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Note from the Director

Institutional and governance issues in tackling climate change and natural resources have become more complicated than before, when there existed less information and capacity to address them. In other words, the conventional system, which relies on sovereign states, has begun to face challenges and reveal its limitations, especially in addressing environmental problems while ensuring sustainable growth.

For example, there has been an increased understanding on the importance of cities in curbing GHG emissions, which seem to represent a large portion, possibly 70 percent, of the total GHG emissions of the world. Cities are not necessarily under the full control of their central governments, and they may have the capability for developing and implementing policy measures to control emissions, based on the low emission development scenario. In a way, they could serve a complementary role to the already existing ones that are governed by central governments. In this sense, the first article of this volume well discusses how a decentralized climate change architecture can contribute both to addressing climate change as well as to pursuing a low emission development.

Furthermore, a low carbon development path requires innovation. R&D, and deployment and market developments of new green technologies are all required to realize a low emission development. However, in a situation where conventional energy sources such as coal are still available at a cheaper price, introducing new green technologies to a society can be of a challenge. A study on the Carbon Capture and Storage technology in the U.K. demonstrates such complex issue.

On the other hand, when it comes to the issue of resources, competition for sovereign claims seem to be more apparent, as they are discussed more in the context of sovereign state's resource ownership. Due to the pressure of securing necessary resources combined with developments in new technologies, states have explored more possibilities in exploiting natural resources in those areas where the exertion of state sovereignty used to be neither apparent nor important. In this sense, it is noteworthy that both cases on the Arctic region and the maritime dispute in Southeast Asia demonstrate a new governance architecture based on soft and cooperative principles that may be a more feasible solution instead of the conventional Westphalian system.

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1. Introduction

In pursuit of economic growth, global climate change has been more apparent. It led to vulnerability to change in human communities with uncertainty "about how large the warming will be and what the patterns of change in different parts of the world [will be]."[1] The recent international climate negotiations articulated the urgent need to avoid exceeding CO_2 emissions above 450 ppm, which is required in order to keep below the 2C agreement. Yet, before meeting the international targets, the bottom line is research on "the science of climate change and the future scale of the human activities,"[2] which is an active undertaking in order to reduce uncertainty. Without unsound scientific knowledge, there will be no effective policies for the government, businesses, and the public as well. Based on scientific confidence, some countries have developed their own green strategies for developing carbon- neutral technologies (such as renewable energy, nuclear energy, and carbon capture and storage) in the pursuit of a low carbon economy. In particular, the UK undertakes an integrated full commercial scale of CCS Demonstration Programme in order to spur the transition to a low carbon economy.

This paper only focuses on eliminating or lowering the causes of climate change. One single technology cannot change the whole socio-technical system, but can contribute to accelerating the speed of transition to another industrial revolution to some extent. In terms of costs and efficiency, the current level of CCS is not so competitive compared to other low carbon technologies such as renewables and nuclear energy. Yet, as its feasibility has been studied, the technology has drawn attention for being both cost effective and environmentally sound.

In this context, this paper is to clarify the strong feasibility of CCS in leading to a low carbon economy through CCS demonstration projects in Yorkshire and the Humber, a 'Low Carbon Economic Area for CCS' in the UK, under three criteria: economic viability, social acceptance and environmental accessibility. This will be accomplished by considering the current socio-technical regime and potential creation of niches. Even though there is not so much remarkable progress at the current level,

1) J.T. Houghton, Global Warming: The Complete Briefing (2009), p.14
2) Ibid., p.15

the processes of undertaking four CCS demonstration projects in the area have given lessons for further advancement.

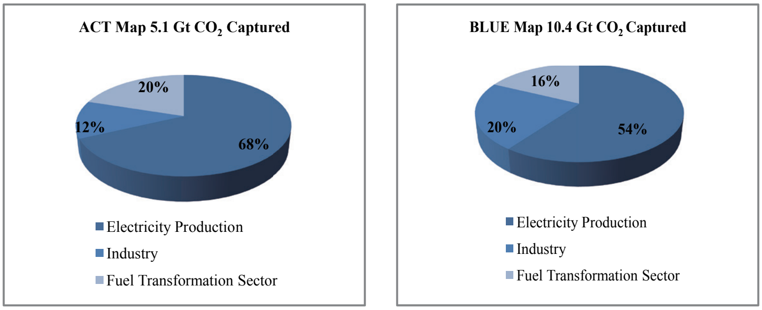
2. Available mitigation option in accordance with national targets

In the face of threats, including climate change challenges and deficiencies of available energy options, governments are taking action to reduce GHG emissions by "accelerating innovation across a range of low-carbon technologies", and by making international commitments to "coordinate emissions reduction."[3] The UK government invests in more research and development on alternative energy sources, while trying to meet its 2050 target to reduce emissions by 80% from 1990 levels[4] by replacing "ageing electricity infrastructure with low carbon alternatives" under the Electricity Market Reform.[5]

