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Stakeholder perceptions of CO_2 capture and storage in Europe: Results from a survey

Simon Shackley[a,*], Holly Waterman[a], Per Godfroij[b], David Reiner[c], Jason Anderson[d], Kathy Draxlbauer[a], Todd Flach[e]

[a]*Manchester Business School, University of Manchester, PO Box 88, Manchester M60 1QD, UK*
[b]*Energy Research Centre of the Netherlands, Westerduinweg 3, 1755ZG Petten, The Netherlands*
[c]*Judge Business School, Trumpington Street, University of Cambridge, Cambridge CB2 1AG, UK*
[d]*Institute for European Environmental Policy, 28 Queen Anne's Gate, London SW1H 9AB, UK*
[e]*Det Norsk Veritas AS, Veritasveien 1, 1322 Hoevik, Norway*

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Abstract

During 2006, a survey was conducted of European energy stakeholders (industry, government, environmental non-governmental organizations (NGOs), researchers and academicians and parliamentarians). A total of 512 responses was received from 28 countries as follows: industry (28%), research (34%), government (13%), NGOs (5%) and parliamentarians (4%). Three-quarters of the sample thought that widespread use of CO_2 capture and storage (CCS) was 'definitely' or 'probably necessary' to achieve deep reductions in CO_2 emissions between now and 2050 in their own country. Only one in eight considered that CCS was 'probably' or 'definitely not necessary'. For a range of 12 identified risks, 20–40% thought that they would be 'moderate' or 'very serious', whilst 60–80% thought that there would be no risks or that the risks would be 'minimal'. A particular risk identified by nearly half the sample is the additional use of fossil fuels due to the 'energy penalty' incurred by CCS. Further concerns are that development of CCS would detract from investment in renewable energy technologies. Half of the respondents thought that incentives for CCS should be set either at the same level as those for renewables or at a higher level. Environmental NGOs were consistently less enthusiastic about CCS than the energy industry.

Keywords: Stakeholders; CO_2 storage

1. Introduction

During the second half of 2006, 512 stakeholders from across Europe participated in a survey of opinion regarding the role of CO_2 capture and storage (CCS) in Europe's possible energy futures. The survey was conducted as part of, and funded under, the EU ACCSEPT project (Acceptance of CO_2 Capture and Storage: Economics, Policy and Technology). The objective of the survey was, for the first time, to capture opinion amongst European energy stakeholders—whom we defined as being those with a professional interest, and/or involvement, in energy and climate policy and economics, energy technologies, climate change mitigation and so on. We sought to include both those directly involved in CCS science, technology and evaluation and those with a wider brief in energy and climate policy and evaluation. The questionnaire is available for inspection in the electronic annexes.

2. The Sample

We distributed 2619 questionnaires to named individuals from the EU25: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the UK. No respondents were identified in two

*Corresponding author. Tel.: +44 121 706 1525; fax: +44 161 200 3701.
E-mail address: simon.shackley@mbs.ac.uk (S. Shackley).

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of the EU25: Malta and Cyprus. In addition, we sent the questionnaire to contacts in other European countries who are not members of the EU but who are involved in CCS research, development and demonstration (RD&D), especially Norway and Switzerland. A few responses were obtained from Bulgaria (part of the EU since 1 January 2007), Croatia, Serbia and Turkey. A few responses also emanated from the USA. Just over half of the questionnaires (1341) were distributed to the members of national parliaments or to the members of the European Parliament. Key data for each country are presented in Table 1.

The names and contact details of the sample were extracted from a range of sources, including attendees at major European and international conferences on energy futures, climate change and CCS, and participants in major EU energy research projects. Along with the survey, we also distributed a three-page fact sheet on CCS in order to ensure that there was a common baseline from which responses were made. The fact sheet briefly outlined the different CO_2 capture technologies (pre- and post-combustion, oxyfuel combustion), their costs, the different geological storage sites (operational and depleted oil and gas reservoirs, saline aquifers and unmineable coal beds), summary information on the potential risks and on options for incentive mechanisms for encouraging the deployment of CCS. Coal and gas were the main fuels mentioned, and in addition to electricity generation, it was noted that the production of liquid fuels such as hydrogen could also be associated with CCS. The fact sheet also noted that the capacity of potential geological reservoirs is not known with any accuracy but "is likely to be sufficient to allow CCS to play a major role in reducing CO_2 emissions in many countries". There was no explicit comparison of CCS with other low- and zero-carbon electricity/energy generation options in the fact sheet, though it was noted that: "Expressed as the cost of avoiding a tonne of CO_2 emissions, the additional costs for most of these CCS technologies are comparable to many renewables and, with more uncertainty, to new nuclear build". Hence, the respondents' opinions were being sought in the context of the state-of-the-art understanding of the range of currently viable CCS technologies, geological storage sites, costs, risks and potential scale of deployment, as expressed in IPCC (2005).

The survey and information note were available in 17 languages: English, German, French, Italian, Spanish, Portuguese, Czech, Lithuanian, Polish, Dutch, Swedish, Norwegian, Finnish, Danish, Estonian, Slovenian and Greek. The survey was available remotely on the web in addition to the paper version. We invited respondents to alert other relevant colleagues to the presence of the survey, and a number of unsolicited responses were therefore received, 103 in total. Not including the unsolicited responses and the parliamentarians in the target sample or list of respondents (only 21 responses having been received), the response rate was 389/1279 or approximately 30%.

Most responses were received from those involved in the commercial energy sector (28%) and in research/academia (34%). Government respondents represented a further 13%, NGOs 5% and parliamentarians 4%. Breaking down further the two largest stakeholder groups, research specializations included geological research (10% of total), engineering research (9%), national geological surveys (5%) and social science/think tanks (5%); energy sector respondents came from electricity generators (8%), oil and gas (7%) and power plant designers and builders (5%). Most of the respondents were energy specialists, with 75% of the sample spending 50% or more of their work time on energy, though nearly half of the sample spent less than 30% of their time working specifically on CCS; 36% of the sample spent at least 50% of their time working on CCS. Hence, just over one-third of the sample could be described as being CCS specialists.

Responses from relatively few countries dominated the sample; 20% of the respondents were from the UK, 11% were from Germany, 9% from the Netherlands, 6% from France and Italy, 5% from Denmark, Spain and Norway, 4% from Belgium, and 3% from Finland and Sweden. To analyse the difference in responses across countries statistically, we selected several countries for individual analysis based upon the absolute number of responses and the population size. We selected two large countries—the UK (at 1.7 respondents per million population) and Germany (0.67 respondents per million); three medium-sized countries—Sweden, Belgium (both at 1.9 respondents per million) and the Netherlands (2.9 respondents per million); and three small countries—Denmark, Norway (both at 4.6 respondents per million) and Finland (2.2 respondents per million). Whilst France, Italy and Spain all had reasonable numbers of respondents (30, 29 and 25, respectively), it was decided that these numbers were too small relative to population size to be representative of the target stakeholder community, hence, these countries were not selected for a more detailed analysis. In the cases of Slovenia and Estonia, which had a high number of respondents per million head of population (at 4 and 3.3, respectively) it was decided that the absolute number of respondents (8 and 6, respectively) was simply too small to justify the selection of these countries for a more detailed analysis.

As a check on this approach, we also worked out the percentage of those who were invited to participate in the survey (with the exception of the parliamentarians) who actually responded in different countries. We reasoned that the number of contacts in our database was a reasonably good proxy for the relative size of the CCS stakeholder community in each country. Where more than a third of invitees responded we decided to include the country in the statistical analysis. This was the case for Sweden (44%), Denmark (51%), Finland (45%), Germany (44%), Belgium (41%), Norway (37%), the Netherlands (36%) and Spain (33%). The percentages were below 33% in Slovenia (30%) and France (24%). This check confirm

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Table 1
Data on countries included in the survey

Country	Questionnaires distributed (excluding parliamentarians)	Responses received	GHG/capita (tCO_{2e})	% Change in GHG emissions in 2004 relative to baseline	Kyoto target and EU burden sharing	Kyoto target status	GDP/capita at current prices (L, ML, MH, H)	Country size (L, M, S)	Regional category (NW, South, CEE, Scand.)
EU countries									
Austria	18	9	11.1	15.7%	−13%	1	H	M	CEE
Belgium	61	21	14.2	0.7%	−7.5%	1	H	M	NW
Czech Republic	17	8	14.4	−25.1%	−8%	3	L	M	CEE
Denmark	49	25	12.6	−1.8%	−21%	1	H	S	Scand.
Estonia	12	6	16.0	−50%	−8%	3	L	S	CEE
Finland	33	15	15.5	14.5%	0%	1	H	S	Scand.
France	130	30	8.8	−0.8%	0%	2	MH	L	NW
Germany	126	55	12.3	−17.5%	−21%	2	MH	L	NW
Greece	9	4	12.2	23.9%	25%	2	ML	M	South
Hungary	15	1	8.2	−32%	−6%	3	L	M	CEE
Ireland	8	2	16.2	22.7%	13%	1	H	S	NW
Italy	97	29	9.9	12.3%	−6.5%	1	MH	L	South
Latvia	1	2	4.7	−58.5%	−8%	3	L	S	CEE
Lithuania	22	7	5.6	−8%	−8%	3	L	S	CEE
Luxembourg	0	0	27.0	0.3%	−28%	1	H	S	NW
The Netherlands	132	48	13.3	1.6%	−6%	1	H	M	NW
Poland	43	14	10.0	−31.6%	−6%	3	L	M	CEE
Portugal	24	7	7.9	41%	27%	1	ML	M	South
Slovakia	13	4	9.4	−30.3%	−8%	3	L	S	CEE
Slovenia	10	8	10.0	−0.8%	−8%	1	L	S	CEE
Spain	59	25	9.5	47.9%	15%	1	ML	L	CEE
Sweden	30	17	7.7	−3.6%	4%	2	H	M	South
The UK	243	100	10.9	−14.1%	12.5%	2	H	L	Scand.
Non-EU countries									
Bulgaria	4	3					L		NW
Croatia	12	1					L		
Norway	68	25					H	S	CEE
Romania	6	0					L	S	CEE
Serbia	3	1					L		Scand.
Switzerland	17	2					L		CEE
Turkey	2	1					H		CEE
The USA	2	4					L		NW
									South

Sources: EEA (2006), Econstats (2007).

