, most SMEs are members of only one external organisations or network. Therefore, opportunities for knowledge transfer may be limited and hindering deployment of new technologies. It is recommended that work is undertaken to improve knowledge transfer in the sector, particularly engaging SMEs in multiple programmes to ensure information flow is not reliant on solely one source which could lead to gaps in knowledge transfer and missed cross-fertilization opportunities. Of the companies that were not members of any network or external organisation, a higher rate of uncertainty around their organisation's interest in alternative carbon sources is observed, indicating that involvement in external organisations is directly correlated to interest in alternative carbon technologies.

2. Introduction

CarbonNext's objective is to evaluate the potential of new carbon sources in Europe. The project primarily focuses on new sources of carbon to be used as a feedstock for the process industry and secondarily the impact this will have on energy availability, price and emissions. The first work packages analysed multiple alternative carbon sources: carbon dioxide, carbon monoxide and other non-conventional fossil sources such as shale gas, tar sands and coal bed methane; mapping and evaluating these alternative carbon sources and investigating symbiotic value chains between industrial sectors. Results from the first half of the project indicated the most promising sources of alternative carbon for the process industry were from CO and CO_2 emissions and as such these are the sources that are undergoing further investigation.

Carbon monoxide (CO) and carbon dioxide (CO_2) can be considered as a carbon source for the process industries, replacing carbon from fossil sources. The processes where CO or CO_2 can be used in the process industry rely technologically and economically on several factors. One factor is the characteristic of CO/CO_2 containing sources. The characteristics of different sources differ strongly. For the process industry it is important to identify sources with the needed volume and purity. Furthermore, the given infrastructure around the sources must be taken into account in order to estimate the potential of each source. A hierarchy of sources to be used in relation to the most promising CO/CO_2 valorisation routes is necessary in order to optimize the integration of CO/CO_2 into the value chain.

The CarbonNext project will provide, as a basis for decision-making, Europe's small and medium sized enterprises (SME's), large industry and policymakers with an enhanced understanding of the impact and opportunities for new sources of carbon for the process industry. The present report contains the results and analysis from a survey conducted in Autumn 2017 to assess the barriers faced by organisations in implementing technologies to use alternative sources of carbon (primarily CO or CO_2 as these have been assessed as the most relevant sources in previous work during CarbonNext). The aim of this survey is to identify any common barriers so that recommendations for tackling them can be made.

2.1 Objective

The role of small and medium sized enterprises (SMEs) in the development of the process industry sector is important. The European Commission states that:

> *"Small and medium-sized enterprises (SMEs) are the backbone of Europe's economy. They represent 99% of all businesses in the EU. In the past five years, they have created around 85% of new jobs and provided two-thirds of the total private sector employment in the EU. The European Commission considers SMEs and entrepreneurship as key to ensuring economic growth, innovation, job creation, and social integration in the EU."*[1]

Therefore, understanding issues that SMEs face is key to encouraging growth (EC (European Commission), 2011). Market growth in CO_2 utilisation is observed from large corporations with research capabilities such as Bayer, BASF or Saudi Aramco and from SME's via new start-ups and spin-offs from Universities commercialising research findings. Examples of these university spin-offs in the field of CO_2 utilisation include – Carbon8 Systems (The University of Greenwich, UK), Novomer (Cornell University, USA), Carbon Capture Machine (Aberdeen University, UK). By comparing issues from all sizes of business conclusions can be drawn as to how best support SMEs.

Barriers affecting the market development for SME's can be broad, from legislative hurdles, lack investment to lack of knowledge in specific areas. The SCOT Project Strategic Research and Innovation Agenda (SERIA) and Joint Action Plan (JAP) (Armstrong, Youssef Travaly, Bolscher, *et al.*, 2016; Wilson, Travaly, Brun, *et al.*, 2016) recommended that further research into the barriers related to market deployment was undertaken in the business, public and policy sectors. As such an understanding of the factors preventing companies from deploying carbon capture and utilisation (CCU) technologies can help remove these barriers though policy changes and industrial collaboration.

2.2 Methodology

A Survey was designed to focus on the factors that are inhibiting SMEs of less than 250 employees and larger companies from implementing technologies that use alternative carbon sources such as CO or CO_2. The survey was open to all sizes of organisation, although specifically targeted small and medium-sized enterprises (<250 employees) in order to ascertain if there are certain barriers specifically inhibiting SMEs from development and growth in the sector (understanding barriers for SMEs is a specific target of CarbonNext). The survey was designed and deployed using Survey Monkey software[2] and was conducted in accordance with the Ethics Policy of the University of Sheffield. A full list of the questions

[1] https://ec.europa.eu/growth/smes

[2] www.surveymonkey.com

can be found in Appendix 1. The survey was designed to capture the thoughts of a wide range of stakeholders who either have alternative carbon-based products on the market, are at an advanced technology readiness level, are interested in the sector due to symbiotic opportunities created by by-products/wastes or are research organisations looking to create spin-off companies in the sector. In conjunction with studying the barriers the respondents felt were inhibiting implementation, the survey also assessed the drivers that have or could increase interest in alternative sources of carbon.

The survey was sent to over 250 contacts and posted to social media via CO2Chem and the SusChem networks. The survey was open for 6 weeks in autumn 2017 and attracted 51 responses (39 full responses and 12 partial responses) - a response rate of approximately 20%. Partial responses were received where the respondent answered the first half of the survey only; these questions related to the respondent's organisation and whether it was interested in alternative carbon sources. The partial respondents did not answer the questions relating to knowledge of CO/CO_2 utilisation or the factors affecting their organisation's decisions to implement the technologies. All statistical analysis conducted on the answers is based on the total number of responses to that particular question (i.e. 51 or 39).

3. Analysis

3.1 Participant data

To ascertain whether barriers were perceived as being geographically-based, respondents were asked where their organisation was based and in which countries it operated. 48 respondents were based in the EU with 3 from Canada. The spread of responses can be seen in figure 1. This geographical spread is unsurprising as mailing lists from the CO2Chem network, which has a membership that is roughly split 50% UK 50% rest of Europe. The survey was also advertised via twitter and Facebook which resulted in the responses from outside the EU, which was unexpected but allows comparisons between response countries. 59% of the respondents reported that their organisations work in more than the country in which they were based. This finding was reflected in all sizes of organisation with 53% micro-enterprises (those with <10 employees), 56% SMEs and 65% of large organisations having operations in more than one country, therefore the size of organisation did not appear to affect where it operated.

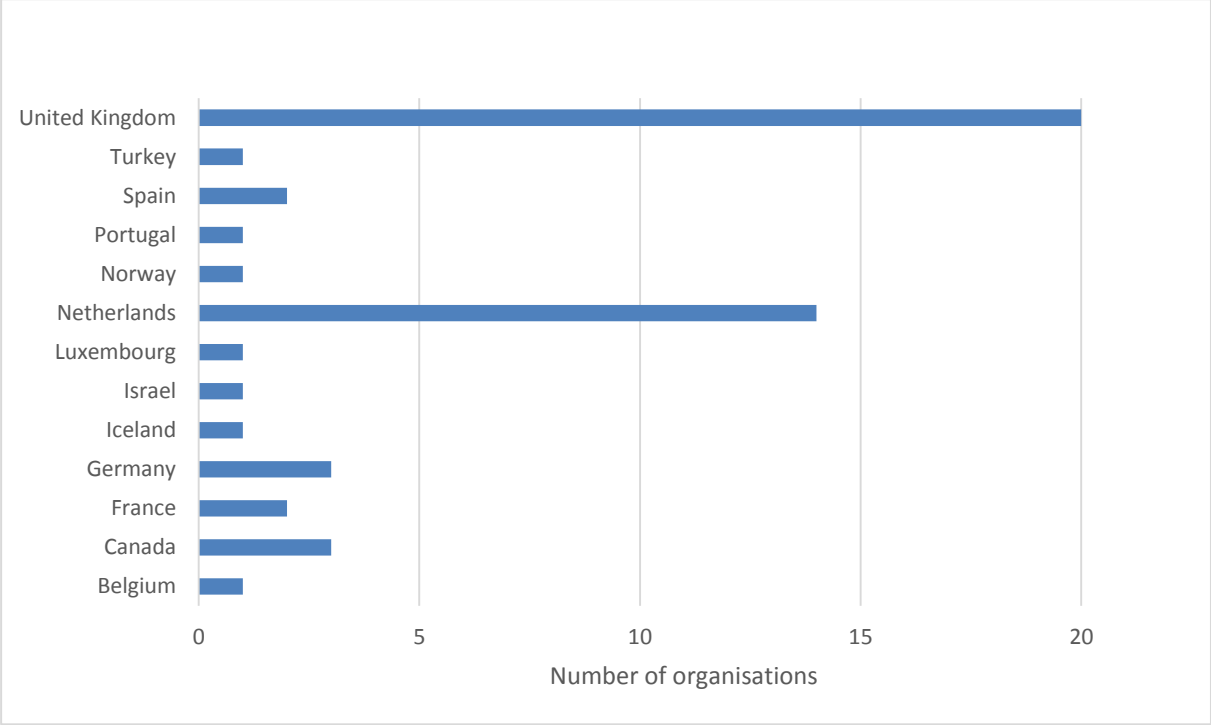


Figure 1. In which country is your organisation based?

The survey was open to all sizes of organisation, although it specifically targeted small and medium-sized enterprises (<250 employees) in order to ascertain if there are certain barriers specifically inhibiting SMEs from development and growth in the sector. Responses were compared between large companies (>250 employees), SMEs (<250 employees) and micro-enterprises (<10 employees). By looking at SME's as a whole and then comparing responses with micro-enterprises, trends/impacts can be observed that specifically affect the very smallest sized enterprises of which there are many in a new technology area such as CO/CO_2 utilisation. 34 of the organisations could be classified as SME's with 19 (37%) of the organisations being micro organisations of less than 10 employees.