During the medium and long-term, renewables, nuclear and CCS would lead the way in climate change mitigation policy. Before active commercialisation of such expensive low carbon technologies, however, fossil fuel use is necessary in order to have time to develop more cost-effective and environmentally sound technologies in the lead time. In addition, since the nuclear accident after the earthquake in Japan in 2011, there have been urgent international demands to guarantee stable energy sources. Then it became inevitable for the international community to continue to employ fossil fuels while trying to reduce GHG emissions. According to IEA, continued use of fossil fuel with CCS (particularly, coal, which is the cheapest and most abundant resource, accounting for about 40% of global electricity generation) is possible under the ACT Map and BLUE Map Scenarios.[6][7]

3)Committee on Climate Change (CCC), Building a low carbon economy - the UK's innovation challenge, CCC (2010), p.18.
4) Ibid., p.7
5) HM Government, Carbon Plan, HM Government (2011), p.7
6) International Energy Agency, Energy Technology Perspectives: Scenarios and Strategies to 2050, IEA (2008b)
7) See Figure 1.

Figure 1. Use of Carbon Capture and Storage in the ACT Map and BLUE Map Scenarios



Source: IEA, 2008b, adapted by author

CCS has its competitive advantages due to its unique feature of "keeping fossil carbon in the ground by allowing fossil fuels to be used, but with the CO_2 produced being safely stored in a geological formation."[8] According to climate change modelling (such as IEA's 2010 World Energy Outlook, United States Energy Information Administration's 2010 Annual Energy Outlook and the IEA CCS Roadmap), CCS will play a crucial role in mitigating climate change impacts in the long term.[9] Yet, in order to make CCS a reality, governments (including the British government) should:

- *Recognise the need to accelerate the CCS technology innovation process through increased demonstration and research and development (R&D) investments;*
- *Develop regulatory frameworks in support of CCS; and*
- *Coordinate with other governments in the international arena in both CCS-specific issues and broader issues under the UNFCCC.*[10]

8) Chalmers and Gibbins (2010), p.505
9) Global Carbon Capture and Storage Institute (GCCSI), The Global Status of CCS 2010, GCCSI (2010), p.16
10) CCC (2010), p.18

3. Feasibilities of CCS demonstration projects

3.1. Yorkshire and the Humber as a Low Carbon Economic Area for CCS

Under the UK Government's strong commitment to "no new coal-fired power stations without CCS", a CCS demonstration project has been undertaken. As one of the efforts for activating CCS projects and one of the UK's CCS industrial strategies, Yorkshire and Humber has been designated as the first 'Low Carbon Economic Area for CCS' (LCEA) in the UK because "it combines the UK's largest cluster of industrial CO_2 emitters, academic expertise and proximity to potential storage sites" with high possibilities of creating more job and investment opportunities along with "expansion in the CO_2 storage industry."[11] Even though the Coalition Government has gradually waived the concept,[12] the core idea would continue to progress. According to CO2Sense, about '£1.8 billion in gross value added (GVA) and 55,000 jobs' could be created as the outcome of building the network, followed by generating £126 million of additional GVA and 2,400 jobs per year in the operation step.[13] In 2010, CO2Sense also indicated that assuming the carbon price is €35 per tonne under the European Union Emissions Trading Scheme, Yorkshire and the Humber could enjoy £31 billion in net benefits from the first 25 years of network operation.[14] According to an interview with Stephen Brown, CO2Sense stands for the idea that innovation benefits "to create a driver of value for CCS" can come from involvement of local companies either "in engineering of plant integration of commercial demonstration projects" or in "development of technology for second generation CCS plants," as well as a cluster by attracting the incumbents with capture technology in the region. From such activities, he argues that considerable economic benefits can be gained while protecting "thousands of existing jobs in heavy industry that could exploit CCS as a carbon management

11) Press Association, "Carbon Capture Storage will 'generate 100,000 jobs and £6.5 billion a year." The Guardian [Online], Mar. 17, 2010
12) Brown, Stephen, Interview by Yu Kyung Oh. 12th August 2011.
13) CO2Sense, CCS Network to the Future, CO2Sense Yorkshire Limited (2010), p.7
14) Ibid.

technology."[15]

Along with industry and academic experts, Yorkshire Forward is in charge of the LCEA, encouraging CCS projects and related infrastructure.[16] From a business perspective, this region has been recognised as a proper location for attracting various businesses (such as a large number of power stations, heavy industry, and other large single-point emitters of CO_2). In addition to the industrial cluster, this region has also geographic advantages such as its proximity to offshore geological CO_2 storage. According to CO2Sense and Gough *et al.*, "it is adjacent to a large concentration of gas fields and saline aquifers in the North Sea representing a large potential for offshore geological CO_2 storage."[17]

Yet, as the UK's fossil fuelled power stations are concentrated in this region[18], Yorkshire and the Humber generates a total of around 90Mt of CO_2 per year. Two-thirds of the CO_2 comes from power stations, steel plants and oil refineries. Yet, if the cluster of CCS projects successfully continues to proceed with sharing pipeline and storage infrastructure, it could be "worth up to £6.5 billion a year, sustaining jobs for up to 100,000 people by 2030 for the UK economy as a whole."[19]

CCS demonstration projects in Yorkshire and the Humber are meaningful in integrating the full CCS system, clustering and being a low carbon economic area for CCS. The CCS project in Yorkshire and the Humber is not the first fully integrated CCS project (e.g., FutureGen of the US) in the world. Yet compared to other international projects, the UK's demonstration programme has competitive advantages along with several drawbacks. These advantages and drawbacks will be identified in the framework of economic viability, public acceptance, and environmental accessibility.