Kyoto target status
1: Long way from target
2: Close to target
3: Have easily exceeded target (beyond target)

GDP/capita (2006) at current prices (not PPP)
L: Low ≤ $19,000
ML: Medium–low, $19,001–29,000
MH: Medium–high, $29,001–39,000
H: High > $39,001

Size of countries
L: Large = > 45 million
M: Medium = 8–45 million
S: Small = less than 8 million

Regional category:

NW: North West Europe
South: Southern Europe
CEE: Central and Eastern Europe
Scand.: Scandinavia.

...tion of the above eight nations for statistical analysis. ...also grouped together respondents from Central and ...ern Europe (54 in total covering Poland, Latvia, ...ania, Estonia, Czech Republic, Slovakia, Slovenia, ...ria, Hungary, Serbia, Croatia and Austria) for the ...oses of comparison.

The main statistical test conducted was the independent *t*-test to compare two means (Statsoft, 2007). By conducting a large number of pair-wise comparisons, it was possible to build up a picture of the significant differences in responses by country, stakeholder group, region and other categories. Where the two-tailed significance is 0.05

Table 2
Questionnaire structure

Part and question number	Questions (text within double quotation marks indicate actual questions)	Corresponding section of paper
Part A	*About you and your organisation*	
1–3	Name, organization, job title	
4–5	Time spent on energy and on CCS specifically	16
6–7	Organizational position on CCS and reason behind this position	3
Part B	The contribution of CCS in meeting Europe's future energy requirements	
8	"Is wide-scale implementation of CCS required to achieve deep reductions in CO_2 emissions between now and 2050 in your own country, the EU and at the global scale?"	4
9–10	Role of CCS in current national climate change debate and whether it is increasing or decreasing	5
Part C	*The enabling context for CCS and incentive regimes*	
11	Importance of different factors in explaining current and future development of CCS in own country	6
12	Opinion on provision of financial incentives for CCS similar to those used to support renewable energy	7
13	Preference for different types of incentive mechanisms	8
14	Scale of application of incentives	9
15	How CCS should be regulated	9
Part D	*The potential risks of CCS*	
16	Opinion on potential risks to health, safety and the environment arising from CCS	10
17	"In your opinion will investment in CCS deter investment in other zero- and low-carbon electricity and energy generation options (e.g. renewable energy) in your own country?"	11
18	"In your opinion will investment in CCS reduce effort spent on improving energy efficiency and on reducing energy demand in your own country?"	11
19	"Use of CCS might make us more dependent upon a centralised power generation system. What is your opinion of CCS and its impact on decentralised power generation over the next 20–40 years, in particular that from renewable energy?"	12
20	Impact of CCS upon energy security in Europe from coal with CCS and gas with CCS	13
21	Opinion on potential public perceptions regarding CCS both in the EU and in own country	14
22	Factors most likely to influence public perceptions regarding CCS in own country	15

or below, the difference has been assumed to be significant (i.e. there remains a 5% chance that any significant difference in the means arises by chance). Bivariate correlations using the Pearson test have also been employed to examine whether different variables are correlated at the 0.05 and 0.01 significance levels (Statsoft, 2007).

It is important to emphasize that the sample is self-selecting and appears to largely represent those most actively engaged in their respective country in CCS research, development, demonstration, promotion and evaluation. Therefore, the sample does not necessarily include the wider opinions of all energy stakeholders and this caveat should be borne in mind when examining the results. The structure of the survey is shown in Table 2, which also shows the relevant section of the paper in which the results are presented and discussed.

3. Organizational position on CCS

Almost half (47%) of the respondents reported that their organization was 'very positive' towards CCS and a further 24% indicated a 'slightly positive' organizational position (Fig. 1). Only 6% of the sample indicated a 'slightly negative' or 'very negative' posture towards CCS. The majority of the respondents therefore work for organizations with a positive stance towards CCS.

The most frequent reasons given for the position taken on CCS are potential to continue the use of fossil fuels, potential magnitude of CO_2 emission reductions, business opportunities, potential for rapid cuts in CO_2 emissions, energy security and environmental risks. Those more sceptical of CCS are concerned about the effect of CCS in discouraging investment in other options (e.g. renewables), environmental risks, high costs, regulatory and legal uncertainty, continuation of the use of fossil fuels and the availability of more effective CO_2 mitigation options.

4. Perceived need for CCS in own country, the EU and globally

A large percentage of respondents believe that CCS is 'definitely' or 'probably necessary' to achieve deep reductions in CO_2 emissions between now and 2050 in their own country. Favourability increases from their own country to the EU scale to globally (Fig. 2). British, Norwegian and Dutch respondents tend to show a similar pattern of response, with enthusiasm for CCS and relatively little scepticism. German, Belgian and Danish respondents show less enthusiasm regarding the role of CCS at the national,

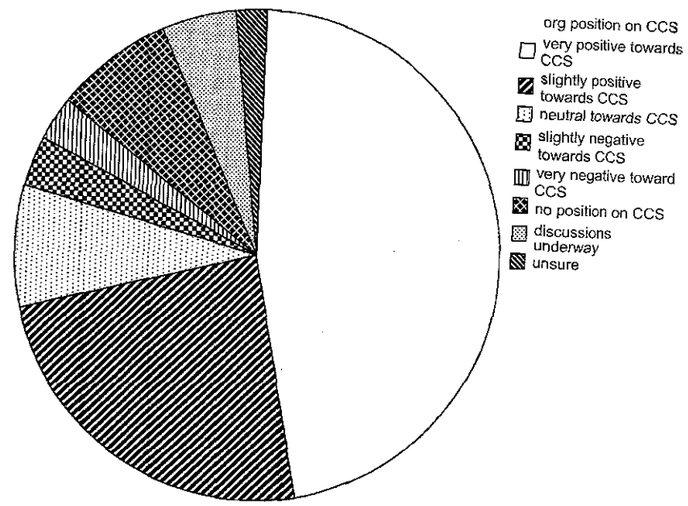

Fig. 1. Respondents' perception of their own organizations' position on CCS.

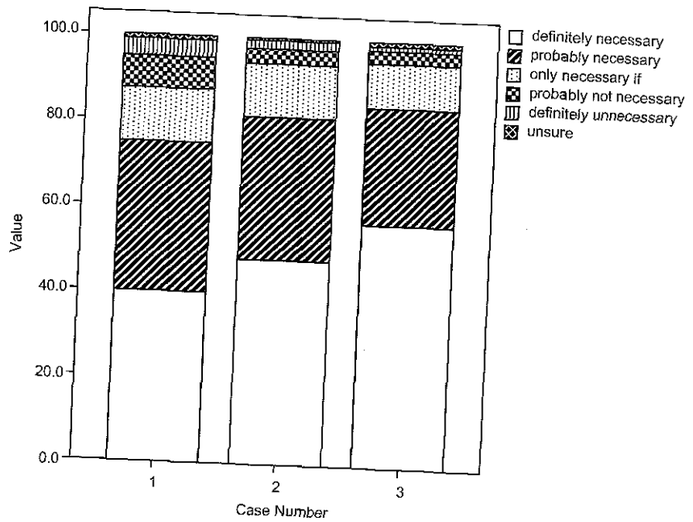

Fig. 2. Perceived need for CCS to meet deep CO_2 cuts in host country (1), EU (2) and globally (3) in percentages.

EU and global scales, although there is still an overwhelming majority of respondents from those countries who support the use of CCS. Least convinced of the need for CCS from the eight countries analysed in detail are the Finnish and Swedish respondents. Respondents from Central and Eastern European countries are also amongst the least enthusiastic about the need for CCS in their own country, though they are still supportive overall.