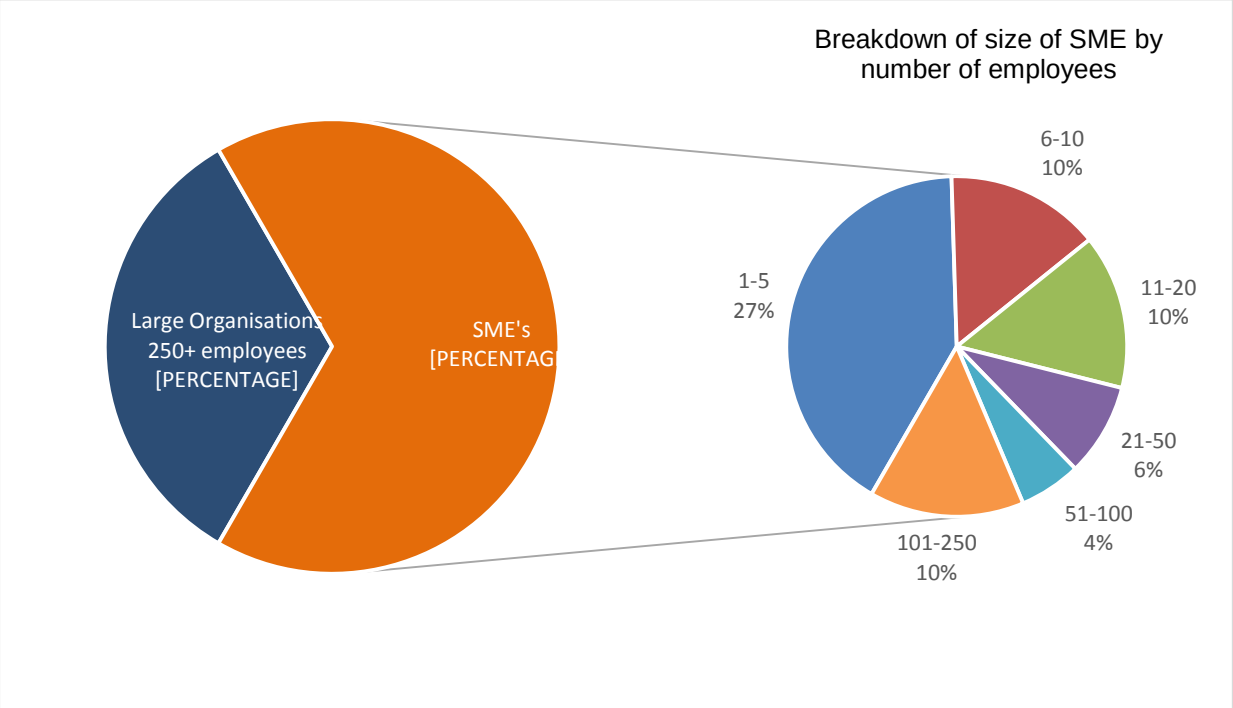


Figure 2. Numbers of Employees in responding organisations

The respondents were asked to identify which sectors their organisations operated in. Respondents were given the following options:

- Chemicals
- Minerals/Construction
- Fuels
- Metals
- Bio-based
- Waste
- Energy
- Other

Respondents could classify their organisation as operating in multiple sectors – for example as a bio-based, waste, and chemicals company. Of the 51 companies, the most popular classifications were operating the chemicals or energy sectors. 10 companies classified themselves as working in 'other' sectors, this included consultancy companies, engineering firms, R&D organisations and two companies working in carbon capture.

Respondents were also asked to classify what Technology Readiness Level (TRL) their organisation worked at. TRLs are used to convey how mature a new technology or process is on the pathway to full commercial operation. TRLs are used by many organisations, governments and funding bodies as a simple scale to enable decision making and classification of activities. The definitions of each TRL as used in H2020[3] are given below (Table 1):

Table 1. Technology Readiness Levels as defined by H2020

Technology Readiness Level	Description	TRL Grouping
TRL 1.	basic principles observed	Research
TRL 2.	technology concept formulated	
TRL 3.	experimental proof of concept	
TRL 4.	technology validated in lab	Pilot
TRL 5.	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	
TRL 6.	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Demonstration
TRL 7.	system prototype demonstration in operational environment	
TRL 8.	system complete and qualified	
TRL 9.	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	Commercial

TRLs can be grouped into 4 basic categories – research, pilot scale, demonstration scale and commercial; for ease, respondents were asked in which of these four TRL categories activity occurs. Many companies operate over a range of TRL levels and so responded in multiple categories (Table 2).

[3] https://ec.europa.eu/research/participants/portal/desktop/en/support/faqs/faq-2890.html

Table 2. Technology Readiness Level (TRLs) reported

TRL Range	% of companies reporting activity at the TRL
Research TRL 1-3	45%
Pilot TRL 4-6	33%
Demonstration TRL 6-8	31%
Commercial TRL 9	35%

It can be observed that responses covered the complete TRL range although the highest percentage of activity was found in research, perhaps unsurprising as CO/CO_2 utilisation is general viewed as an emerging technology with a strong research based. The responses were then further broken down to assess if there were differing responses depending on the size of the organisation (Table 3). It can be observed that the size of the organisation does not seem to have any direct correlation to the range of TRLs that the organisations are operating in. For micro-enterprises (<10 employees) the split across the TRLs is generally even; though less commercial (TRL9) operations are observed. For large companies a higher level of research (TRL1-3) was observed, this can be accounted for as several R&D specialist organisations responded to the survey and these organisations only operate at low TRL. Although medium sized SMEs (21-250 employees) accounted for 20% of the sample, there were no reported operations at pilot scale, which was surprising, however 30% reported demonstration and 30% reported commercial operations. Possible reasons for this include moving directly from large scale lab research to small demonstration, by-passing pilot scale or SME's being spun-out from research organisations where the research has previously reached pilot scale before the company is formed.

Table 3. TRLs reported by varying organisation size

	Research TRL 1-3	Pilot TRL 4-6	Demonstration TRL 6-8	Commercial TRL9
Less than 20 employees	39%	43%	35%	30%
21-250 employees	40%	0%	30%	30%
250 + employees	59%	41%	29%	47%

40 of the respondents were members of organisations such as SPIRE, CEFIC, CO2Chem or other low carbon initiatives. This question was asked to ascertain if there was a correlation between the knowledge and support that these organisations offer and the perceived barriers to implementing new carbon technologies that their members reported. The majority of SME's were members of only one organisation/network compared to larger companies who, on average, were members of 2 organisations/networks (range 0-5 memberships). 11 of the respondents were not part of any low carbon initiatives or programmes, of these, 3 stated further on in the survey that they were interested in CO/CO_2 utilisation options but had not explored it further, 2 were unsure if their organisation would be interested in such options and one stated it would not be interested. This can be compared to those who were members of organisations/networks all of whom were interested in CO/CO_2 utilisation options. Therefore,

it is recommended that work is done to increase knowledge transfer via networking, as it appears that membership of such organisations/networks enables an increased understanding of the opportunities available to utilise alternative carbon technologies and hence increase deployment.

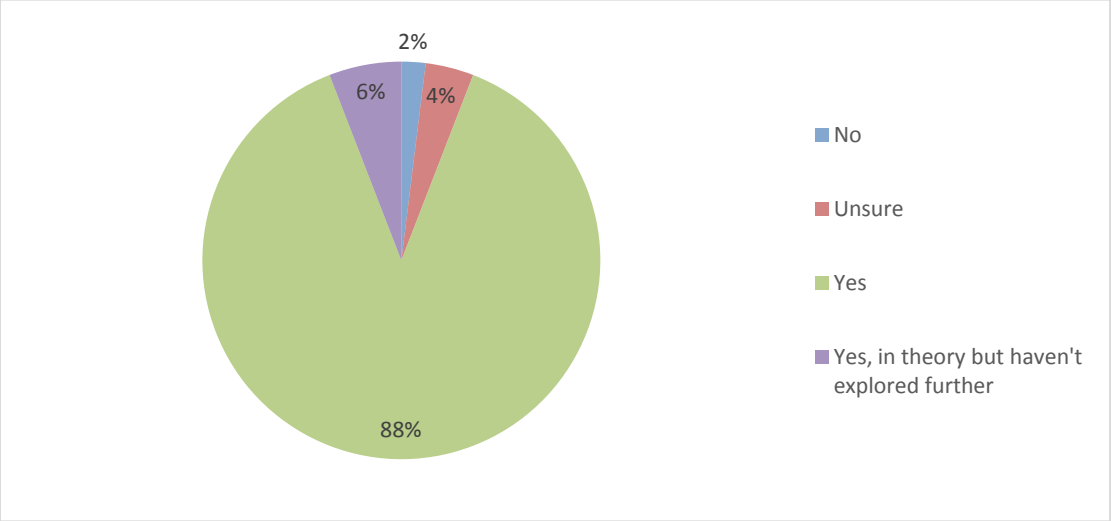


Figure 3. Would your organization be interested in options that could allow waste CO_2 or CO to be used to create a value added product?

The respondents were asked if their organisation was interested in options that could allow waste CO_2 or CO to be used to create a value added products (Figure 3). 88% of the respondents answered yes, with a further 6% saying they were interested but had not explored options further. One small sized (<20 employees) R&D consultancy stated that they would not be interested in options to utilise waste CO/CO_2; this response may be due to the

respondent interpreting the question to mean would their organisation be interested in actually making products with their own waste CO/CO_2 and as a R&D organisation they do not actually produce products, however no reason for the response is given in the survey.

To establish if the motivation for respondent's interest in alternative carbon technologies was based on their emissions (they wished to utilise their CO/CO_2 emissions to produce products), respondents were asked to state whether they were emitters of CO/CO_2, users of CO/CO_2 or both an emitter and user. The highest percentage of respondents were users of CO/CO_2 (43%) and 23% of companies identified themselves as both and emitter and user (Figure 4). Those that identified their organisation as 'other' were often technology or research (R&D) providers who are looking to provide solutions to other organisations and as such did not classify themselves as being 'using CO/CO_2 as a raw material' because although their technology 'uses' CO/CO_2 they themselves do not manufacture and sell a CO/CO_2 based product. Predominately, SME's were users of CO_2 rather than emitters.

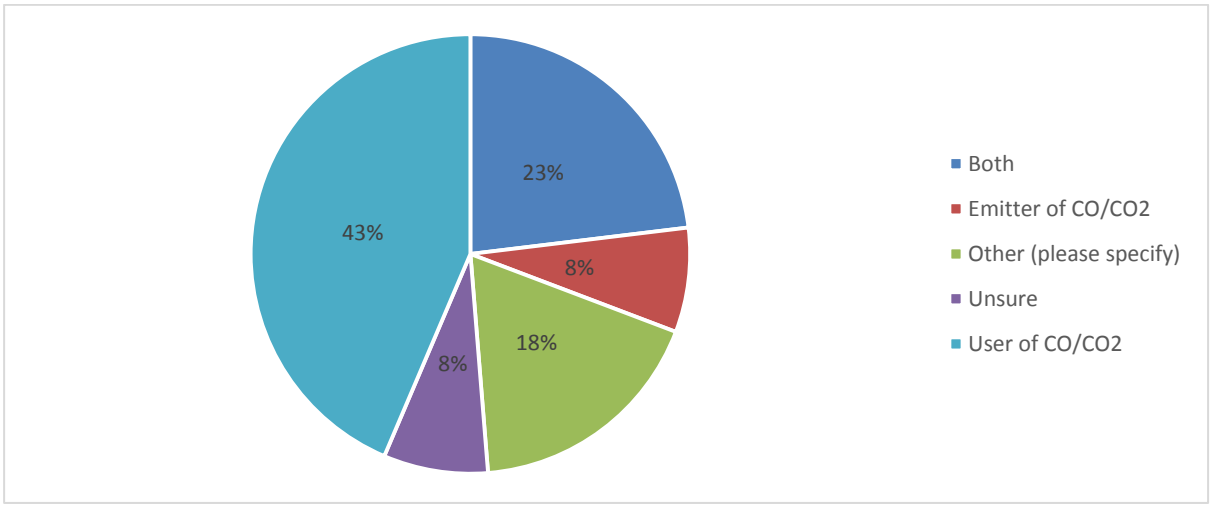


Figure 4. Is your organisation an emitter of CO/CO_2 who would like to find utilisation options or do you use CO/CO_2 as a raw material?