From a technical perspective, there are no technical barriers to CCS because all

15) Brown, Stephen, Interview by Yu Kyung Oh. 12th August 2011.
16) Yorkshire Forward, Yorkshire and Humber designated as Low Carbon Economic Area for CCS, Yorkshire Forward (2010).
17) Gough, Clair, Michelle B., Simons S. and Sam H., "A Regional Integrated Assessment of Carbon Dioxide Capture and Storage: East Midlands, Yorkshire and Humberside Case Study," in Simon Shackley and Clair Gough, eds. Carbon Capture and its Storage: an integrated assessment (2006), p.209
18) Ibid.
19) Press Association (2010)

technologies of CCS are already proven.[20] In other words, a full scale of deployment is highly possible due to already deployed and tested component technologies for diverse objectives.[21] Yet, economic or social or political factors are always concerns for developing CCS technology despite low technical barriers.

Table 1. Overview of CCS demonstration projects in Yorkshire and the Humber

Project Name	Project Operators	Commercial Operation	Funding Sources	Capture Technology Type	Possible Storage Reservoir Type
Demonstration Project: Powerful Power Coal (Hatfield)[22]	Powerful Power (2Co Energy)[23] National Grid[24]	2014	€180m EEPR European funding in Dec 2009 More funding under the EU's NER 300 competition	A new 900MW Pre-combustion CCS technology with CCGT and IGCC station with capturing approximately 97%[25]	EOR Project under the North Sea
Demonstration Project: Powerful Power Gas (Hatfield)	Powerful Power Calix	2015	The European NER 300 competition for European grant funding	450 MW Endex CCGT(Initially a gas fired plant)	Depleted hydrocarbon formations beneath the southern North Sea
Demonstration Project: Drax Power(Selby)	Drax Power Alstom National Grid	Before 2015	The European NER 300 competition for European grant funding	426MW Coal Power station with Oxy-firing CO_2 capture technology	Saline formations in the Southern North Sea
Demonstration Project: C.Gen (Killingholme)	C.Gen	2015-2016	The European NER 300 competition for European grant funding	430MW Pre-Combustion CCS technology with CCGT or IGCC plant (up to 570 MW)	

20) Shackley, Simon and Clair Gough, "Conclusions and Recommendations" in Simon Shackley and Clair Gough, eds. Carbon Capture and its Storage: an integrated assessment (2006), p.291;
International Energy Agency, Technology Roadmap: Carbon Capture and Storage, IEA (2009)

21) Socolow R., "CCS Technology: ready to go" in Tom Nicholls, ed. Fundamentals of Carbon Capture and Storage Technology (2007), p.7

3.2. Economic feasibility of CCS demonstration projects

Economic feasibility of CCS demonstration projects is closely interconnected with technical viability, social acceptance, and environmental accessibility. Its importance can be found in the sustainability of CCS demonstration projects. Yet, weak or strong economic feasibility highly depends on several variables, such as policy changes, legal frameworks, public and private investments, technological innovation, and carbon price. In other words, economic feasibility could reflect each stakeholder's willingness to handle CCS projects and climate change issues. Economic feasibility can be realized in several areas such as capture technology innovation, transport technology innovation, Enhanced Oil Recovery (EOR) innovation, and sound legal and financial framework, as well as in increasing private investments.

When it comes to technical maturity, carbon capture technology is still costly and lacks infrastructure for large-scale transportation and storage of CO_2 in the UK. Yet, the trade-off can occur through technological innovation from learning-by-doing, the cluster effect (such as attracting "a few OEMs [original equipment manufacturers] with capture technology"[26] and EOR projects. According to DTI, the cost of capture and transportation technology can be offset by the financial return from storing CO_2 in depleted oil fields along with EOR[27], as well as a fluent connection along the full chain of CCS projects.[28]

As a cost-effective way for transporting large quantities of CO_2, pipelines are

22) The Hatfiled Project will be renamed as 'the Don Valley Power Project', capturing and storing 5 million tonnes per annum.
23) In 2011, under advice from KPMG, 2Co Energy acquired Powerfuel Power Ltd and the Hatfield Project with keeping the EU funding. 2Co Energy is in collaboration with Talisman Energy in order to research storing CO2 in oil fields and Enhanced Oil Recovery (EOR) potential in the North Sea.
24) While keeping its partnership with 2Co Energy, National Grid is in charge of transportation (pipeline design) and storage options.
25) A gas fired plant (CCGT) will be built and operational by the end of 2013, and then converted to IGCC by addiding the pre-combustion technology at the end of 2015.
26) Brown, Stephen, Interview by Yu Kyung Oh. 12th August 2011
27) Department of Trade and Industry (DTI), Review of the Feasibility of Carbon Dioxide Capture and Storage in the UK, DTI (2003)
28) CO2Sense, CCS Network to the Future, CO2Sense Yorkshire Limited (2010)