Energy, government and academic stakeholders are generally supportive of CCS, with a small minority of 10% or so of each group stating that CCS would only be necessary 'if other options fail to live up to current expectations'. The level of support by these stakeholder groups for CCS increases from their own country to the EU and global scales. The NGOs are more ambivalent regarding the role of CCS, and do not perceive an increasing need for CCS from their own country to the EU and global scales. The parliamentarians are largely in favour of CCS, though there is again a tendency towards more scepticism than for energy, academic and government stakeholders.

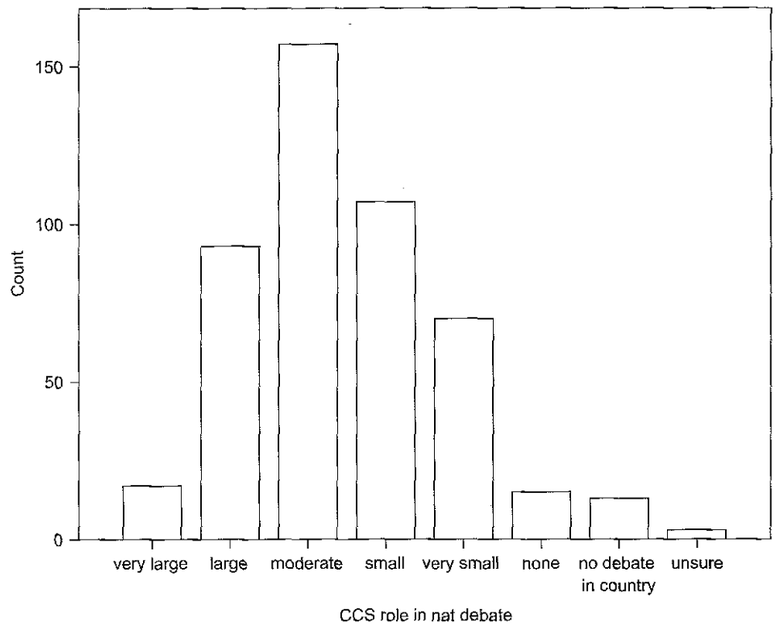

Fig. 3. Current role of CCS in the national climate change debate.

5. Role of CCS in the national climate change debate

CCS is perceived to play a very large, large or moderate role in the current national climate change debate (56%), although there is a sizeable percentage (37%) stating that CCS has a small or very small role (Fig. 3). The role of CCS in the national debate is generally increasing: substantially (26%), slightly (53%) or staying the same (18%).

Norwegian respondents identified CCS as playing the largest role in the national debate followed by the Netherlands, UK, Germany and Denmark with other Scandinavian countries and Central and Eastern European countries reporting the smallest role for CCS (Fig. 4). The role of CCS is seen as increasing most in Norway, Germany, the Netherlands and the UK, i.e. in those countries where it is already most prominent.

6. The enabling context for CCS in home country

The most important perceived factors influencing the development of CCS are availability of suitable geological storage sites and price of carbon under the EU Emissions Trading Scheme (EU ETS), followed closely by reduction in costs of CO_2 capture, development of the research and technological base for CCS, a post-Kyoto phase with tighter national emission reduction requirements, development of the legal and regulatory basis for CCS and public perceptions of CCS. The least important factors identified are availability of venture capital, development of the hydrogen economy and availability of domestic supplies of coal.

Those countries with domestic coal supplies (e.g. Poland, Germany, the UK and Spain) tended to regard coal supplies as a more important factor influencing CCS development, whilst oil and gas producers (Norway, the UK, the Netherlands and Denmark) tended to regard enhanced oil and gas recovery as a more important factor.

7. Should CCS receive similar subsidies to renewable energy development?

Half of the respondents think that incentives for CCS should either be set at the same level as those for renewables (39%) or that higher incentives should be applied (11%). By contrast, 33% of respondents consider that incentives should be lower than those for renewables and a further 12% feel that incentives for CCS are not needed at all (Fig. 5).

NGOs and parliamentarians are the least enthusiastic about generous incentives for CCS, with 52% and 38% of respondents, respectively, opposed to any incentives for CCS, though 40–48% of respondents are still in favour of incentives comparable to, or set at a lower level than, those for renewables.

Danish, Dutch and British respondents favour a more generous incentive structure for CCS, whilst the German respondents seem to be more divided in their opinions. Norwegian respondents are less supportive of more generous incentives for CCS than might have been

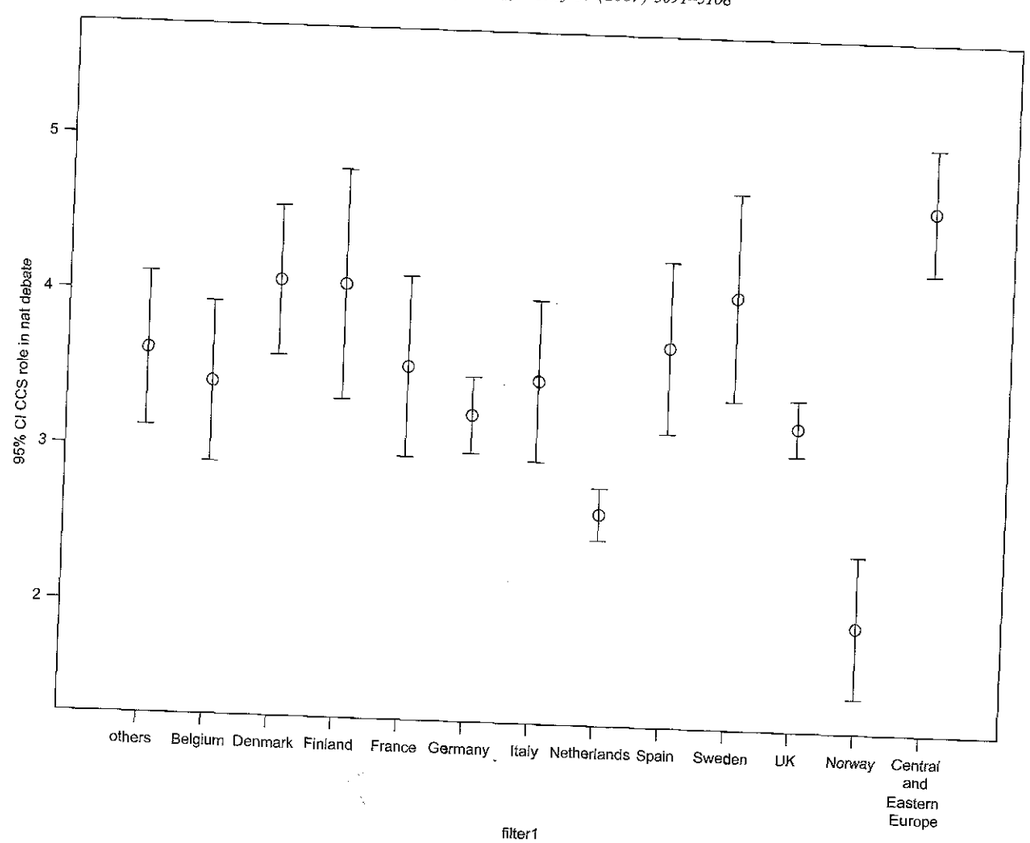

Fig. 4. Role of CCS in the national climate change debate (1 indicates 'very large', 2 'large', 3 'moderate', 4 'small', 5 'very small', 6 'none' and 7 'there is no debate'). The mean value is shown as a circle and the line indicates the 95% confidence interval.

anticipated, given the prominence of CCS in energy and climate policy in Norway, though nearly half still wish to see incentives for CCS set at a comparable level as those for renewables.

8. What are the most appropriate incentives for CCS development in the home country?

By far, the most popular option is for RD&D, with over 90% of respondents in favour. This is followed by early commitment to extend the EU ETS with tighter emissions caps (77% in favour, 8% against) (Fig. 6). The third most popular option is a requirement for electricity generators to supply a given percentage of zero- or low-carbon electricity, but without specifying the source of the electricity (i.e. it could be from CCS or also from renewables or nuclear). The next three most popular options in descending order are (i) an economy-wide carbon tax; (ii) a capital subsidy scheme to support construction of CCS plant; and (iii) a requirement for electricity generators to supply a given percentage of zero- or low-carbon electricity through CCS specifically. The least popular option is a guaranteed feed-in price for electricity produced by CCS, but even in this case, those in favour ('like it a lot' or 'like it some what') outnumber those against ('dislike a bit' or 'dislike a lot') (48% versus 30%).

The UK, the Netherlands and Belgium are most in favour of a requirement for electricity generators to supply a given percentage of low-carbon electricity through the use of CCS, with Germany, Denmark, Finland and Sweden being neutral to a bit negative regarding this option (between 'neither like or dislike' and 'dislike a bit').