3.2 Knowledge

To assess the reasons why organisations were or may be driven to look for new sources of carbon we asked if the organisation had goals for reducing environmental impacts. 84% responded 'yes' with 6% responding 'no' and 10% 'unsure'. 'Yes' respondents were then asked to select the areas that the environmental goals impacted. Most organisations had multiple goals. Unsurprisingly, 84% of the organisations had goals to decrease their carbon footprint (Figure 5). Later in the survey, 12 of the respondents who reported having carbon

footprint reduction goals also reported that lack of life cycle analysis (a method of calculating your carbon footprint) knowledge was a barrier to their CO/CO_2 utilisation deployment. Therefore, it may be that although these organisations have carbon footprint reduction goals, they may also lack the knowledge to be able to assess their success in achieving these goals beyond very basic carbon footprinting due to lack of LCA expertise. The least common environmental goal concerned recycling with 42% of respondents reporting their organisation had targets in this area.

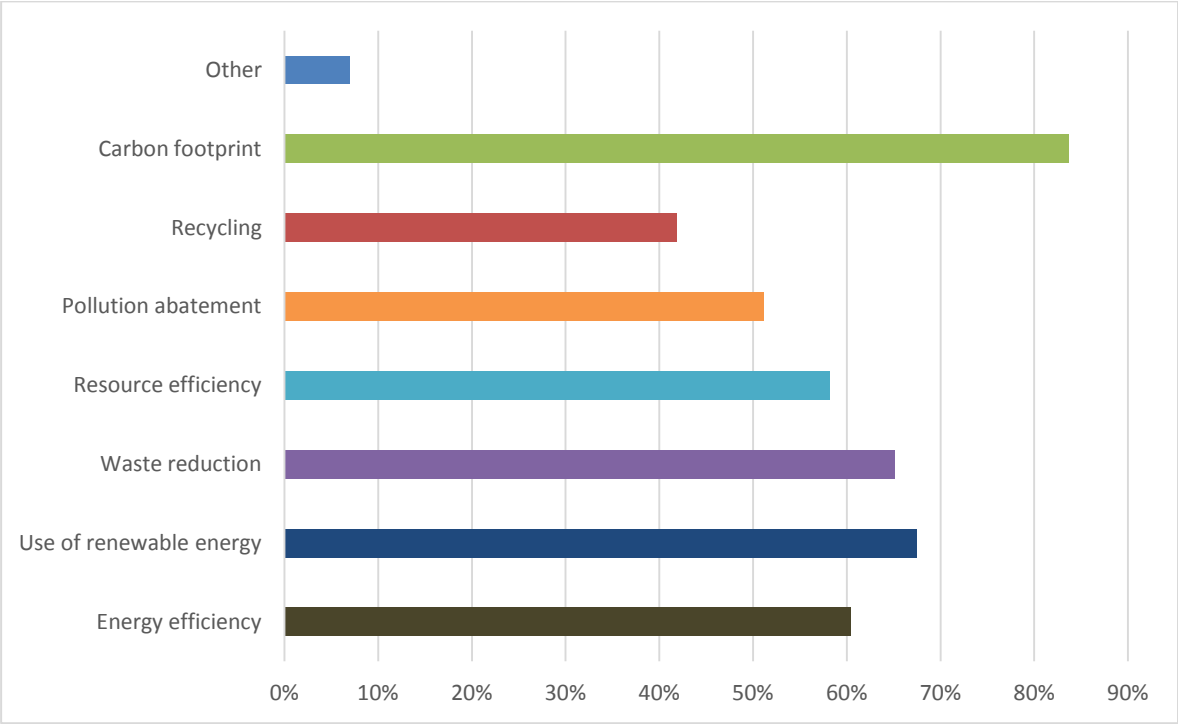


Figure 5. Areas in which the respondent's organisation has environmental goals

Respondents were asked to assess their familiarity of CO/CO_2 utilisation in general; 79% of participants responded that they we very familiar with these technologies, with 13% assessing their familiarity as good and 8% as basic (**Fehler! Verweisquelle konnte nicht gefunden werden.**). No respondents classified their familiarity as vague or never heard. Those reporting a basic familiarly all classified themselves as being in the Energy sector, all reported being interested in alternative sources of carbon however two of the organisations reported that they haven't explored this further. No clear trends were observable in those rating their familiarity as 'good'; this group contained both emitters and users of CO/CO_2 and covered a range or sectors (chemicals, fuels, energy and metals). In general, those in the waste, fuels, metals, minerals and bio-based sectors had the highest rating of familiarity with nearly all respondents their familiarity with CO/CO_2 utilisation as 'very familiar'.

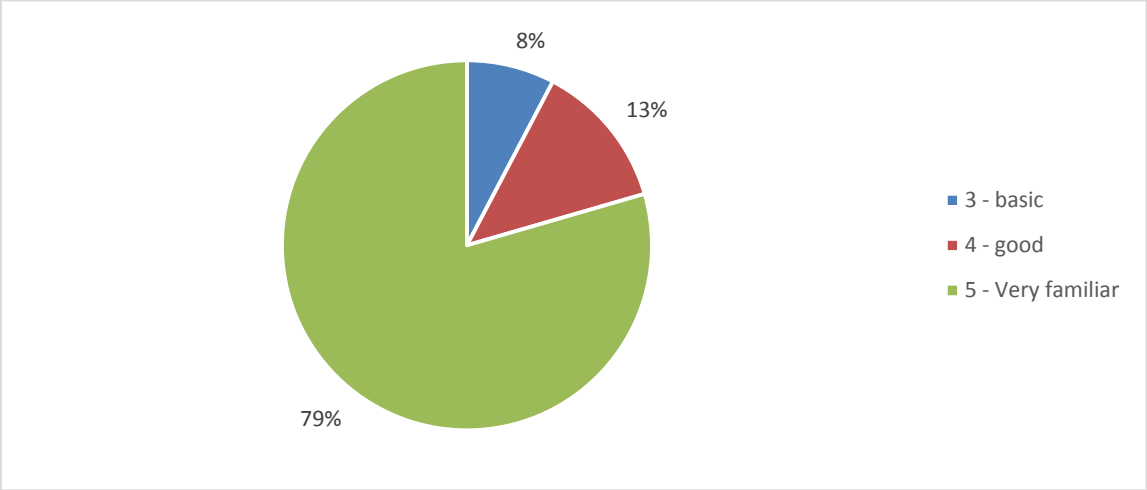


Figure 6. Assessment of knowledge of CO/CO_2 utilisation

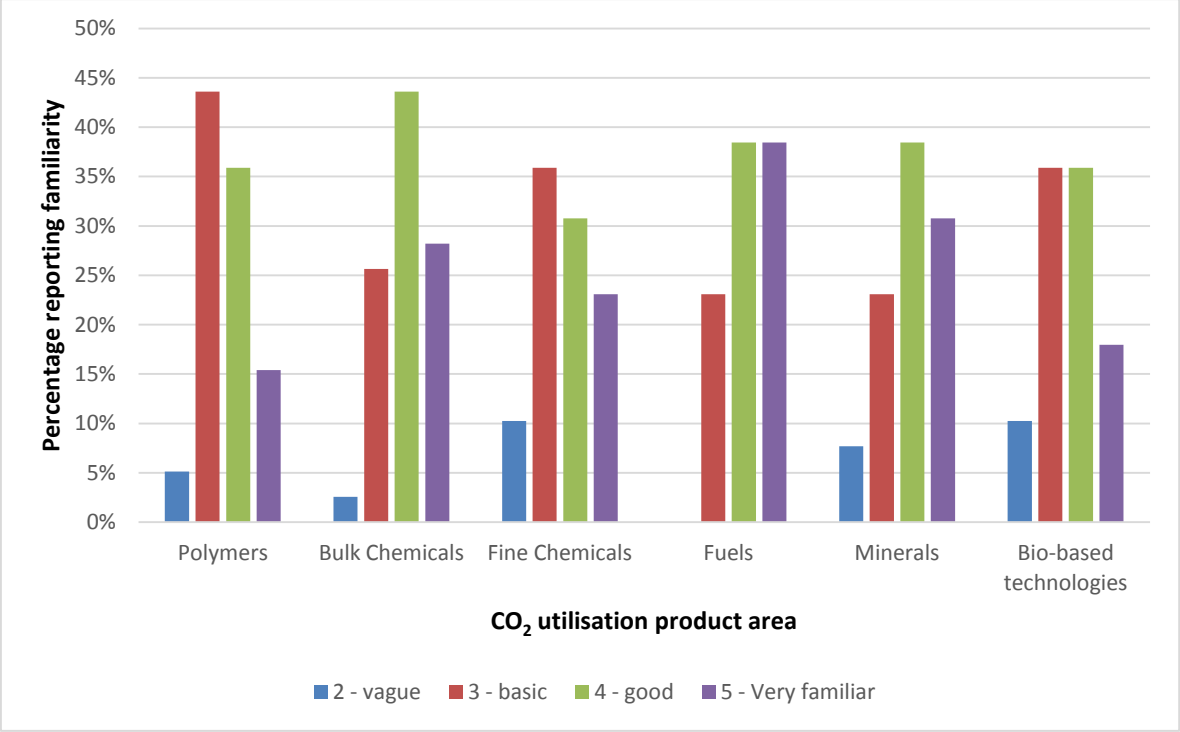


Figure 7. On a scale from 1 (never heard of) to 5 (extremely familiar), please rate how familiar you are with these specific CO2 utilization technologies

After general familiarity with CO/CO_2 utilisation was assessed, the respondents were asked to assess their familiarity with different product areas to identify if gaps in knowledge existed in specific areas in specific sectors. Figure 7 shows the greatest level of familiarity was with fuel based applications, however only 14% of respondents reported that their organisation worked in the fuels sector. The high level of familiarity with the production of fuels from CO_2 may be due to the relatively high number of published papers on methanol production from CO_2 (methanol can be used as both a fuel and a chemical feedstock) for example Olah,

Goeppert and Prakash, 2009; Goeppert, Czaun, Jones, *et al.*, 2014; Pérez-Fortes, Schöneberger, Boulamanti, *et al.*, 2016; Roh, Frauzem, Nguyen, *et al.*, 2016.