dominant.[29] Possible sharing of a pipeline in this region would allow CO_2 emitters to reduce costs to some extent. According to Yorkshire Forward, building a CO_2 transport network covering emitters in Yorkshire and the Humber could "bring 55,000 jobs and £2 billion investment while keeping approximately 60 million tonnes of CO_2" from going into the atmosphere every year.[30] According to CO2Sense's study on cost reduction in a cluster pipeline in the Aire Valley, transportation costs can decrease if more emitters use the same pipeline (for instance, construction of two pipelines for two users is £481 million, but linking them into a single pipeline and storage location costs £322 million, a saving £159 million). Yet, according to Yorkshire Forward (n.d.), the economic issue concerning transportation is closely related to "the financial cost of the timing difference between expenditure in transport infrastructure and revenue from transporting CO_2."[31]

EOR can refer to "using CO_2 to 'wash' out more oil from depleted fields in which the balance between CO_2 in and oil carbon out is currently approximately even."[32] "Oil density and viscosity, the minimum miscibility pressure, microscopic sweep effects, and the formation of vertical and lateral heterogeneities" are parameters for choosing EOR technologies.[33] Given such factors, the CO_2-EOR method[34] fits into the North Sea. When it comes to economic benefits from the EOR project in the North Sea, there have been studies on its feasibility and prediction. According to Norway's Climate BIGCO2 project, which gives predictions for 19 Norwegian and 30 United Kingdom North Sea oil fields, "an average incremental oil recovery of 8.8%" and recovered

29) International Energy Agency, CO2 Capture and Storage: A key carbon abatement option, IEA (2008a)
30) Yorkshire Forward (2010)
31) Yorkshire Forward, A Carbon Capture and Storage Network for Yorkshire and Humber, Yorkshire Forward (n.d.), p.5
32)Gibbens J., H. Chalmers and S. Haszeldine, "Assessment of Mitigation Scenarios, Technologies and Hedges against Uncertainty" UK Carbon Capture and Storage activity in the next decade-creating UK and global options for the 2020's, Work stream 2, Report 5B of the AVOID programme (AV/WS2/D1/R05B), (2010), p.5
33) IEA (2008a), p.91
34) According to IEA (2008a, p.91-92), it "is limited to oil fields deeper than 600 metres where a minimum of 20% to 30% of the original oil is still in place and where primary production and secondary production methods applied" with improving oil production over time according to "characteristics of the hydrocarbon and on the reservoir conformance".

"4-5 billion incremental barrels" can be achieved by following "a total investment cost of $60 billion" at "the optimum time-window for CO_2-EOR" no later than 2012.[35] CO_2-EOR technology is already mature and proven, but there should be more R&D for further deployment within the full chain of CCS when dealing with 'offshore environments' for large reservoirs, deciding "the optimum window of opportunity for EOR with offshore infrastructures", and building infrastructure leading to reduction in CO_2 cost.[36]

As for supporting CCS demonstrations, regulations and financial mechanisms should be guaranteed, along with drawing more investments from the private sector. Yet, private investors cannot be sure of the economic feasibility of CCS at the current level because clear legal and financial frameworks at a national and international level have more influences at the early stage of commercial scale CCS demonstration projects.

In Yorkshire and the Humber, there are pending and proceeding national and international funding sources. At the international level, EU ETS is well known as a crucial funding source where investors (particularly, in energy-intensive industry) invest in low carbon technologies for a long term.[37] Two EU funding packages for CCS demonstrations are the European Energy Programme for Recovery (EEPR) and 300 million EU Emission Trading System allowances from the New Entrant Reserve (EU's NER 300 scheme[38]) for supporting twelve CCS demonstrations. The Don Valley Power Project is already guaranteed €180 million EEPR funding in 2009. Yet, under the British government's application for seven CCS projects to the European Investment Bank for consideration, the Don Valley Power Project applied to the EU's NER scheme, along with Alstom Consortium's Drax oxyfuel power project and C.GEN's IGCC power project in the region

Despite the global economic slowdown, the British government has increased

35) IEA (2008a), p.94
36) Ibid. p.96
37) Enkvist *et al.* (2007), p.35-45
38) The funding stems from selling 300 million allowances to emit CO2 under a cap and trade scheme in the EU. It would worth approximately €4.5billion for supporting at least eight CCS projects and thirty four renewable energy schemes in the EU. Three projects per member state could be covered, and the final selection of projects would be in the second half of 2012.

its spending on Carbon Abatement Technologies (CATs) as well as CCS. Such a government level of R&D investment is important for reducing technological costs. In addition, competition for supporting four commercial-scale CCS demonstration projects is underway to deploy CCS on a commercial scale by 2020. Yet, as the Office of Carbon Capture and Storage points out, inherent problems such as "delays in commencing the competition for projects two to four" and UK funding based on "general taxation rather than the Levy mechanism" can be barriers for investors to have confidence in investment decision.