When analysed in terms of stakeholder groups, it is found that there is a sizeable minority of energy sector, government, NGO and research stakeholders who are sceptical of the requirement for generators to use CCS; by allowing the generator the choice of selecting zero- or low-carbon electricity from other sources, the objection seems to a large extent to be overcome. There are substantial minorities against set feed-in tariffs for CCS amongst NGOs and parliamentarians. NGOs, and parliamentarians, are also somewhat sceptical of capital subsidy

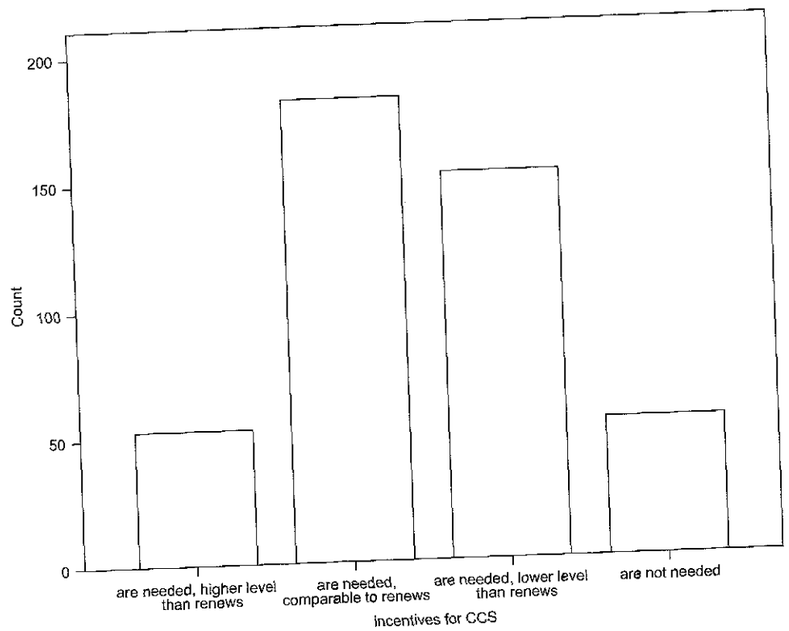

Fig. 5. Opinion on provision of financial incentives for CCS.

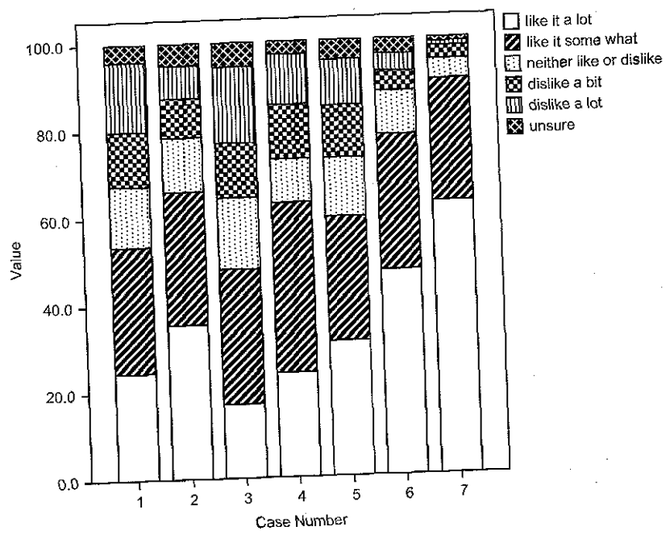

Fig. 6. Opinion on financial incentives for CCS expressed as a percentage of respondents. (1) A requirement for electricity generators to supply a given % of zero- or low-carbon electricity through CCS. (2) A requirement for electricity generators to supply a given % of zero- or low-carbon electricity (all sources). (3) A guaranteed feed-in price for electricity produced by CCS. (4) A capital subsidy scheme to support construction of CCS plant. (5) An economy-wide carbon tax. (6) An early commitment to extend the EU ETS beyond 2012 with tighter emission caps. (7) Support for research, development and demonstration projects.

schemes (between 'neither like or dislike' and 'dislike a bit').

Energy stakeholders are, overall, in favour of an economy-wide carbon tax, but there is a sizeable minority against, as there is also amongst parliamentarians. All stakeholder groups appear to support an early commitment to extend the EU ETS with tighter emission caps.

9. Scale at which incentives and regulation should be applied

The two most popular regulatory options were (i) having a common price for CO_2 across the EU25 under the EU ETS but then allowing national governments to introduce additional incentives (50% in favour); and (ii) a common incentives structure across the whole EU25 but without any additional national incentives (36%).

The common price for CO_2 plus national incentives received the highest score from all groups except from NGOs. Government stakeholders were the most in favour of the common CO_2 price + national incentives option. Very few supported phasing out the EU ETS and passing over full responsibility to member states (8% of energy industry stakeholders, 1.5% of government officials, 8% of academics and 0% of NGOs).

There was substantial support for both the major options in all countries and little support for phasing out the EU ETS. Respondents from the UK, Denmark, Germany, Italy and the Netherlands all preferred a common CO_2 price with additional national incentives, whilst there was greater support for common incentives across the EU25 (without additional national incentives) from respondents from Poland, Belgium and Sweden.

The most popular option for regulating CCS is through an internationally agreed set of standards (43%), followed by EU-wide standardization but national implementation (32%). Least popular is a system of information sharing (8%). Regulation through an agency of the EU commission is also not popular (12%).

The NGO respondents seem sceptical of EU-wide harmonization with national implementation (9% of responses), and favour an EU Commission agency more frequently than other stakeholder groups (17% of responses). NGO respondents are the most enthusiastic of all groups about relying primarily upon an international set of standards being developed (57%).

10. Potential risks of CCS

The sample as a whole did not consider the risks of CCS to be particularly large (Fig. 7). The most common response for all the risks assessed is 'minimal risk'. 'Very serious' risk never appears as a prominent response for the sample as a whole with respect to any of the risks. Those issues that are identified as being the highest risks are additional fossil fuel use because of the energy penalty, human health and safety from onshore CO_2 storage and environmental damage from both onshore and offshore CO_2 storage. The lowest levels of perceived risk are associated with accidents arising from the inclusion of CO_2 capture at power stations and human health and safety risks from offshore CO_2 storage site leakage.

NGO respondents are far more concerned than the average respondents about the additional extraction of fossil fuels to compensate for the energy penalty associated with CO_2 capture, with 52% of respondents identifying this as a 'very serious risk', a view shared by some parliamentarians at 30%, but by relatively few in government (16%), academia (10%) and the energy industry (5%). All stakeholder groups do regard the additional use of fossil fuels as, at least, a moderate to minimal risk. The NGO and parliamentarian respondents tend to perceive the potential risks of CCS as higher (either 'very serious risk' or 'moderate risk') when compared to energy, government and academic stakeholders.

11. Impact of investment in CCS upon other low- and zero-carbon energy technology (LZCT) options and upon energy efficiency and limiting energy demand

The sample is split between those who regard CCS as having a negative impact upon other LZCT development (15% significant negative, 29% minor negative) and those who do not consider that there will be any negative impact (35%) or those who see it as having a potentially positive impact (16%) (Fig. 8).

The NGO respondents are the most concerned about the impact of CCS upon investment in other LZCTs (65% significant negative impact, 22% minor negative impact, 9% no impact and 4% positive impact). By contrast, energy stakeholders are much less concerned (5% significant negative impact, 33% minor negative impact, 40% no impact, 18% positive impact). The response of government officials, academics and parliamentarians is broadly similar to that of energy industry stakeholders, though with a somewhat higher percentage of respondents expressing the view that the impact could be a significantly negative one (12–14%).

Turning to the impact of investment in CCS upon effort devoted to improving energy efficiency and reducing energy demand, the overall response was similar to the impact on investment in other LZCTs, though with slightly fewer negative impacts anticipated. Furthermore, more positive impacts upon energy efficiency/demand reduction were anticipated from CCS development (Fig. 9).

Most NGOs (57%) are of the view that CCS investment will have significant negative impacts on energy efficiency/demand reduction. Other stakeholder groups have a much lower concern that there will be such negative impacts (between 7% for energy sector and 15% for parliamentarians). By contrast, the energy industry and government stakeholders were the most positive about the effects of CCS investment on encouraging energy efficiency (37–39%), whereas NGOs were the most sceptical (13%, all for 'small positive effect').

12. Effects of CCS upon development of decentralized power generation systems

Half of the respondents perceive a very negative (15%) or slightly negative (35%) impact arising from CCS for

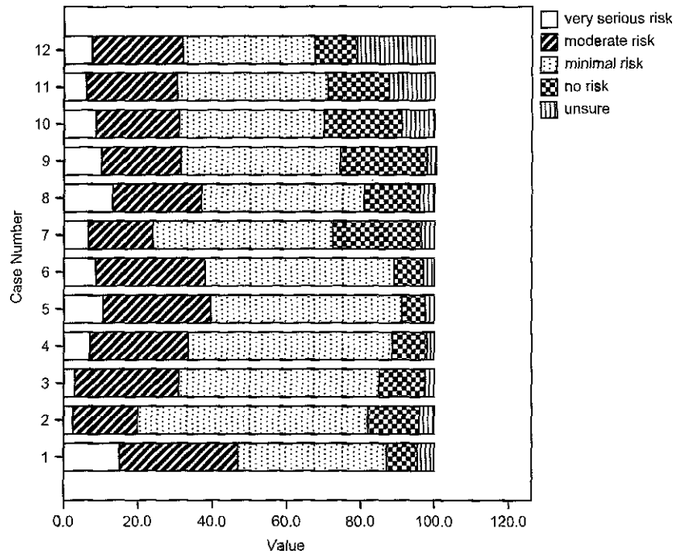

Fig. 7. The potential risks to health, safety and environment arising from CCS expressed as percentage of respondents. (1) Impacts arising from additional extraction of fossil fuels to compensate for the energy penalty associated with CO_2 capture. (2) Accidents arising from inclusion of CO_2 capture at power stations. (3) Impacts of new CO_2 pipeline network on landscape and environment. (4) Human health and safety risks from leakage from CO_2 pipelines. (5) Human health and safety risks from *onshore* CO_2 storage site leakage. (6) Local environmental damage from *onshore* CO_2 storage site leakage. (7) Human health and safety risks from *offshore* CO_2 storage site leakage. (8) Local environmental damage from *offshore* CO_2 storage site leakage. (9) Global climate impacts from CO_2 storage site leakage. (10) Global climate impacts due to additional greenhouse gas emissions resulting from enhanced hydrocarbon recovery. (11) Impacts of CO_2 storage upon drinking water reservoirs. (12) Impacts of CO_2 storage upon micro-organisms within the storage site.