3.3 Motivation for alternative carbon sources

In order to assess the motivation for respondent's interest in alternative carbon technologies they were asked to assess the importance of a number of regulator, economic, environmental and business factors (Table 4). The highest rated factor was new business and diversification opportunities that these technologies bring with 97% of respondents rating this as an important or very important factor. Environmental factors (reducing carbon footprint and making 'greener' products) also rated highly with over 70% rating these are important or very important. The least influential factors were those related to raw materials (broadening raw material base and security of supply) indicating that these issues are not currently problematic or in shortage, though this is then counteracted by the desire for the product to be 'green' and hence move away from using fossil carbon. The use of excess energy/heat was of divided importance, those in the fuels sector tended to rate it as an important or very important influence, this was also observed though to a lesser extent, in the energy sectors answers. However, in all other sectors the influence was mixed with responses ranging from very important to not important at all.

Table 4. Importance of factors influencing interest in alternative carbon technologies

	Very Important	Important	Moderately important	Low importance	Not important	Not applicable
Regulation/taxation	**46%**	31%	13%	5%	5%	0%
New business opportunities/ diversification	**56%**	41%	3%	0%	0%	0%
Broaden your raw material base	21%	**23%**	18%	18%	10%	10%
Using current waste streams	33%	**38%**	15%	3%	5%	5%
Public relations/social responsibility	28%	**33%**	23%	10%	3%	3%
Reducing carbon footprint	**56%**	23%	13%	5%	0%	3%
Making 'greener' products	**46%**	28%	23%	0%	3%	0%
Security of supply of raw materials	23%	**33%**	10%	18%	10%	5%
Use of excess energy/heat	**36%**	31%	8%	21%	5%	0%

It was expected that regulatory/taxation implications would play a factor in the increasing interest in alternative carbon sources and 77% of respondents rated this as very important or important. This issue was then further explored to ascertain which policies and regulations are having the highest impact. The RED, ETS and Circular economy package showed the highest positive impact over the choice to implement alternative carbon feedstock technologies (Figure 8). Overall, the Circular Economy package was reported to have the most positive impact, with no negative impacts reported. The issue of inconsistent policies between countries was found to have the most negative impact on the implementation of new alternative carbon feedstocks. This has been recognised anecdotally within the community for some time, often specifically regarding 'end of life' legislations for waste-derived products which can differ from country to country causing issues when trying to establish an existing process in a new country.

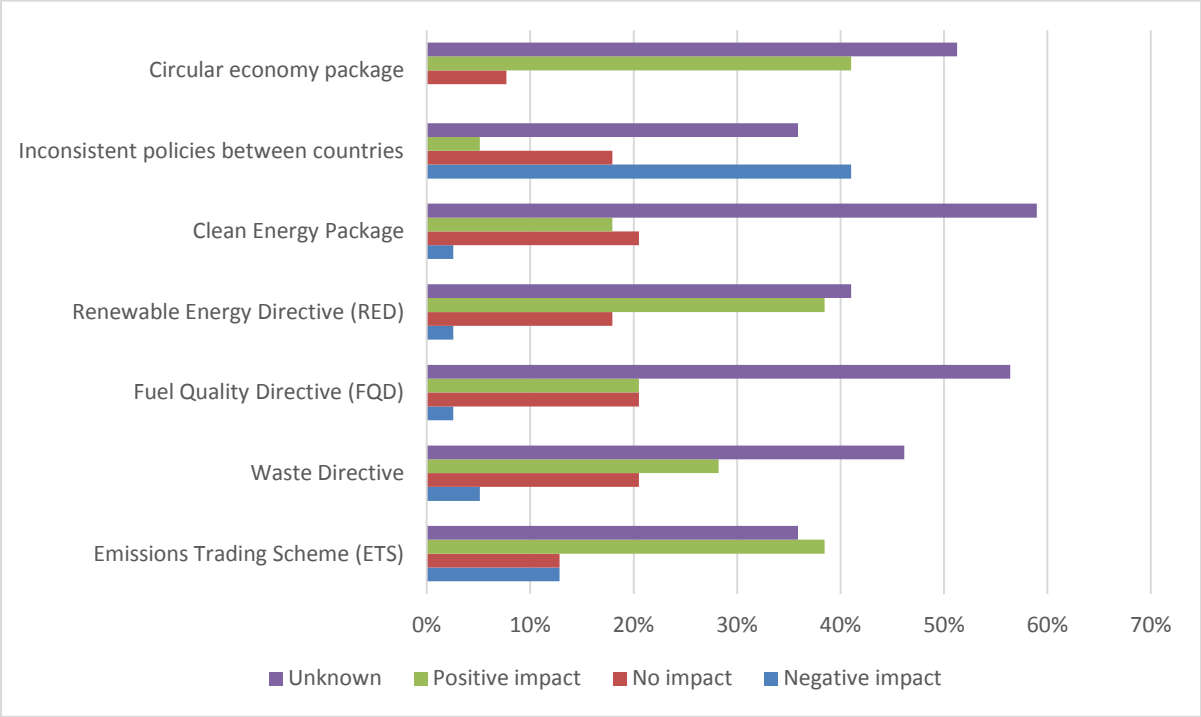


Figure 8 Impact of regulations/polices on implementation of alternative carbon feedstocks

The ETS is often seen as both a help and hindrance in the CCU sector, and this is reflected with of responses stating it has a negative effect and positive effect. One large company in the chemicals sector stated:

> "*ETS is not consistent with the new energy package"*

whilst a different large chemicals company commented:

> *"Until there is a credible price on carbon or clear legislation most of these technologies will not compete with current technologies."*

The SCOT Project explored the issue of the impact of ETS on CDU (see http://www.scotproject.org/content/briefing-paper-eu-ets) concluding that the ETS was only applicable in cases where a mineralised product was produced hence storing the CO_2 for long time periods. In all other cases how the ETS could be applied to CDU is very ambiguous and would rely on careful allocations and life cycle assessment. Further work to clarify how the utilisation of CO/CO_2 is or is not included in the ETS should be undertaken.

For each regulation more than 35% of the responses indicated that respondents (in all sizes of organisation) did not know how regulations/policies have impacted decisions. This rose to more than 50% of responses for the circular economy package, FQD and clean energy package. Comments respondents included:

> "*Not enough knowledge on the content of these packages to know (the impact)"*

and

> "*It is unknown how these regulations may affect our customer's decisions to invest in CCU R&D".*

Therefore, it can be concluded that further efforts to interpret the impacts of particular regulations/policies for different sectors within the CO/CO_2 utilisation community should be undertaken (such as the fore-mentioned ETS briefing paper from the SCOT Project) to ensure organisations are deriving the maximum benefits from these schemes.

One SME in the minerals sector summed up their views on the legislative/regulatory impacts in the following statement:

> *"Using CO_2 as a feedstock is still new. Mineralisation has got advantage about lacking discussions on leakage, storage. And more attention towards "negative CO_2 emissions" is happening. Including these developments into the revised ETS would facilitate the acceptance. In addition to bio-based we need to move to CO_2-based. And consider CO_2 also a re-useable feedstock."*

This statement sums up several issues, often CCU is considered as a whole single sector and compared with CCS; this can lead to various problems such as only considering the mitigation aspects of the technology (see Bruhn, Naims and Olfe-Krautlein, 2016 and Artz *et al.*, 2017, for further discussion) and not other additional benefits such as diversifying supply, symbiotic opportunities and the circular economy. The understanding of 'negative emissions' is often mistaken, nearly all CO_2 utilisation technologies will emit some CO_2 due to the energy and other inputs needed but often this is not clearly explored through LCA and is not understood by decision makers.

3.4 Inhibiting factors

The SCOT project in its Strategic European Research and Innovation Agenda (Armstrong, Youssef Travaly, Bolscher, *et al.*, 2016) identified a number of issues that should be tackled to increase the uptake of CO_2 utilisation. Hence, in this survey, respondents were asked to assess how a number of factors (economic, technical, regulatory) affected the ability of the companies to implement technologies using alternative carbon sources (Figure 9) . This also gave the opportunity to assess whether SMEs had differing factors inhibiting them than larger organisations with greater resource availability.

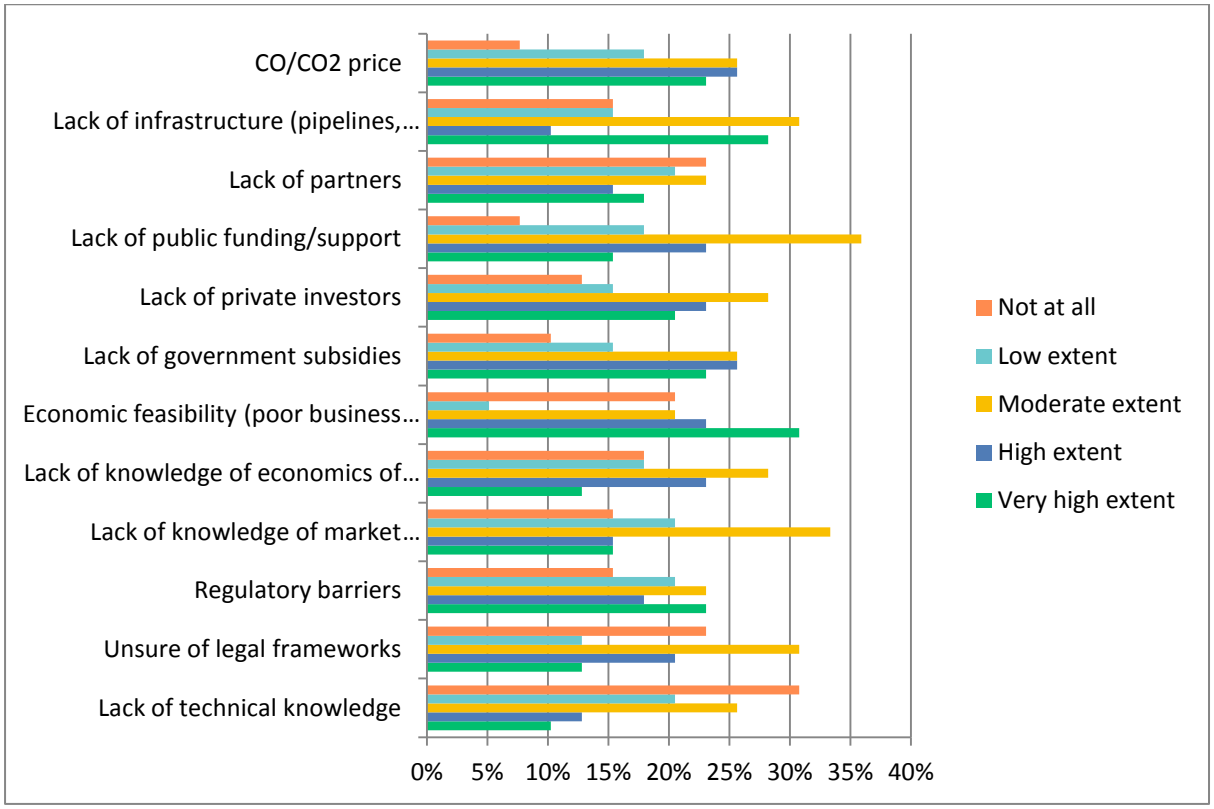


Figure 9. To what extent do the following factors prevent your organisation from implementing technologies to use alternative sources of carbon to their full potential?