Yet, as 25% of the UK's electricity generators (including outdated power stations) will be closed over the next decade, and "more than £110 billion in investment is needed to build the equivalent of 20 large power stations and upgrade the grid"[39], a new form of Climate Change Levy came out. The UK's revolutionary path to reform the electricity market with low carbon electricity started in July 2011, along with the publication of 'Planning our Electric Future: A White Paper for Secure, Affordable and Low-carbon Electricity'. The market reform includes four important factors: a *Carbon Price Floor, Feed-in Tariff with Contracts for Difference, Emissions Performance Standard (EPS), and Capacity Mechanism.* This reform is assumed to bring huge influence in low carbon technology deployment and diffusion, and substantial progress by lowering uncertainty, increasing credibility in investments, and predicting carbon price in accordance with the EU ETS.

As an emission trading scheme is characteristic of neoclassical economics, there should be "equilibrium of supply and demand" with "a single price for emission reduction methods."[40] As the carbon price under the EU Emissions Trading Scheme was between €11-14 in 2011, it was necessary to increase it up to €35-45 so as to run a commercial-scale demonstration project by 2020. Yet, the carbon price under the EU ETS is volatile and vulnerable in the extreme as a result of changes in oil prices, consumers' preferences, policy changes, etc. Thus there is the urgent necessity for stabilising carbon price in conjunction with the EU ETS. It is crucial for creating niche markets in which private actors can actively invest in CCS with credibility and

39) Department of Energy and Climate Change (DECC), Planning Our Electric Future: a White paper for secure, affordable and low-carbon electricity, DECC (2011), para.4-7
40) Bode and Dietrich (2008), p.75

confidence in the future. As a supplement to the EU ETS, *a Carbon Price Floor* will "strengthen the carbon price signal in the UK", along with drawing more investments in CCS-related infrastructure and accelerating decarbonisation.[41] The proposed price floor puts "a fair price on carbon", starting from £16/tCO_2 in April 2013 and targeting £30/tCO_2 in 2020 and and £70 /tCO_2 in 2030. This plan will provide "£1.9 billion of net present value benefits."[42] According to HM Treasury, if the 2020 price floor of £30/tCO_2 increases to £70/tCO_2 in 2030, "£30-£40 billion of new investment in low-carbon electricity generation", which is "equivalent to 7.5-9.3 giga watts (GW) of new capacity", will be attracted.[43]

Feed-in Tariff with Contracts for Difference, which will replace renewable obligations from 2017, is a cheaper but sounder mechanism and "a new system of long-term contracts . . . providing clear, stable and predictable revenue streams for investors in low-carbon electricity generation."[44] In comparison to the necessity for "installing at least 20-30GW of fossil-fuel power generation capacity", with CCS technology by 2030[45], FIT, with contracts for difference, will reduce "the cost of capital" by making available "clean technologies with high up-front and low long-run costs" in competition with "traditional unabated fossil fuels."[46] *The Emission Performance Standard* prevents the building of coal-fired power stations without CCS. According to DECC, the standard "sets as an annual limit equivalent to 450g CO2/kWh", which is "a clear regulatory signal" indicating how much carbon that emitters can generate.[47]

As Foxon indicates, however, more investments in novelties on their own would require "a very high carbon price", which is nearly impossible in a political and social sense.[48] For this reason, a mix of the above-mentioned national and international support for technological innovation should be continued, which would allow the

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41) HM Treasury, Carbon Price Floor Consultation: the government response, HM Treasury (2011), p.8
42) Ibid., p.4
43) Ibid.
44) DECC (2011), p.7
45) Carbon Capture Journal, UK Government launches electricity market reform, http://www.carboncapturejournal.com/displaynews.php?NewsID=817 (visited on August 19, 2011), para.55-58
46) Ibid., para.30-33
47) DECC (2011), p.7
48) Foxon (2010), p.3477

private sector to take first mover's disadvantage, such as high costs and risks. For the reason, it would be premature that the newly started British Electricity Market Reform is beneficial for CCS technology innovation, but the prospect is quite bright in encouraging CCS innovation in the pursuit of low carbon economy.

3.3. Social acceptability of CCS demonstration projects

Among options for mitigating climate change impacts, CCS is still perceived as a less competitive technology due to the lack of related knowledge and information. According to an in-depth interview conducted by Shackley *et al.*, respondents mentioned the leakage issue (although they were uninformed of CCS technology before the interview) even though there are other, more potential risks.[49] Such lack of information and knowledge has led to low support for CCS technology in spite of its huge potential. As Shackley *et al.* indicate, public perceptions greatly influence "planned projects involving new technologies and infrastructure."[50] In addition, public support could allow CCS projects to be developed to "acceptable costs and timescales."[51]

For this reason, a shift in public perception would be a signal for CCS developers to proceed even though the level of public perception on CCS is still low, even in the UK and other developed countries.[52]