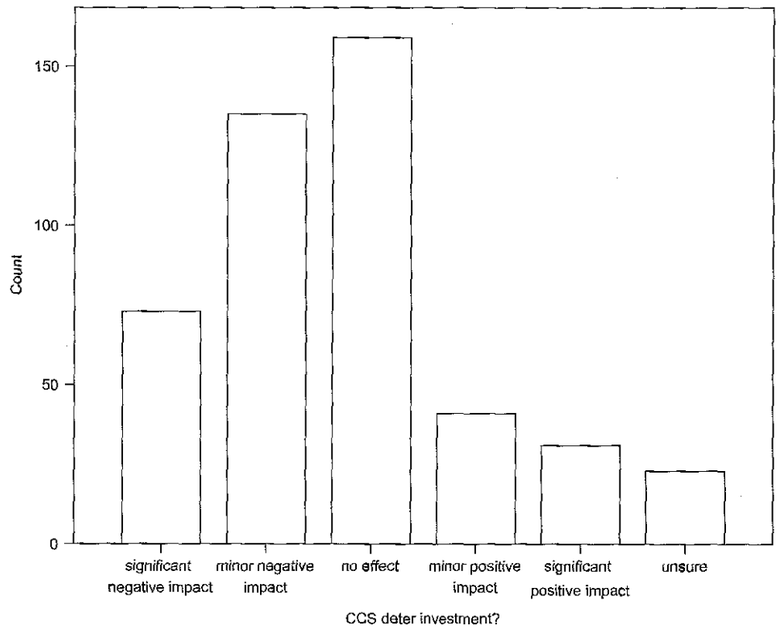

Fig. 8. Impact of investment in CCS upon development of other zero- and low-carbon energy generation options.

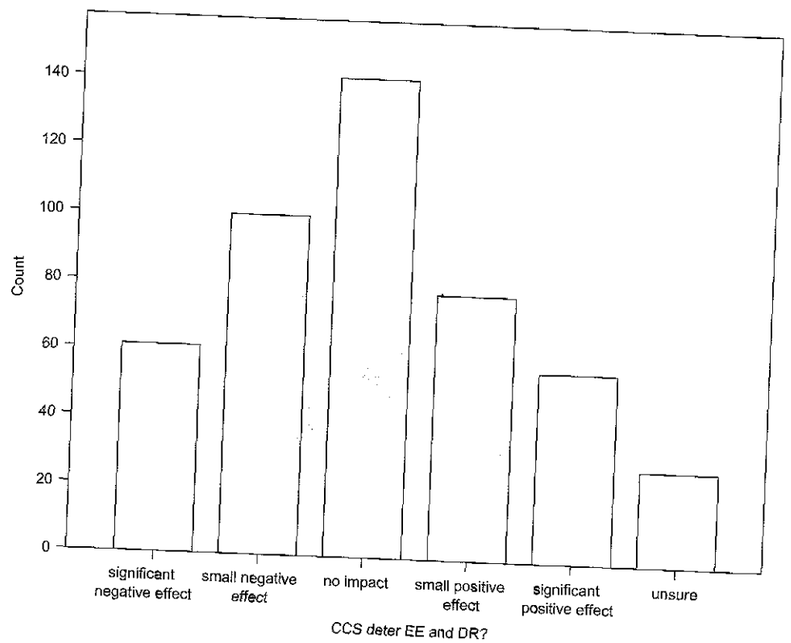

Fig. 9. Perceptions of the impact of investment in CCS upon effort spent on improving energy efficiency and reducing energy demand.

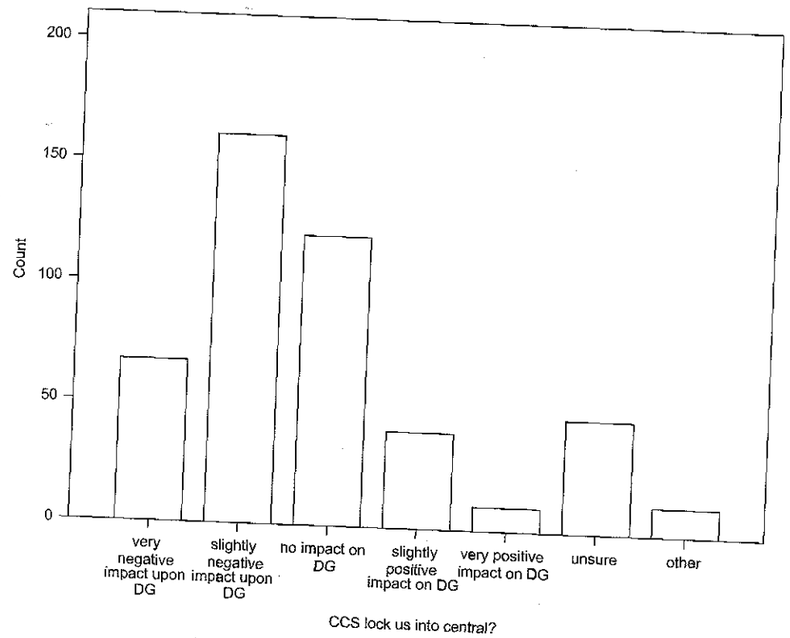

Fig. 10. Perceptions of the effect of CCS upon development of a decentralized power generation system in the next 20–40 years.

decentralized generation (DG) (Fig. 10). A further 26% of the sample perceived no effect, while about 11% thought there could be a slightly or very positive impact.

Energy, government and academic stakeholders do not perceive a very negative impact of CCS upon DG (8%, 9% and 15%, respectively) in contrast to NGOs (50%) and

parliamentarians (29%). All stakeholder groups do, however, consider that there will be a slightly negative impact of CCS upon DG (36% for energy, 48% for government and 33% for academics). Only a small number of stakeholders identify any potentially positive impact from CCS upon DG systems.

13. Impacts of CCS upon energy security

The most common response regarding the impact of coal-powered generation with CCS upon energy security is that there will be no impact (28%). Overall, 44% of respondents thought that the use of coal with CCS would increase energy security in the EU (Fig. 11).

Many NGO respondents consider that coal with CCS is more likely to reduce energy security (29% of respondents) and more parliamentarians are also concerned about this, although there is still a large number of respondents within each group who consider that energy security will be improved (33% for NGOs and 30% for parliamentarians) (compared to a frequency of 44% for the whole sample). The energy and government stakeholders are much less concerned about a reduction in energy security with coal CCS (6% for energy and 3% for government respondents).

The respondents perceived that there were much greater risks for energy security in the EU arising from gas with CCS than for coal with CCS. A total of 37% thought that natural gas with CCS would increase reliance on fuel supplies from politically unstable countries and thereby reduce energy security (cf. 12% for coal), and 27% thought that there would be no impact. Only about 18% thought that gas with CCS would actually improve energy security (Fig. 12).

The NGOs and parliamentarians are the stakeholder groups most concerned about the use of natural gas with CCS reducing energy security (48% and 53% of the sample, respectively, compared to 35–37% for energy, government and academic stakeholders).

14. Public perceptions of CCS in the home country and in the EU

The most common response is that the public in home countries will 'moderately support' CCS (34%), although only 5% thought that the public would be strongly supportive. By contrast, only 4% of respondents thought that the public would be strongly opposed to CCS and that 19% would be moderately opposed. A further 30% expected the public to be 'neutral'. Hence, on balance, the respondents regarded public support for CCS as greater than public opposition (40% versus 25%) (Fig. 13).

Norwegian stakeholders perceive that their public will strongly support CCS (48%), with a further 39% moderately supportive. Only 4% of Norwegian respondents thought that there would be moderate opposition to CCS, and no respondent thought that there would be strong opposition. Respondents in the UK and the Netherlands also expected little opposition (roughly 10%, of which only 1–2% expected strong opposition). Respondents from Denmark and Germany were the most likely to express the view that there would be greater public opposition to CCS than the sample average: 35% and 31% would be moderately opposed, respectively (compared with a frequency of 19% for the whole sample), with a further 9% and 4% strongly opposed.