Overall, the factors most reported as having a very high or high impact were economic feasibility (poor business case), lack of government subsidies and CO/CO_2 price; which all are relate to the economic viability of the process. However, 21% of all respondents said that the economic feasibility did not affect their implementation at all, but interestingly these were all SME companies. When comparing between SMEs and large companies, economic feasibility was a greater issue for large companies with 88% stating it prevented the implementation by a high or very high extent, however for SME's the figure was only 30%. Possible causes of this are SME's are general more optimistic about the technology as this is

their primary focus and for SMEs the use of the alternative carbon technology will predominantly be their core business. If this is true, then it is likely that they will have carried out specific economic feasibility studies before launching the business. However, for many larger companies the implementation of alternative carbon technologies may be a new opportunity and they are searching for the most economically viable options or that the lack of published techno-economic studies causes issues for larger companies seeking to make new investment decisions.

Responses to the lack of government subsidies appears to slightly affect larger organisations more with 56% of large companies stating that the issue highly or very highly prevented their organisation from implementing new carbon alternatives compared with 43% of SMEs. This may be due to the element of risk that the larger companies encounter when moving into a new technology area. Conversely CO/CO_2 price inhibited SME's to a greater extent than larger companies (57% vs 37%). This may be due to a far higher percentage of the SME's classifying themselves as 'users of CO/CO_2' when compared with the larger companies where more were both 'users and emitters'. Hence, it can be deduced that the SME's are more reliant on obtaining CO/CO_2 from external sources and therefore more affected by the cost of doing so whereas the larger companies are more concerned with utilising their own emissions.

To expand upon the specific technical barriers that are perceived as inhibiting implementation, respondents who indicated that technical knowledge was a barrier were asked to indicate which specific areas are an issue. 27 out of 39 respondents stated that some aspect of technical knowledge was a factor preventing implementation. Of those that cited technical knowledge as being a barrier, 14 were large companies and 13 SMEs; when compared with the overall sample (of 39, 16 large companies, 23 SMEs) this shows that 89% of large companies cited technical knowledge as an issue compared with 57% of SMEs. Possible causes of this may stem from large companies wishing to diversify into this new technology area and therefore recognising that they do not yet have specific technological knowledge of the field whereas the SME's have specifically chosen the field to work in and therefore have a stronger knowledge base.

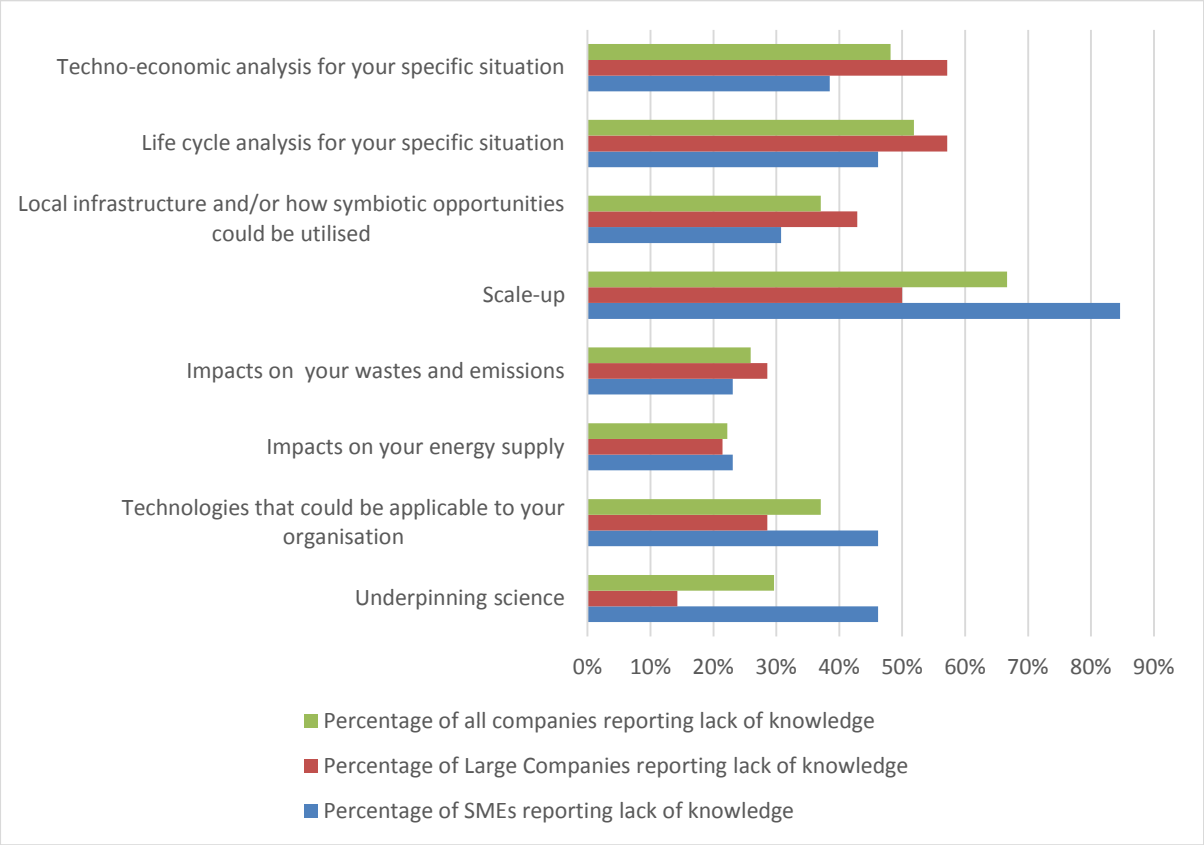


Figure 10. Assessment of areas where lack of knowledge is a factor

Figure 10 shows the responses to the question 'If technical knowledge is a factor, please assess in which areas you are lacking information'. The figure shows the total percentage of companies reporting the issue (from 27 responses), and then breaks down the responses showing percentages for large companies (14 responses) and SMEs (13 responses). The overall highest rated issue was 'lack of knowledge regarding scale-up of technologies' with 67% indicating this is an issue. Although a lack of knowledge concerning scale-up affected companies of all sizes, the issue was skewed toward SMEs with 85% reporting it as an issue compared to 50% of large companies. Scale-up was the highest rated issue amongst SME's by a considerable margin (next highest 46%), indicating that SME's particularly struggle in this area. Life Cycle Analysis (LCA) and Techno-economic Analysis (TEA) are the highest rated issues amongst larger companies. This reflects the previous responses regarding lack of knowledge of economics hindering deployment and finding from the SCOT project that identified LCA and TEA as areas that needed particular resource. A possible reason that LCA and TEA are particularly identified as problems for large companies is the need for larger companies to assess various different alternative carbon technologies to determine the best fit for their organisation. LCA and TEA are methodologies for doing this type of assessment, however there is currently a lack of standardisation in the application of these

methodologies and a lack of published data resulting in knowledge gaps and the observed results. SMEs may not encounter this issue in the same fashion, as they only need to conduct their studies on their own specific products or focus areas rather than compare across a wide range of technology options.

Finally, the respondents were asked what factors could increase their interest in new sources of carbon, responses are shown in Figure 11. Increasing the carbon price within the EU-ETS or introducing a carbon tax was the most popular response with 77% of respondents stating this would increase their interest. If the ETS or carbon tax was increased, it is general perceived that this would have a positive benefit on the use of CO_2 as a feedstock due to the desire of emitters to add value to the CO_2. However, this is a 'grey area' (Armstrong, Youssef Travaly, Bolscher, *et al.*, 2016) and more clarity on the economic impacts (positive and negative) of increasing ETS or carbon tax is needed. Additionally, CO_2 utilisation is not currently allowed as a way of reducing CO_2 emissions within the EU-ETS and moves to get CCU included tend to be focussed upon the permanent storage offered by mineralisation rather than the more short-term storage offered by chemicals and fuels.

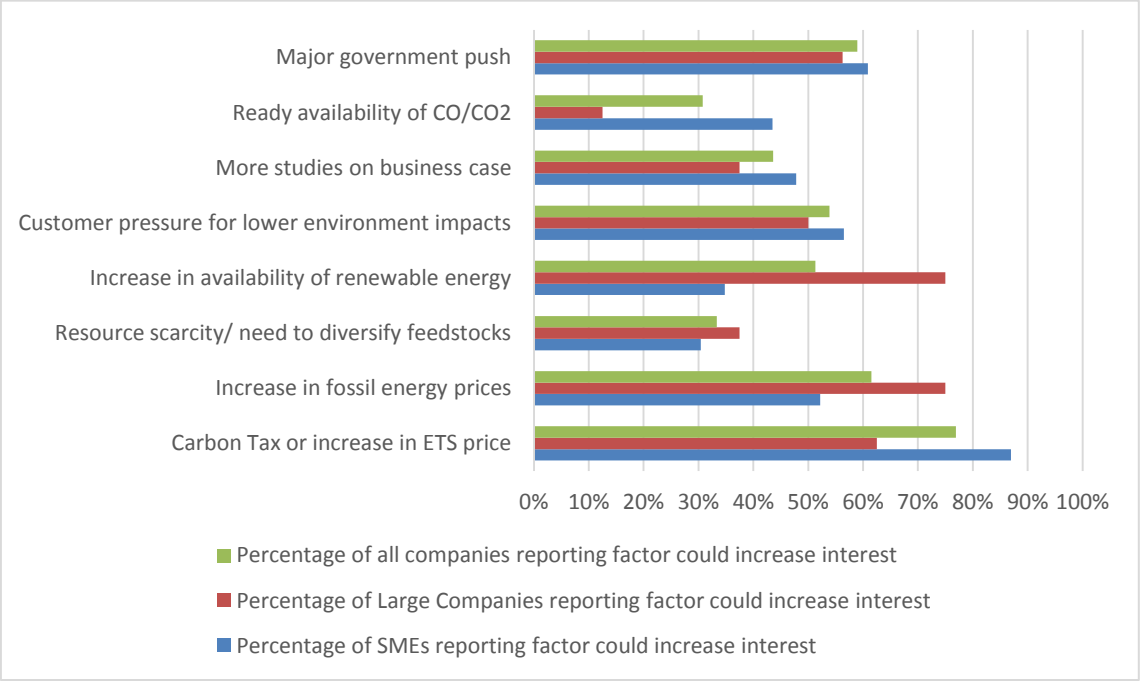


Figure 11. Factors that could increase interest in new sources of carbon.