49) Shackley, Simon, Clair Gough and Carly Mclachlan, "The Public Perception of Carbon Dioxide Capture and Storage in the UK" in Simon Shackley and Clair Gough, eds. Carbon Capture and its Storage: an integrated assessment (2006), p.141-169
50) Ibid., p.141
51) CO2Sense, CCS Network to the Future, CO2Sense Yorkshire Limited (2010), p.7
52) Shackley *et al.*, (2006);

Reiner, David, Tom Curry, Mark de Figueiredo, Howard Herzog, Steven Ansolabehere, Kenshi Itaoka, Makoto Akai, Filip Johnsson and Mikael Odenberger, An international comparison of public attitudes towards carbon capture and storage technologies, Paper presented at the 8th International Conference on Greenhouse Gas Control Technologies, June 19-22, 2006, in Trondheim, Norway

Table 2. Responses to: "Have you heard of or read about any of the following in the past year?"

(Japanese respondents were also asked if they "know to some extent" these technologies)

Technology	UK	US	Sweden	Japan (heard or read)	Japan (know to some extent)
Wind energy	69%	50%	83%	44%	52%
More efficient appliances	40%	49%	68%	45%	38%
Nuclear energy	39%	54%	87%	41%	54%
Hydrogen cars	26%	48%	46%	45%	33%
Bioenergy/biomass	10%	10%	54%	34%	18%
Carbon capture and storage	5%	4%	15%	22%	9%
Carbon sequestration	2%	3%	8%	38%	52%

Source: Reiner *et al.*, 2006, p.3, adapted by author

Even though there is a lack of comparison of national data on social awareness of CCS, general studies on social awareness and attitudes towards climate change issues have been conducted along with focus group studies for CCS in order to "test the response of participants to information and provide a more detailed reaction to CCS."[53] Considerable social acceptability of CCS demonstration projects is crucial because these projects eventually lead to economic prospects, environmental and health issues, and even technological developments. According to the CO_2 Capture Project, the widespread use of CCS requires stakeholders to trade off benefits against risks of CCS implementation:

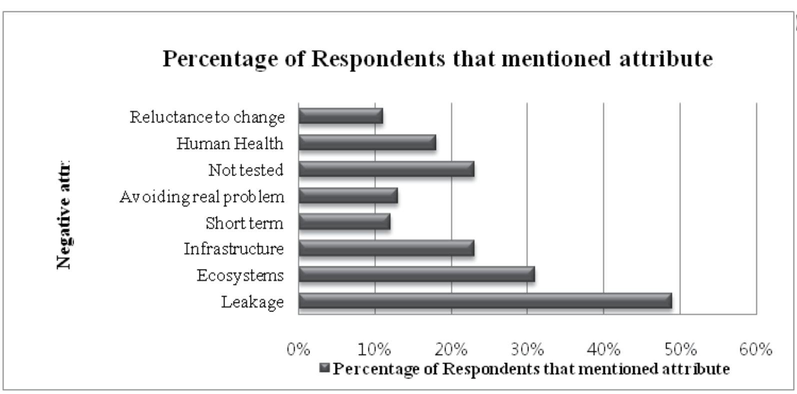
- *Industry, during the process of developing CCS projects;*
- *The financial community, in deciding whether to invest in CCS;*
- *Regulators, in the process of permitting CCS facilities;*

53) Reiner *et al.*, (2006), p.1

- *The public, in choosing whether to live near CCS facilities;*
- *The public and civil society, in discussing whether to accept CCS as a viable climate change mitigation option in the context of other available options; and*
- *Consumers, by deciding whether they are willing to pay higher prices for low-carbon electricity.*[54)]

The CCS demonstration project in Yorkshire and the Humber is actively accomplished with interaction among industry, the British government, the EU regulator, and the regional development agency. Yet, perception of local community groups in the UK, the main source of government funding, still remains low with the public showing concerns (e.g., the leakage issue [49%], ecosystems [31%], the new and untested nature of CCS technology [23%], and human health impacts [18%]), [55)] about CCS projects in their region[56)]. Even though the figure came out of two citizen panels from York and Manchester in 2002 and 2003, it would be still meaningful for academics and the Government to measure more reactions towards CCS and climate change.

Figure 2. Percentage of Respondents that mentioned attribute



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Source: Shackley *et al*., 2006, p.150, adapted by author

54) International Energy Agency, Public Perception of Carbon Dioxide Capture and Storage: Prioritised Assessment of Issues and Concerns. Summary for Policy-makers, IEA (2007), p.4
55) Shackley *et al.* (2006), p.149-150
56) See Figure 2.