NGOs and parliamentarians are the least convinced that the public will be supportive of CCS in their countries; indeed, none selected the 'strongly supportive' option.

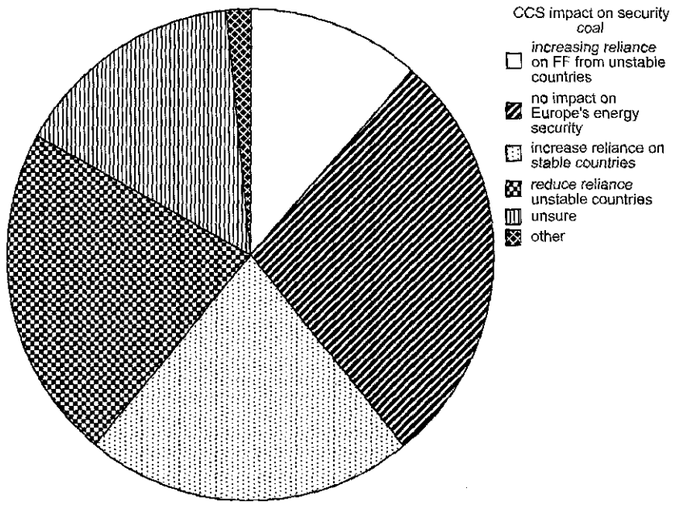

Fig. 11. Perceptions of the effect of using coal with CCS upon energy security in the EU.

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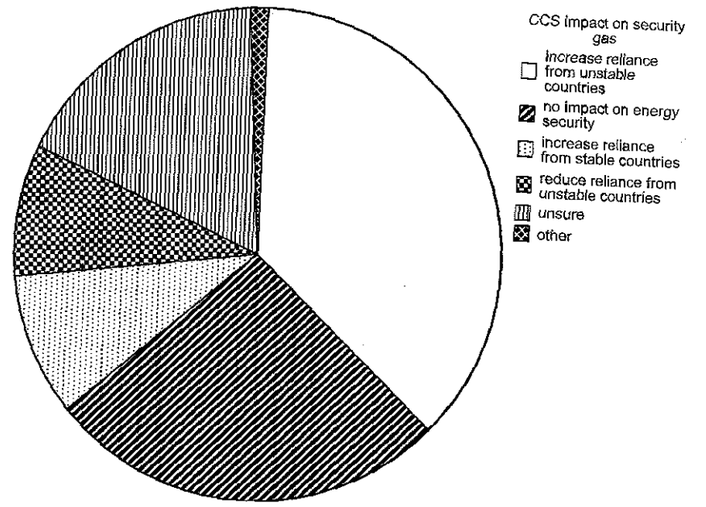

Fig. 12. Perceptions of the effect of using gas with CCS upon energy security in the EU.

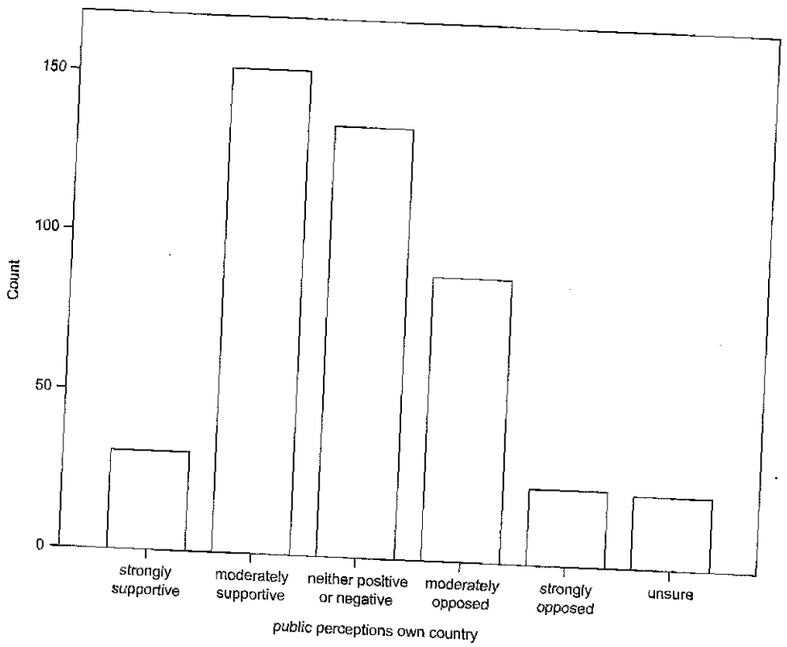

Fig. 13. Perceptions of public perceptions of CCS in own country.

NGOs and parliamentarians do not, however, think that there will be much public opposition to CCS and, on balance, they perceive the public as being 'neither positive nor negative' about CCS (48% and 41%, respectively, compared to 23% for energy industry respondents and 24% for government stakeholders). NGO respondents do consider, however, that a larger percentage of the public will be either moderately or strongly opposed to CCS than will be moderately or strongly supportive (32% versus 18%). This contrasts with energy industry stakeholders, who are more likely to think that the public will be strongly or moderately supportive (46%) than strongly or moderately opposed to CCS (29%). The respondents thought that CCS would be more supported by the public at the EU

scale than in their home country: overall support (48%) would easily outweigh opposition (14%).

15. Factors that will influence public perceptions of CCS in the home country

There is little difference in the opinions of the respondents regarding which factors will influence public perceptions of CCS. The most significant factor is the 'views of major opinion formers', followed by the 'perceived urgency of responding to climate change'.

16. Correlations

There are significant positive correlations between many variables and a few of these are mentioned below. Organizational position on CCS is strongly correlated with perceived need for CCS in own country. A perceived larger role for CCS in one's own country is correlated with a larger role for CCS in the national debate, and, where it is already important, CCS also appears to be growing in importance. For the North West Europe region, there is no correlation between perceived need for CCS and role of CCS in the national debate, however, suggesting that respondents in this region consider that CCS has too small a role in the national climate change debate given its potential role as a mitigation option.

There is stronger support for generous incentives for CCS from respondents who perceive a larger role for CCS; and support for most of the individual incentive mechanisms also grows with a greater perceived role for CCS. There is, however, no correlation between the perceived role for CCS and an economy-wide carbon tax. This reflects the unpopularity of such a carbon tax amongst many of the respondents who are (to a greater or lesser extent) supportive of CCS.

The perceived risks of CCS are significantly negatively correlated with the perceived need for CCS in one's own country (i.e. a lower risk perception is associated with a greater perceived need). Those who perceive a greater role for CCS in their own country also tend not to regard investment in CCS as having a negative impact upon investment in other low- and zero- carbon energy technologies; in efforts directed at improving energy efficiency and reducing energy demand; or in efforts at creating more decentralized power generation systems.

Those who regard CCS as most necessary in their own country also tend to see no significant negative impact arising for energy security considerations. Finally, as the perceived need for CCS in one's own country increases, so does perception that public opinion towards CCS will be positive.

Correlations were also tested between work time spent on energy and on CCS and other questions. So, for example, increasing work time spent on energy did not correlate with the perceived need for CCS in own country, though it did with CCS globally. Increasing work time on CCS specifically was associated with greater support for CCS in one's own country as well as globally. Work time on energy did not correlate with the provision of incentives, whereas this was the case for work time on CCS, i.e. those more in favour of CCS nationally are also more favourably inclined towards generous incentives for CCS. Preference for individual incentive mechanisms tended not to correlate with work time on energy or on CCS.

Work time on energy and on CCS tends to be significantly negatively correlated with risk perceptions arising from CCS, i.e. the more heavily involved the respondent is in energy and CCS research, the lower tends to be his or her perception of the potential risks arising from CCS. There is no correlation between work time on energy and impact of CCS upon investment in other LZCTs or between work time and having a negative impact upon moves to a more decentralized power generation system. Both these aspects are significantly negatively correlated with work time spent on CCS, i.e. those working more on CCS also tend to perceive less risk for loss of investment in other LZCTs and less risk that moves to decentralization in power generation will be adversely affected.

It might be surmised that those most closely involved in CCS have a tendency to perceive the potential negative aspects as being smaller and to perceive the potential positive dimensions as larger than other respondents. Those who spend more than 50% of their work time on CCS are more likely to perceive CCS positively, and less likely to perceive it negatively, than those who spend less than 50% of their work time on CCS. Someone working 50% of their time on CCS is more likely to express a more positive outlook on CCS than someone working, say, 10% of their time on CCS. On the other hand, it is not more likely that some one who spends 90% of their work time on CCS is more positive about CCS than some one who spends 60% of their time on CCS. This suggests that there is a threshold effect at about 50% of work time on CCS, whereby there is a tailing-off of 'positive' (or lack of negative) impressions of CCS.

Hence, there is some evidence that those most familiar with CCS do not allow this level of involvement to unduly bias or influence their perceptions of CCS as a carbon mitigation option. It may also reflect the greater knowledge that those most closely involved in CCS research have regarding the uncertainties, gaps in knowledge and technical, policy and economic hurdles which will need to be overcome before implementation can happen.

17. Analysis by European regions

The respondents were divided into four European regions: North Western Europe (264 respondents), Southern Europe (66 respondents), Central and Eastern Europe (63 respondents) and Scandinavia (81 respondents) (Table 1).