More ready available CO/CO_2 sources and the need to diversify feedstocks or resource scarcity were the least popular options, though more than 30% of respondents stated these would increase interest. The ready availability of CO/CO_2 was particularly not of interest to

large companies, this is probably a reflection on the fact that most of the large companies were CO/CO_2 emitters and therefore are not reliant on external CO/CO_2 supplies. For large organisations, increasing the availability of renewable energy and increases in fossil energy prices were factors that could strongly increase interest in new carbon sources. These two factors both concern the energy inputs for the process, increased fossil energy prices would encourage organisations to seek alternative sources of energy and carbon feedstocks that were less susceptible to price fluctuations and more readily available renewable energy would decrease carbon emissions leading to products with lower carbon footprints.

3.5 Comparisons between micro-enterprises, SMEs and larger companies

The data was filtered to analyse trends for differing sized organisations comparing micro-enterprises (<10 employees), SMEs (<250 employees) and large companies (+250 employees). As CO/CO_2 utilisation is an emerging technology there are numerous micro-enterprises trying to bring new technologies to market. By comparing the results between different sized companies, trends could be identified that affect companies at different stages and between those (usually large companies) who are diversifying into the field and those whose primary business is in the field. Notable trends included the following:

- 53% of micro-enterprise companies reported working in the energy sector, this is significantly higher than in all SMEs (30%) and in large companies where only 18% operate in the energy sector.
- 32% of micro-enterprises and 47% of SMEs had projects either at demonstration or commercial scale, compared with 65% of large companies. It is encouraging that nearly 50% of SMEs have technology at this scale as often SME's struggle to overcome the 'Valley of Death' in moving technologies from pilot to demonstration scale, though scale-up issues or lack of investment.
- Most of the SMEs were part of the CO2Chem network (free to join) or CO2 Value Europe (membership fee) but only 6 out of the 34 were part of any other networks or groups. Large companies had a much more varied membership with 65% of the companies being members of more than one external organisation/network. Only 1 larger SME was a member of CEFIC or SPIRE, this is not unexpected as membership of CEFIC is geared towards large organisations; though it was

unexpected to discover that the SME's were not greatly participating in other knowledge transfer networks such as KICs or other relevant associations.

- 71% of micro-enterprises reported a lack of technical knowledge regarding scale up of technologies was an inhibiting factor to deploying technologies. However, only 1 further SME (size 11-20 employees) reported lack of knowledge of scale up as an issue; indicating that this is a problem specifically affecting the smallest sized SMEs.
- 87% of SMEs and 86% of micro-enterprises report that an increase in carbon price or ETS would increase interest in alternative carbon technologies, this is similarly reflected in the responses from large companies although at a slightly lower percentage, 63%.
- Large companies reported a higher level of lack of information for technical knowledge related to LCA and TEA (63% of respondents) compared to SMEs (35%). This may be due to large companies looking to invest in alternative carbon technologies and so wishing to assess opportunities and therefore using LCA and TEA as a method to do this whereas SME's are likely to have conducted LCA and TEA on their own technologies at a developmental stage. In general, there is a lack of publically available LCA and TEA on comparisons between alternative carbon technologies (Artz, Müller, Thenert, *et al.*, 2017), therefore it is expected that large companies would report a higher lack of information than SMEs.

3.6 Trends relating to different sectors or countries

- Companies in the Chemicals Sector ranked new business opportunities as their primary motivation for influencing their interest in alternative carbon technologies. This is encouraging for projects such as CarbonNext, where the European Commission is seeking to identify opportunities for the utilisation of alternative sources of carbon for the process industry, indicating that the findings of such projects will be positively received.
- 50% (10 respondents) of the 20 respondents from the UK were from micro-enterprises (<10 employees), compared to the survey average of 37%. Of the UK micro-enterprises 40% had operations at demonstrator or commercial scale, compared with 32% of all micro-enterprise. This may be the result of specific UK government funding programmes to encourage and develop alternative carbon technologies such as the Energy Entrepreneurs Fund.

- Those reporting to work in the mineralisation sector have the highest percentage of companies at commercial scale (60%) and conversely the lowest level of low TRL (TRL1-3) operations. This data reflects the conclusions of the SCOT project (Wilson, Travaly, Brun, *et al.*, 2015) that mineralisation technologies will be amongst the first of the CO_2 utilisation technologies to reach commercialisation.
- 10 respondents reported operating in the waste sector, of these 7 were based in the UK, 2 were in the Netherlands and 1 in Belgium. Of these, 4 responded that the impact of the Waste Directive upon their organisations decision to implement alternative carbon feedstock was unknown. This result is surprising and suggests better understanding of how legislation affects alternative carbon feedstocks would be welcome.
- For those organisations operating in the fuels sector, 2 organisations reported the Fuels Quality Directive (FQD) had a positive impact on their decision to implement alternative carbon feedstocks, for 1 organisation it made no impact and for 2 the impact was unknown. This result is similar to the Waste Directive, indicating again that further work to assess legislative impacts on alternative carbon technologies is necessary.
- The three responses from Canada were all from organisations with demonstration or commercial scale operations; the companies did not report any activities at low TRL. All three Canadian companies were SME's with fewer than 50 employees and are working in the minerals/construction sector. All three were also users of CO/CO_2 and stated they had a high level of familiarity in CO_2 utilisation technologies. Two respondents reported that regulation had played a very important role in their interest in alternative carbon sources and reducing carbon footprint was rated as important or very important by all three respondees. These responses are similar to similar sized and TRL organisations in the UK and the Netherlands. The Canadian respondees reported that 'customer pressure for lower environment impacts' would increase interest but similar sized UK companies also with commercial operations did not report the same. In general, there were no different trends observed between the responses from Europe and Canada.

4. Conclusions and Recommendations

Although the survey is limited in size due to the small size of the sector sampled, a number of conclusions can be drawn from the responses.

There is an observed lack of knowledge of how various policies and regulations have impacted decisions to implement alternative carbon feedstocks. This finding echoes a recommendation from the SCOT Joint Action Plan (Wilson, Travaly, Brun, *et al.*, 2016), where it is recommended that policy assessment is undertaken to increase deployment of CO_2 utilisation technologies. 47% of the responses gave 'unknown' as the impact of different policies or regulations on the organisations decision to implement alternative carbon technologies. No difference in knowledge of the impacts of policies/regulations was observed between SMEs and large companies indicating that it is a sector wide issue. In particular, increasing the ETS/carbon tax was perceived as having a positive impact on future decisions to engage with alternative carbon technologies, however the SCOT project highlighted a number of 'grey areas' within the ETS regarding the inclusion of CO_2 utilisation technologies and confirmed that clarity is needed to understand possible implications for the process industry.

Recommendation: It is recommended that comprehensive policy assessment of all relevant policies/legislation is undertaken as a priority and conclusions are as widely distributed as possible through organisations/networks to ensure knowledge transfer.

In general, most SMEs are members of only one external organisations or network. There may be a number of reasons for this including capacity/time and cost of joining. Therefore, opportunities for knowledge transfer may be limited and hindering deployment of new technologies. This may particularly occur in knowledge transfer between SMEs and larger companies, and can be observed in the responses of larger companies saying they were lacking information on the LCA and TEA of alternative carbon process which the SME's have as innovators. It is recommended that work is undertaken to improve knowledge transfer in the sector, particularly engaging SMEs in multiple programmes to ensure information flow is not reliant on solely one source which could lead to gaps in knowledge transfer and missed cross-fertilization opportunities. Of the companies that were not members of any network or external organisation, a higher rate of uncertainty around their organisation's interest in

alternative carbon sources is observed, indicating that involvement in external organisations is directly correlated to interest in alternative carbon technologies.

Recommendation: Encourage active membership in external organisations with a knowledge transfer focus to improve engagement in alternative carbon technologies as a whole.

The chemicals sector respondents appear to be the most positive to the deployment of new carbon technologies, with all companies rating new business opportunities as important or very important. This is encouraging as the chemical sector responses have generally rated their knowledge of CO_2 utilisation as 'very familiar', with 45% of the companies saying they did not lack the technical knowledge to implement new carbon technologies. The chemical sector respondees rate inconsistent policies between countries as a having a highly negative effect on implementing new technologies and would like to see a higher carbon tax/ETS and a major governmental policy push to increase interest. Therefore, it can be concluded that due to the high levels of knowledge that already exist in the chemicals sector, the major barriers to deployment are economic and policy related; which could be eased by implementing an incentive mechanism.

Recommendation: Investigate and initiate incentive mechanisms for the chemical industry to deploy alternative carbon technologies including new governmental policy and economic incentives.

Differences were observed between micro-enterprises and SME's, particularly regarding scale-up of technologies. Here access to knowledge transfer opportunities and partnerships with universities to utilise external skills-sets may be useful to bridge the knowledge gap. It was encouraging to observe that 32% of micro-enterprises had demonstration or commercial scale projects, indicating that nearly a third had overcome scale-up barriers. Funding programmes for SMEs directed at this development stage (TRL5-8) would enable technology deployment to be expedited. New SME funding programmes that necessitate that TEA and LCA studies are published (within the bounds of commercial confidentiality) could also be particularly beneficial to larger organisations wishing to make decisions about which new technology solutions to invest in.

Recommendation: Initiate a funding mechanism for SMEs relating to TRL5-8, this should include a requirement to publish LCA & TEA (within the bounds of commercial confidentiality).

The highest level of familiarity was found to be with the production of fuels from CO/CO_2, although only 14% of respondents reported their organisation worked in this sector. This may be due to the relatively higher levels of research in this area compared with other sectors, or could be a result of companies investigating diversifying into a new market/sector but yet to have made the transition. Lower levels of familiarity were observed in the production of fine and bulk chemicals indicating that if alternative sources of carbon are to be introduced in these areas a greater level of knowledge and investment is required. Implementing research targets to particularly focus on core feedstocks for the process industry could address this issue.

Recommendation: Increase research and knowledge regarding the opportunities to produce core chemical feedstocks for the process industry via research targets and increased funding in FP9 and other mechanisms.

5. Bibliography

Armstrong, K., Youssef Travaly, Bolscher, H., Brun, T., Knippels, H., Kraemer, D., Rothengatter, N., Wilson, G., Styring, P., Veenstra, E., Saussez, G. and Buck, L. (2016) *A Strategic European Research and Innovation Agenda for Smart CO2 Transformation in Europe*.

Artz, J., Müller, T. E., Thenert, K., Kleinekorte, J., Meys, R., Sternberg, A., Bardow, A. and Leitner, W. (2017) 'Sustainable Conversion of Carbon Dioxide: An Integrated Review of Catalysis and Life Cycle Assessment', *Chemical Reviews*, p. acs.chemrev.7b00435. doi: 10.1021/acs.chemrev.7b00435.