3.4 Environmental accessibility of CCS demonstration projects

Amounts of CO_2 emissions in Yorkshire and the Humber are the second highest in the EU, behind the Ruhr Valley in Germany, generating 60 million tonnes of CO_2 per year, which is nearly half of all emissions from UK households.[57] A high concentration of power stations and proximity to storage sites are advantageous for this region to become a low carbon economic area for CCS. According to *Carbon Capture Journal*, "the potential suitability of North Sea geology for storing CO_2 and its ability to use the CO_2 to enhance the security of energy supply with incremental oil production" allows the UK to take a unique status in Europe.[58]

Yet, as to the public concern for the leakage problem, the possibility of ecosystem degradation, untested CCS technology, and human health has a high possibility of increasing in this region; several national and international regulations are required. For instance, under the Health and Safety at Work etc. Act of 1974, the Health and Safety Executive will be applied to "the length of the CCS process chain from power generation to CO_2 injection" and will be in charge of examining the necessity for newly applying or extending 'existing regime (e.g., Pipeline Safety Regulations)' along with scientific developments.[59] Furthermore, under the EU Directive on the Storage of Carbon Dioxide (Directive 2009/31/EC), CCS transport and storage infrastructure will be the subject (DECC). Yorkshire and the Humber has a shared network (e.g., from existing coastal gas terminals into the southern North Sea Storage), which keeps infrastructure from congestion and disruption caused by the construction of multiple pipelines. According to CO2Sense, as repeated infrastructure is limited in the region, there are low possibilities for incurring environmental and local community impacts. In addition, companies such as Drax Power and C.GEN follow

57) CO2Sense, CCS Network to the Future, CO2Sense Yorkshire Limited (2010)
58) Carbon Capture Journal, 2Co Energy acquires Powerfuel and Hatfield Project, http://www.carboncapturejournal.com/displaynews.php?NewsID=788&PHPSESSID=vo6hpj51111vhlpnrh21sdo566 (visited on August 2, 2011), para.11
59) Office of Carbon Capture and Storage (OCCS), UK Carbon Capture and Storage (CCS) Commercial Scale Demonstration Programme: Delivering Projects 2-4, DECC (2010), p.23

recommendations from the Environment Impact Assessment (EIA) by categorising scenarios- construction, operation, and decommissioning. For instance, when C.GEN is under consideration of taking IGCC or CCGT plant in a CCS project, six scenarios are put in place in corporate strategy: “construction of CCGT; operation of CCGT (opening year, design year); construction of IGCC at the outset; operation of CCGT with construction/conversion to IGCC; operation of IGCC (opening year, design year); decommissioning.”[60)]

When it comes to storage in the North Sea, two international legal frameworks are applied: the London Protocol and the OSPAR Convention (which makes it possible, under the Convention, to inject CO_2 into the sub-seabed). These frameworks allow “long-term liability for CO_2 storage,”[61)] making contracting parties responsible for creating “strict regimes for authorisation and regulation” of CCS activities, and for meeting treaty obligations “to protect marine eco-systems.”[62)] Under Article 6 of the London Protocol, exporting CO_2 from one country to other countries “for injection into sub-seabed geological formations” is prohibited; this prohibition would encourage more CCS activities,[63)] thus lowering environmental impacts in marine ecosystems. In sum, such national and international monitoring of environmental impacts in the local community is underway in the Yorkshire and Humber, but hidden environmental issues will be emerging with CCS project development and its legal frameworks.

4. Conclusion

4.1. CCS technology innovation chain in the UK

Carbon Capture and Storage technology has both incremental and radical innovation

60) Brinckehoff, P., "North Killinghome Power Project Environmental Impact Assessment: Request for Scoping Opinion," Amber Court, May 2011. Prepared for C.GEN Killingholme Ltd., p.15
61) International Energy Agency, Carbon Capoture and Storage: Legal and Regulatory Review, IEA (2011)
62) DTI (2003)
63) Ibid., p.15

characteristics. In terms of incremental innovation, the technology has already been proven and advanced with existing technologies through learning-by-doing, or using. Yet, in terms of radical innovation, along with R&D activities, this technology has the possibility of changing social structure in the future by contributing to changes in the 'techno-economic paradigm'. Then it is hard to determine whether CCS is an incremental or a radical innovation.

Yet, the clear point is that this technology has emerged in low carbon technology areas. It has been driven by a strong demand from the public and private sectors. Such a movement eventually leads to lowering climate change impacts in people's daily lives and meeting national and international targets for carbon abatement as well as keeping energy security. Given that nuclear power has environmental and operational risks, renewable energy and CCS began to draw more attention as competitive low carbon technologies. Inclusion of CCS as part of the CDM, which was handled in the UNFCCC meetings (COP 16th and 17th), can be an example of international effort to encourage CCS development.

As CCS technology innovation is at the early stage, it is somewhat premature to confirm this technology innovation's progress status. Even though there are no remarkable outcomes for the effectiveness of CCS in climate change mitigation, there are several feasibility studies on CCS projects in the UK, US, Austria, Japan and Norway. Rather than integrating a full chain of CCS, the mere focus on developing each technology cannot bring reduction in GHGs. Nevertheless, developments of each technology in capture, transport and storage, and even usage of carbon have allowed stakeholders to consider CCS's strong and feasible possibility. A full chain of CCS demonstrations at a commercial scale in the UK could be a big adventure and challenge, but should be deployed in order to pursue a low carbon economy.