It was found that the role of CCS was significantly less in the national debate and perceived as less necessary in Central and Eastern Europe and Scandinavia than in the other regions. The perception of all 12 potential risk aspects arising from CCS was also higher in Central and Eastern Europe than in the other regions. Respondents from Central and Eastern Europe also perceived CCS to have more negative impacts upon decentralization than in the other regions. Central and Eastern European respondents are, on average, somewhat more sceptical of CCS than are those from other parts of Europe.

Scandinavian respondents are more positive about CCS at both the EU and global scales, but they were also more concerned about some of the potential risks and the adverse effects of CCS upon decentralization of power generation. Scandinavian respondents tended to prefer common incentives across the EU (i.e. without additional national incentives) and also preferred use of an internationally agreed set of standards to regulate CCS rather than EU standardization of regulation (the latter being preferred in North Western and Southern Europe). The response of Scandinavia was bimodal since it included Norway, the most pro-CCS country in Europe, but also Finland, Sweden and Denmark, which were all, to a greater or less extent, more sceptical than average about the role and impacts of CCS. There was, however, agreement amongst the Scandinavian countries that they did not like a CCS electricity generation requirement or a guaranteed feed-in price as incentive mechanisms.

North West European and Southern European countries preferred early commitment to extend the EU ETS beyond 2012 with tighter emission caps as an incentive mechanism. Southern European respondents thought that public perceptions of CCS in their own country would be more negative than did respondents from the other regions.

18. Analysis by population size of the country

The sample was split into three groups depending upon the population size of the country: large (>45 million) (243 respondents), medium (8–45 million) (133 respondents) and small (<8 million) (98 respondents) (Table 1). In general, country size did not appear to influence the pattern of the responses.

Large country respondents were more supportive of CCS in their own country and had a larger proportion of respondents from organizations which were 'very positive' regarding the role of CCS. Large country respondents also tended to regard the availability of domestic supplies of coal and of suitable geological storage sites as more important than respondents from the smaller countries.

19. Analysis by GDP per capita

The sample was split into four groups according to GDP per capita (at 2006 prices, not corrected for purchasing price parity): low (<$19 K) (56 respondents), medium–low ($19–29 K) (36 respondents), medium–high (114 respondents) ($29–39 K) and high (>$39 K) (268 respondents) (Table 1).

The low group was less enthusiastic about the need for CCS than other groups and thought that CCS had a smaller role in the national debate. The low group was also more concerned about the potential risks of CCS and perceived more adverse impacts arising from CCS upon decentralization and energy security. The low group is identical to the Central and Eastern European region with the exception of the inclusion of Austria in the latter; hence the responses of the low group and of the Central and Eastern European region are very similar.

The high group was most favourably disposed towards early extension of the EU ETS with tighter emission caps as an incentive mechanism compared to the other groups. The high group also tended to regard the risks of CCS as lower than did the other three groups.

20. Analysis by fossil fuel status

The sample was split into four groups depending upon the status of fossil fuel production in the home country of the respondent: coal producers only (68 respondents), oil and gas producers only (133 respondents), coal, oil and gas producers (159 respondents) and no significant fossil fuel production (114 respondents). It was generally found that differences between the four groups were not large.

The 'no fossil fuels' group did not perceive such a large need for CCS in their own country as did fossil fuel-producing countries, but there was no notable difference in the perceived need for CCS at the EU and global scales.

The 'oil and gas only' and 'coal, oil and gas' groups perceived enhanced oil and gas recovery to be a more important enabling factor in the development of CCS than the other groups, but regarded the availability of domestic supplies of coal as a less important enabling factor.

The 'coal only' group was less enthusiastic about an early commitment to extending the EU ETS with tighter emission caps as an incentive mechanism than the other groups. The 'coal only' group preferred the adoption of the same incentives across the EU without additional national incentives. The 'coal only' group also thought that CCS would have a more negative impact upon the moves to decentralization of the power generation system than did the 'no fossil fuels' group.

The 'oil and gas only' and 'coal, oil and gas' groups tended to regard the potential risks arising from CCS to be lower than did the other two groups, especially those risks associated with infrastructure such as pipelines, offshore installations and power plants.

21. Analysis by penetration of renewable energy

Countries were classified into six groups depending on the percentage of renewable energies in their gross electrical consumption in 2005: 1–5%, 5.1–10%, 10.1–15%, 15.1–25%, 25.1–35% and over 35% (data obtained from Directorate-General for Energy and Transport, 2007). The level of penetration of renewable energy was then

correlated with the perceived need for CCS in own country (question 8, part 1). It was found that there is a significant negative correlation (at the 0.01 level) between penetration of renewable energy and perceived need for CCS in own country. In other words, respondents from countries with less penetration of renewable energy tended to perceive a greater need for CCS in their own country, and vice versa. We repeated the analysis but omitting the UK, which contributed 20% of the respondents and had a low level of renewables (providing 4.3% of electricity consumption in 2005) and hence which could have distorted the correlation. Even without the UK, there is a significant negative correlation, though at the 0.05 level. These results suggest that perceptions of the need for CCS might be related to the success, or otherwise, of the development of other low-carbon energy generation options, in this case renewables, i.e. the failure to effect a successful deployment of renewable energy within a country may make CCS appear to be a more attractive option for cutting CO_2 emissions. However, further evidence of a causal relationship of this sort would be required before having confidence in its validity.

22. Limitations of the survey and suggestions for improvements

The survey has a number of limitations.

- The number of respondents in most countries is too small to allow meaningful analysis of differences in perceptions between most of the EU25 countries. With larger samples, it would be possible to undertake a more detailed analysis of national variations and to explore underlying reasons for these differences.
- The number of respondents in different stakeholder groups is unevenly spread. In particular, there was a lack of responses from chemical and transport sectors, government officials (with the exception of geological surveys) and parliamentarians. With a more even response across stakeholder groups and countries, it would be possible to have more confidence in the findings that are presented here.
- The translations were not always as precise as they might have been.
- Clearly, there is a much smaller absolute number of NGO stakeholders who can be regarded as CCS stakeholders than is the case for the energy sector, government and research. The 25 NGO respondents included within the survey may potentially capture a good proportion of the key people within the NGO movement who have given focused attention to the CCS issue. However, it is not clear how the 25 respondents could be tested as being more widely representative.
- More generally, there is no obvious and objective method by which the representativeness of the respondents can be tested.

Future work in this area could be improved in the following ways:

- Given that highly technical language is being employed, it would be desirable to employ a technical specialist to check the language translations.
- A more precise target population of stakeholders could be developed for each country, though this would be time consuming and run the risk of overly pre-selecting the population.
- Making use of existing business and research networks on CCS would be highly desirable for bulking-up the sample population, though this reduces the researcher's own control of who is included in the sample.
- Including well-connected research partners in as many target countries as possible would also help in accessing stakeholders in that country.
- Use of an appropriate incentive might help to improve response rates.

23. Conclusions

The overwhelming response of stakeholders in this survey was moderately to strongly positive towards CCS. All the results must be interpreted in the context of the sample, which is largely made up of professionals working in the energy sector and research, most of whom have at least some CCS component to their work. Hence, three-quarters of the organizations for which the respondents work adopt a positive attitude towards CCS. The perceptions collected in the survey largely reflect and confirm this positive outlook towards CCS.

Where the sample is split into stakeholder groups, we find that NGOs and, to a lesser extent, parliamentary stakeholders have quite different perceptions of CCS than the energy industry, government or academic stakeholders. NGOs are much less enthusiastic regarding CCS, more concerned about the potential risks to the environment, health and safety arising from CCS, consider that investment in CCS will deter investment in other LZCTs and in energy efficiency and demand reduction measures and will inhibit the move towards a more decentralized power generation system. In summary, many NGOs are sceptical as to the future role of CCS in creating a sustainable energy system. We can term this a '*critical observer*' position. Despite these reservations, however, approximately half of the NGO respondents still perceive that there is a need for CCS in their own country, in the EU and globally.

The energy industry is the most confident regarding the role of CCS and demonstrates a consistently lower perception of the risks than the average respondent. The other stakeholder groups line up somewhere in between the strongly positive views of the energy industry and the relatively negative views of the NGOs. The government and academic and research stakeholders tend to fall along this line somewhat closer to the energy industry. Parliamentary respondents are not as sceptical as NGOs and are more ambivalent or neutral regarding the potential role and impacts of CCS; their opinions tend to be in between those of the energy, research and government stakeholders on the one hand, and the NGOs on the other.

We have also identified some interesting differences across the countries surveyed. To be more confident that these differences are meaningful, and not anomalous, it would be desirable to increase the sample sizes. In the current report, only eight countries have been compared for statistical significance due to small sample sizes. If larger numbers of respondents were obtained across the range of countries, then it would be possible to extend the comparison of country-level responses. It would also be possible to test the relationships between responses at the national level and other characteristics of those countries. It might also be possible to cluster countries in terms of their response patterns. This has only been possible to a limited extent in the current paper.