Bruhn, T., Naims, H. and Olfe-Krautlein, B. (2016) 'Separating the debate on CO2 utilisation from carbon capture and storage', *Environmental Science and Policy*. Elsevier Ltd, 60, pp. 38–43. doi: 10.1016/j.envsci.2016.03.001.

EC (European Commission) (2011) 'Thinking Big for Small Businesses. What the EU does for SMEs', p. 25p.

Goeppert, A., Czaun, M., Jones, J.-P., Surya Prakash, G. K. and Olah, G. A. (2014) 'Recycling of carbon dioxide to methanol and derived products – closing the loop', *Chem. Soc. Rev.* doi: 10.1039/C4CS00122B.

Olah, G. a, Goeppert, A. and Prakash, G. K. S. (2009) 'Chemical recycling of carbon dioxide to methanol and dimethyl ether: from greenhouse gas to renewable, environmentally carbon neutral fuels and synthetic hydrocarbons.', *The Journal of organic chemistry*, 74(2), pp. 487–98. doi: 10.1021/jo801260f.

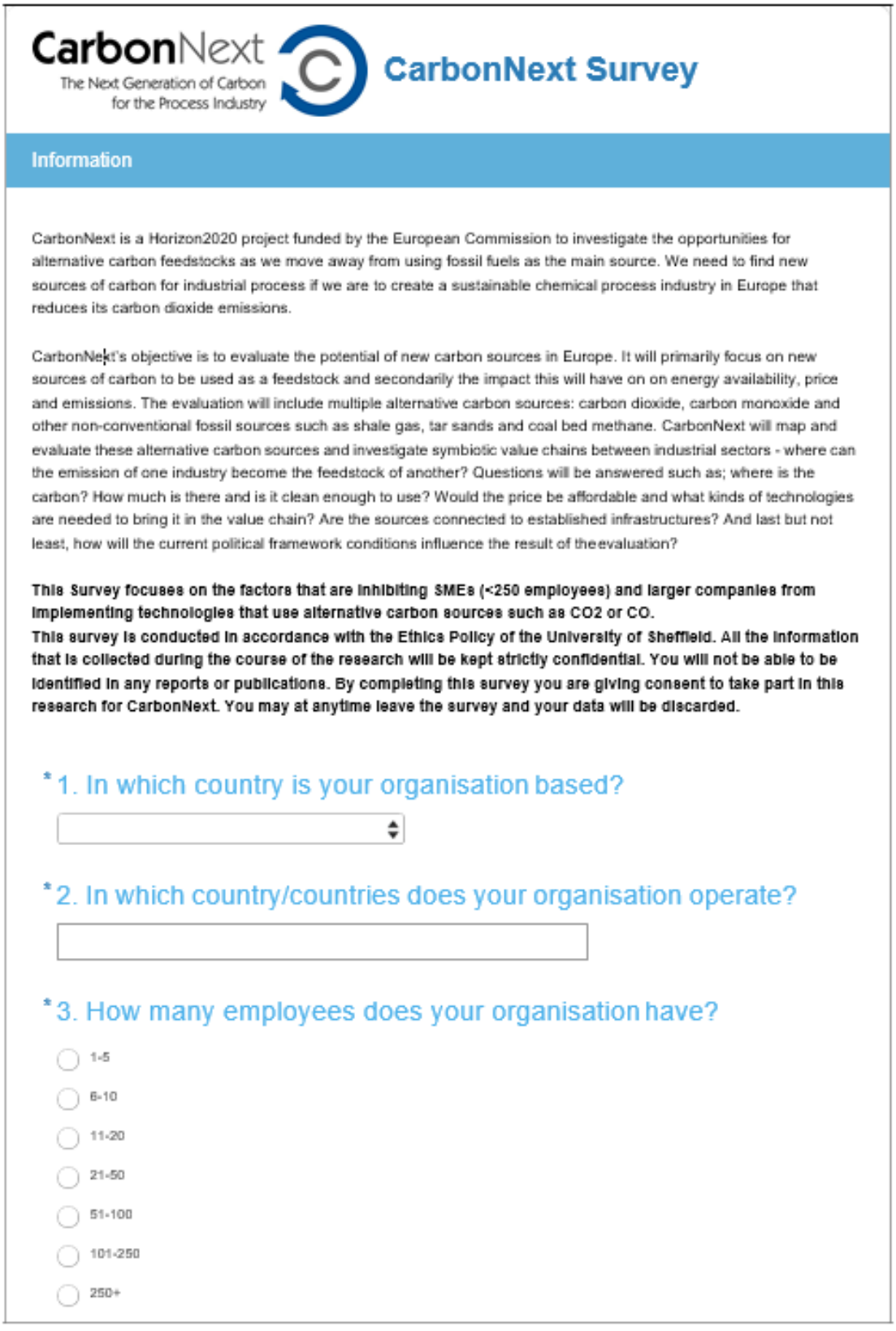
Pérez-Fortes, M., Schöneberger, J. C., Boulamanti, A. and Tzimas, E. (2016) 'Methanol synthesis using captured CO2 as raw material: Techno-economic and environmental assessment', *Applied Energy*, 161. doi: 10.1016/j.apenergy.2015.07.067.

Roh, K., Frauzem, R., Nguyen, T. B. H., Gani, R. and Lee, J. H. (2016) 'A methodology for the sustainable design and implementation strategy of CO2 utilization processes', *Computers and Chemical Engineering*, 91. doi: 10.1016/j.compchemeng.2016.01.019.

Wilson, G., Travaly, Y., Brun, T., Knippels, H., Armstrong, K., Styring, P., Krämer, D., Saussez, G. and Bolscher, H. (2015) *A Vision for Smart CO2 Transformation in Europe: Using CO2 as a resource*.

Wilson, G., Travaly, Y., Brun, T., Knippels, H., Armstrong, K., Styring, P., Krämer, D., Saussez, G. and Bolscher, H. (2016) *Joint Action Plan for Smart CO2 Transformation in Europe: CO2 as a resource*.

6. Appendix 1



CarbonNext
The Next Generation of Carbon for the Process Industry

CarbonNext Survey

Information

CarbonNext is a Horizon2020 project funded by the European Commission to investigate the opportunities for alternative carbon feedstocks as we move away from using fossil fuels as the main source. We need to find new sources of carbon for industrial process if we are to create a sustainable chemical process industry in Europe that reduces its carbon dioxide emissions.

CarbonNext's objective is to evaluate the potential of new carbon sources in Europe. It will primarily focus on new sources of carbon to be used as a feedstock and secondarily the impact this will have on on energy availability, price and emissions. The evaluation will include multiple alternative carbon sources: carbon dioxide, carbon monoxide and other non-conventional fossil sources such as shale gas, tar sands and coal bed methane. CarbonNext will map and evaluate these alternative carbon sources and investigate symbiotic value chains between industrial sectors - where can the emission of one industry become the feedstock of another? Questions will be answered such as; where is the carbon? How much is there and is it clean enough to use? Would the price be affordable and what kinds of technologies are needed to bring it in the value chain? Are the sources connected to established infrastructures? And last but not least, how will the current political framework conditions influence the result of the evaluation?

This Survey focuses on the factors that are inhibiting SMEs (<250 employees) and larger companies from implementing technologies that use alternative carbon sources such as CO2 or CO.
This survey is conducted in accordance with the Ethics Policy of the University of Sheffield. All the information that is collected during the course of the research will be kept strictly confidential. You will not be able to be identified in any reports or publications. By completing this survey you are giving consent to take part in this research for CarbonNext. You may at anytime leave the survey and your data will be discarded.

* 1. In which country is your organisation based?

* 2. In which country/countries does your organisation operate?

* 3. How many employees does your organisation have?

- 1-5
- 6-10
- 11-20
- 21-50
- 51-100
- 101-250
- 250+

* 4. What sector is your organisation part of?

- [ ] Chemicals
- [ ] Minerals/Construction
- [ ] Fuels
- [ ] Metals
- [ ] Bio-based
- [ ] Waste
- [ ] Energy
- [ ] Other

Please specify the exact field

5. What stage is your organisation at? (you can have more than one answer for different areas of the organisation).

- [ ] Research (TRL 1-3)
- [ ] Pilot (TRL 4-6)
- [ ] Demonstrator (TRL 6-8)
- [ ] Commercial (TRL 9)
- [ ] Other (please specify)

6. Please indicate if any of the below listed points apply for your organisation? Please select all that apply.

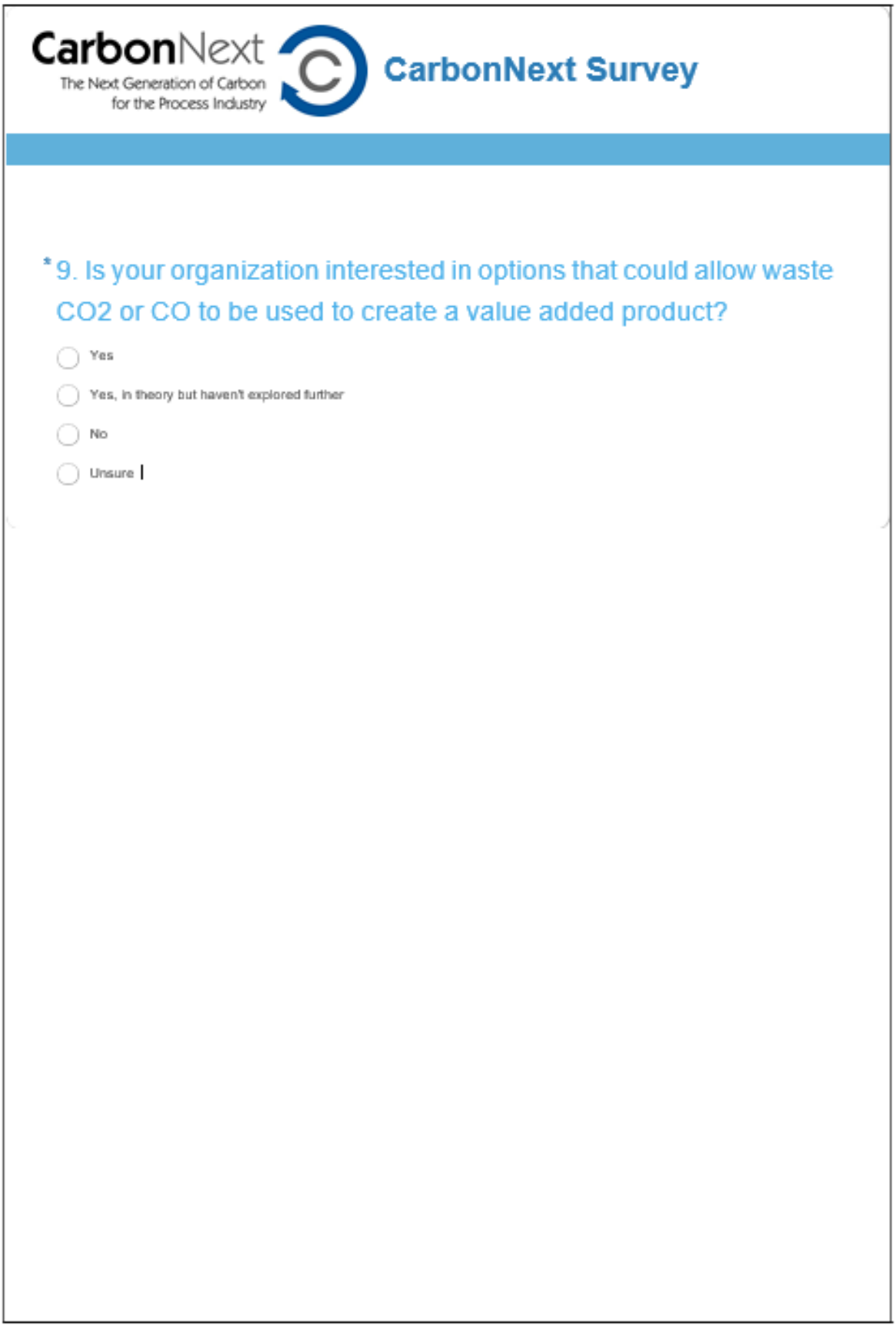
- [ ] Member of Spire
- [ ] Member of Cefic
- [ ] Member of Eurofer and/or Eurometaux
- [ ] Member of The European Cement Association
- [ ] Member of Hydrogen Europe and/or European Hydrogen and Fuel Cell Association
- [ ] Member of CO2Chem or CO2 Value Europe
- [ ] Have participated in the German funding programme on CO2 utilisation
- [ ] Member of KIC's (e.g. Climate, Energy, Raw materials)
- [ ] Member of BBIC (Bio-based industries consortium)
- [ ] Other CO/CO2 or low carbon related organisations (please specify)