CCS technological innovation does matter along with financial and legal frameworks rather than just technology itself. Failure in securing financial mechanism from public and private sectors and in political support (e.g. mismatch regulations with CCS technological innovation) can be the biggest challenges to undertaking CCS technological innovation. Yet, "uncertainties external to the CCS chain" (CO2Sense), such as "political and financial" issues, can be handled "by engaging with government," while “interdependencies and complexities within the CCS chain” (CO2Sense) should be resolved along with “good project design and selection of the appropriate project partners.”[64)]

Despite substantial government support for Carbon Abatement Technologies (CATs) R&D for several years, an ongoing high technology costs and investment risks are huge barriers for stakeholders to invest more in CCS projects. Nevertheless, support from the British government, and positive effects from the newly created Electricity Marker Reform, the EU support mechanism, that is, the European Energy Programme for Recovery (EEPR) and EU’s New Entrant Reserve (NER) 300 scheme, can give credibility to private investors to consider or to continue to invest in CCS projects.

In addition, an ongoing construction of a CCS network in Yorkshire and the Humber region can be helpful for giving credibility to private sectors. In particular, CO2Sense plays a bridge role in encouraging businesses to participate in CCS projects. According to Stephen Brown, project manager of CCS in CO2Sense, innovation benefits will come true if “local companies either get involved in engineering of plant integration of commercial demonstration projects, or develop technology for second generation CCS plants”. Yet when businesses consider becoming involved in CCS projects, the following factors should be considered in advance:

> *“Availability of sites for development including access to fuel supply, grid connection and cooling water;*
> *Access to potential safe offshore storage in large quantities.”*[65)]

Besides such economic and technical perspectives, winning public acceptance and lowering environment impacts in the region are also influential factors for CCS project development. As public resistance could delay CCS demonstration projects because of a concern about health issues, monitoring and evaluation processes should be followed under national and international agreements. A demonstration phase, in the sense, provides opportunities to examine storage sites as an arena for licensing, monitoring, and verification processes. Despite the fact that there should be more continuous

64) Brown, Stephen, Interview by Yu Kyung Oh. 12th August 2011
65) Ibid.

amendments to legal frameworks, the EU Directive on the Storage of Carbon Dioxide, the OSPAR Convention and the London Protocol can be good examples to keep the region from being contaminated by external concerns coming from CCS activities, and to gain credibility from the local community and private sectors.

In sum, the current ongoing CCS demonstration projects on a commercial scale in the region allow stakeholders to test their capacity for accommodating CCS innovation in a non-linear but systemic way, and to examine to what extent British legal and financial framework is sound before moving into a commercial scale of CCS projects after 2020. In addition, it would be a good chance to test CCS innovation in accordance with the Electricity Market Reform. Considering more active participation (even if the Government and EU are still dominant) from stakeholders, and a mix of 'demand pull' from the market and a 'technology push' from R&D, the current innovation status in Yorkshire and the Humber seems to be moving from linear to non-linear characteristics. The market-push policy for CCS should be followed in the near future beyond the current technology-push policy so as to achieve market penetration and cost reduction.

A complete niche for CCS has not been created, but the speed of creation would be faster if it were based on established technologies, advanced legal and financial mechanisms, and rising public awareness of climate change and CCS. As Stephen Brown indicates, the EU and the British government are the main players in creating a new low carbon market. Beyond remaining within the support mechanism at the national and international levels, however, a low carbon innovation system would become a reality after accommodating more active participation by stakeholders to exchange and share knowledge, a combination of technology-push and market-pull policy for commercialising CCS, and regulatory and financially sound mechanisms for attracting more investors. This CCS demonstration phase, in a sense, can be regarded as a precious opportunity for learning and examining by correcting systemic errors for further development of a low carbon innovation system.

4.2. Suggestion for stakeholders of CCS technology innovation

Even though the current CCS innovation phase is at the early stage of the whole low carbon technology innovation chain, the role of stakeholders in the technology innovation system should be focused so as to build an effective innovation system. In the private sector, as Stephen Brown already mentioned, local companies should be involved in CCS activities in person while the financial community should evaluate whether CCS innovation in a region is suitable for investment or not. As Yorkshire and the Humber case shows, regulators (such as the Health and Safety Executive or the EU Directive on the Storage of Carbon Dioxide) should evaluate whether or not to permit CCS facilities in the region. From the public perspective, such a regulatory issue is crucial for them because CCS technology operations would impact the local community in terms of environmental, health and economic aspects. Even though CCS is at the demonstration step in the UK, integrating CCS into British electricity prices is a sensitive issue for consumers, businesses, and policy makers. Particulary, as *willingness to pay higher price for low-carbon electricity* depends on consumers, the British government should consider its intention in the development of CCS as well as equipping other stakeholders with a political support mechanism in order to encourage the novelties.

Beyond a linear innovation system, the UK (other countires as well) shows more complicated and interrelated characteristics in transition to low carbon economy. Yet, like the full chain of integrated CCS technology innovation, the socio-technical transition for a low carbon economy should be interpreted by considering each role of stakeholders within the multi-level perspective under the innovation system in a co-evolutionary way.

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