The opinions of stakeholders in different countries tend to reflect the different state of play on CCS in those countries. Hence, Norway and, to a lesser extent, the UK and the Netherlands, tend to show a more pro-active and engaged response. There is generally more optimism in these countries that CCS will be deployed without major impediments, that it is a 'good thing' with manageable risks and that the public will not object. These three countries stand out as being those in which CCS is probably furthest developed and most widely debated within the climate change and energy communities. Norway is a major oil and gas-producing nation, the UK also produces oil and gas and retains a small coal mining industry and the Netherlands is a major producer of natural gas. All three nations also border the North Sea, which is a large potential repository for billions of tonnes of CO_2 (IPCC, 2005; Holloway et al., 2006).

This means that all three countries enjoy major opportunities for CO_2 storage in onshore and/or offshore sites and also have oil and gas industries which are capable of taking advantage of CCS, i.e. their industries have the skills and human resources necessary for implementation of CCS. A further important factor to note is that Norway, the UK and the Netherlands have strong domestic commitments to take action on climate change. The economic conditions in the three countries is also promising, with Norway being one of the wealthiest countries in the world, and the UK and the Netherlands both having experienced reasonably healthy economic growth over the past decade. We can term the position of energy, research and government stakeholders in these countries one of '*developer optimism*'.

Respondents from most other countries were more ambivalent in their opinions, sometimes more positive regarding CCS but also often 'neutral' or slightly negative. For example, there was a noticeable streak of scepticism in other Scandinavian countries (Sweden, Finland, Denmark), Germany and Belgium regarding aspects of CCS such as the potential risks, impacts on development of other low-carbon technologies and so forth. Nevertheless, on-balance countries such as France, Germany, Spain, Italy and Belgium express considerable support for CCS.

By dividing the sample into four regions (North West Europe, Southern Europe, Central and Eastern Europe and Scandinavia), we were able to identify significant differences between opinion on CCS in Central and Eastern Europe and in other parts of Europe. There was less enthusiasm for CCS and greater concern about the potential risks and potential adverse impacts of CCS from respondents in Central and Eastern Europe. To some extent, the perception of greater risks could be an indication of lack of knowledge, since the CCS debate appears to be less advanced in Central and Eastern Europe than in the other European regions, e.g. it plays a smaller role in the national debate on climate change. It is somewhat difficult to understand why academics, government officials and energy sector respondents from Central and Eastern Europe should regard the risks of CCS as being greater than do the same types of stakeholders in other parts of Europe, and lack of knowledge and familiarity could certainly be one explanation. However, the sample size of Central and Eastern European respondents is small (54), hence the responses obtained may not be representative of wider stakeholder opinion.

The Central and Eastern European countries are also those which appear in the low GDP per capita group (<$19 K), with the exception of Austria. Many of these countries have been suffering from relatively high unemployment and have required extensive structural economic reforms since the end of the Cold War in the late 1980s. What is more, most of these countries have already met their Kyoto emission targets, due to economic restructuring during the 1990s. Measured against their Kyoto targets, the current state of emissions reductions are as follows: Czech Republic (reduction of −25% against a target of −8%), Estonia (−50% against a target of −8%), Hungary (−32% against a target of −6%), Latvia (−58% against a target of −8%), Poland (−32% against a target of −6%) and Slovakia (−30% against a target of −8%) (EEA, 2006). There is, therefore, no need for CCS (or indeed any other low-carbon technologies) to meet current Kyoto targets in Central and Eastern European countries. Given this combination of circumstances, it is understandable that CCS does not currently feature as a major option for Central and Eastern European countries.

It is also interesting to note that CCS does not appear as a more important option for some other EU countries which are struggling to meet their targets adopted as part of the so-called 'EU bubble' target. Member states that are currently furthest from their Kyoto targets include Austria (16% increase in emissions since 1990 relative to target of −13%), Denmark (−2% relative to −21%), Finland (+14% relative to target of 0%), Ireland (+23% relative to target of +13%), Portugal (+41% relative to target of +27%), Italy

(+12% relative to target of −6.5%) and Spain (+48% relative to +15%) (EEA, 2006). On the other hand, there may, of course, be other reasons why certain countries find CCS appropriate or desirable (e.g. availability of geological storage sites, characteristics of the power sector, presence of oil, gas or coal industries, domestic priority placed on taking action on global climate change and so on). In any case, CCS is an option that will be employed for emission reductions not to any extent in the Kyoto-reporting period, but post-Kyoto. Hence, interest in CCS from countries that are currently more or less on track to meet their Kyoto targets, such as Germany, Sweden and the UK, reflects the need for much larger CO_2 reductions in those countries in the post-Kyoto commitment period.

The responses of some respondents reflected the particular resources available in their country. For example, we tended to find that countries with domestic supplies of coal regarded this as a more important factor enabling the development of CCS than countries without their own coal supplies. Likewise, oil and gas producers tended to regard enhanced oil and gas recovery as a more important enabling factor for CCS than countries without their own oil and gas reserves. These responses may be explained in part by greater awareness and knowledge, but there may also be an element of 'self-interest' involved, i.e. the perception that the particular country (or industry or sector in that country) will stand to gain from implementation of CCS as a carbon mitigation option on an equal footing to other options such as renewables.

We find weak to moderate evidence that those more in favour of CCS tend to regard specific risks and impacts of CCS more benignly. However, it is not possible to know the direction of causality. It may be that the benign perception of risks and impacts of CCS is what results in the respondent's overall perception that CCS is required as a carbon mitigation option (rather than the causality being the other way around). There are almost certainly other factors contributing to the respondent's perceptions and opinions that have not been analysed in the survey. One interesting finding was the existence of a threshold at about 50% of work time on CCS, whereby there is a tailing-off of positive (or lack of negative) perceptions of CCS. One might therefore conclude that those most involved in CCS research are probably not unduly biased in favour of CCS, or 'self-serving' in presenting CCS in a more attractive light than respondents who are less involved in working on CCS. This could reflect the greater knowledge of uncertainties, risks and challenges facing implementation of CCS on the part of those who are most actively involved in CCS issues, whether as researchers, developers, government officials or NGOs.

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Appendix A. Supplementary Materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2007.05.001.

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Environmental and economic assessment of the chemical absorption process in Korea using the LEAP model

Ho-Jun Song, Seungmoon Lee, Sanjeev Maken, Se-Woong Ahn, Jin-Won Park*, Byoungryul Min, Wongun Koh

Department of Chemical Engineering, Yonsei University, 134 Shinchon-dong, Seodaemoon-ku, Seoul 120-749, South Korea

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Abstract

CO_2 emission from fossil fuels is a major cause for the global warming effect, but it is hard to remove completely in actuality. Moreover, energy consumption is bound to increase for the continuous economic development of a country that has an industrial formation requiring high-energy demand. Therefore, we need to consider not only a device for CO_2 mitigation but also its impact when a CO_2 mitigation device is applied. The device for CO_2 emission mitigation can be classified into three fields: energy consumption reduction, development of CO_2 removal and recovery technology, and development of alternative energy technology. Among these options, CO_2 removal and recovery technology has a merit that can be applied to a process in the near future. Therefore, research for CO_2 removal and recovery is actively progressing in Korea. In this study, environmental and economic assessment according to the energy policy change for climate change agreement and increase of CO_2 mitigation technology is accomplished, on the bases of operating data for the CO_2 chemical absorption pilot plant that is installed in the Seoul coal steam power plant. The Long-range Energy Alternatives Planning system (LEAP) was used to analyze the alternative scenario, and results were shown quantitatively.

Keywords: CO_2; Pilot plant; Alternative scenario through LEAP

1. Introduction

Global warming caused by greenhouse gases (GHGs) has been recognized as a worldwide problem. Of all the GHGs, CO_2 is the most significant, accounting for half of the greenhouse effect. In 1992, over 150 countries signed the United Nations Framework Convention on Climate Change (UNFCCC) on the Climate Conference in Rio. Six years later, the third meeting was held in Kyoto, and 175 countries agreed to take further actions to reduce GHG emissions. In February 2005, the Kyoto Protocol, in which it was agreed to decrease GHG emissions by 5.2% in industrialized countries (Annex I) during 2008–2012, was put into effect.

Due to rapid industrialization, energy demand and consequently CO_2 emission owing to increased use of fossil fuels are expected to increase (Ang, 2004; Boudri et al., 2002; Choi and Ang, 2001; Choi et al., 1995; Chen and Chen, 2007; Finon and Lapillonne, 1983; Geller et al., 2006; Kroeze et al., 2004; Pachauri and Pachauri, 1985). Developing countries (Non-Annex I), including Korea, are exempted from the reduction duty for the time being. But Korea would be receiving the burden for early duty demand from the international society according to the world situation which discussed the burden of duty for developing countries from 2002 (IPCC, 1997).

If Korea is restricted by the Kyoto Protocol, it will undergo serious influences because of industrial formation that requires much energy. Korea has been developing an industrial structure requiring much

*Corresponding author. Tel.: +82 2 364 1807; fax: +82 2 312 6401.
E-mail address: jwpark@yonsei.ac.kr (Jin-Won Park).

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