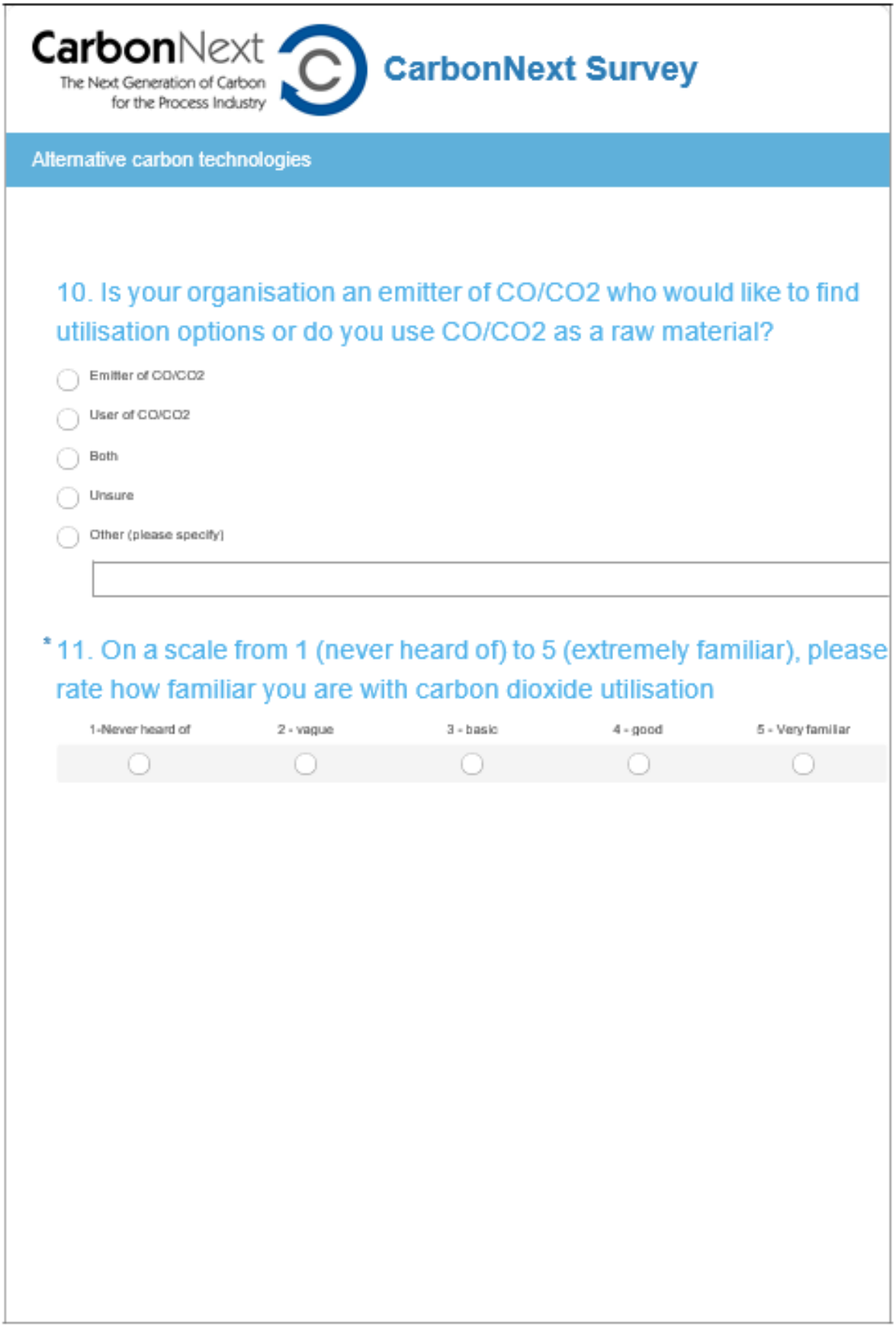
7. Does your organisation have goals for reducing environmental impacts?

- ( ) Yes
- ( ) No
- ( ) Unsure

8. If yes, what areas do the environmental goals impact?

- [ ] Use of renewable energy
- [ ] Energy efficiency
- [ ] Waste reduction
- [ ] Resource efficiency
- [ ] Pollution abatement
- [ ] Recycling
- [ ] Carbon footprint
- [ ] Other (please specify)


CarbonNext
The Next Generation of Carbon for the Process Industry
CarbonNext Survey
*9. Is your organization interested in options that could allow waste CO2 or CO to be used to create a value added product?
Yes
Yes, in theory but haven't explored further
No
Unsure



CarbonNext
The Next Generation of Carbon for the Process Industry

CarbonNext Survey

Alternative carbon technologies

10. Is your organisation an emitter of CO/CO2 who would like to find utilisation options or do you use CO/CO2 as a raw material?

- Emitter of CO/CO2
- User of CO/CO2
- Both
- Unsure
- Other (please specify)

* 11. On a scale from 1 (never heard of) to 5 (extremely familiar), please rate how familiar you are with carbon dioxide utilisation

1-Never heard of	2 - vague	3 - basic	4 - good	5 - Very familiar
○	○	○	○	○

* 12. On a scale from 1 (never heard of) to 5 (extremely familiar), please rate how familiar you are with these specific CO2 utilization technologies. Please answer for each option.

	1-Never heard of	2 - vague	3 - basic	4 - good	5 - Very familiar
Polymer production from CO2/CO	○	○	○	○	○
Bulk Chemical production from CO2/CO	○	○	○	○	○
Fine Chemical production from CO2/CO	○	○	○	○	○
Fuel production from CO2/CO	○	○	○	○	○
Mineral production from CO2/CO	○	○	○	○	○
CO2/CO bio-based technologies	○	○	○	○	○

* 13. Assess the importance of the following factors influencing your interest in alternative carbon technologies? Please answer for each option

	Very important	Important	Moderately important	Low importance	Not important	Not applicable
Regulation/taxation	○	○	○	○	○	○
New business opportunities/diversification	○	○	○	○	○	○
Broaden your raw material base	○	○	○	○	○	○
Using current waste streams	○	○	○	○	○	○
Public relations/social responsibility	○	○	○	○	○	○
Reducing carbon footprint	○	○	○	○	○	○
Making "greener" products	○	○	○	○	○	○
Security of supply of raw materials	○	○	○	○	○	○
Use of excess energy/heat	○	○	○	○	○	○

* 14. To what extent do the following factors prevent your organisation from implementing technologies to use alternative sources of carbon to their full potential?

	Very high extent	High extent	Moderate extent	Low extent	Not at all
Lack of technical knowledge	○	○	○	○	○
Unsure of legal frameworks	○	○	○	○	○
Regulatory barriers	○	○	○	○	○
Lack of knowledge of market opportunities	○	○	○	○	○
Lack of knowledge of economics of the process	○	○	○	○	○
Economic feasibility (poor business case)	○	○	○	○	○
Lack of government subsidies	○	○	○	○	○
Lack of private investors	○	○	○	○	○
Lack of public funding/support	○	○	○	○	○
Lack of partners	○	○	○	○	○
Lack of infrastructure (pipelines, capture facilities etc)	○	○	○	○	○
CO/CO2 price	○	○	○	○	○

15. Please provide further details on the barriers you encounter and how these could be overcome

16. If technical knowledge is a factor, please assess in which areas you are lacking information

- [ ] Knowledge of underpinning science
- [ ] Knowledge of technologies that could be applicable to your organisation
- [ ] Knowledge of impacts on your energy supply
- [ ] Knowledge of impacts on your wastes and emissions
- [ ] Knowledge of scale-up
- [ ] Knowledge of how local infrastructure and/or how symbiotic opportunities could be utilised
- [ ] Knowledge of life cycle analysis for your specific situation
- [ ] Knowledge of techno-economic analysis for your specific situation
- [ ] Other - please detail below

Please give further details

* 17. What impact do the following regulations/policies have on your decision to implement alternative carbon feedstocks?

	Negative impact	No impact	Positive impact	Unknown
Emissions Trading Scheme (ETS)	○	○	○	○
Waste Directive	○	○	○	○
Fuel Quality Directive (FQD)	○	○	○	○
Renewable Energy Directive (RED)	○	○	○	○
Clean Energy Package	○	○	○	○
Inconsistent policies between countries	○	○	○	○
Circular economy package	○	○	○	○

Comments - please give further details on the positive and negative impacts you have encountered.

18. Please tell us about any other factors that are influencing or could influence your organisation's use of alternative carbon technologies?

19. What factors could increase your interest in new sources of carbon? Please tick all that apply.

- [ ] Carbon Tax or increase in ETS price
- [ ] Increase in fossil energy prices
- [ ] Resource scarcity/ need to diversify feedstocks
- [ ] Increase in availability of renewable energy
- [ ] Customer pressure for lower environment impacts
- [ ] More studies on business case
- [ ] Ready availability of CO/CO2
- [ ] Major government push
- [ ] Other (please specify)

20. Thank you for completing the CarbonNext survey. If you have any feedback please contact, katy.armstrong@sheffield.ac.uk, or add it in the box below.