SUSTAINABILITY FRAMEWORK FOR CARBON CAPTURE AND STORAGE

SUSTAINABILITY FRAMEWORK FOR CARBON CAPTURE AND STORAGE

Monique Hoogwijk [1)]

Andrea Ramírez [2)]

Chris Hendriks [1)]

[1)] Ecofys Netherlands B.V.

[2)] Utrecht University, Copernicus Institute for Sustainable Development and Innovation, Research group Science, Technology and Society

January 2007

EEP03017 – WP1.1

Preface and acknowledgements

This research is part of a larger carbon dioxide capture and storage (CCS) program in the Netherlands called CATO, which has as main goal to assess whether or no CCS is a viable option to be implemented in the Netherlands. This report is the outcome of a project conducted in 2005 – 2006.

For this project several workshops have been held. We would like to thank the participants Jos Bruggink (VU Amsterdam/ECN); Dancker Daamen (Leiden University), Sander de Bruyn (CE), Wouter de Ridder (MNP), Bert de Vries (UU-STS/MNP), Louis H.J. Goossens (TU Delft), Peter Hofman (UT Twente), Daniel Jansen (ECN), Anne Kets (Rathenau Instituut), Karel Mulder (TU Delft), Jos Post (RIVM), Marko Hekkert (Copernicus Instituut, UU), Christoph Tönjes (Clingendaal), Eise Spikers (Groningen University), Mart van Bracht (TNO), Maarten Gnoth (Electrabel), Hans Hage (CORUS), Jos Maas (Shell), Jan Maas (DELTA), Huub Paes (Electrabel), Bert Stuij (SenterNovem), Chris te Stroet (TNO), Wim Turkenburg (UU, Copernicus Instituut) and, Bram Van Mannekes (NoGePa).

Finally, the authors wish to thank Dr. Dancker Damen (Leiden University) for his comments on the interpretation and analysis of the survey's results and Erika de Visser (Ecofys), Joris Koornneef and Klaas van Alphen (Utrecht University) for their support during the workshops.

Summary

Carbon Capture and Storage (CCS) is a mitigation option that has gained increasing interest over the past years. However, whether CCS can contribute towards sustainable development is an important but complex policy question. In this study a sustainability framework for the implementation of CCS in the energy system has been developed. Using the framework a (more objective) consideration can be made if and how CCS can contribute to a sustainable energy system. The framework has been developed in close discussion with experts on sustainability, and with the relevant stakeholders with respect to CCS.

Based on literature and stakeholder consultations the following comprehensive set of criteria for a sustainable energy system was developed (a definition of the criteria is included in Section 4.1):

- Clean;
- Safety;
- Justice;
- Flexibility;
- Continuity;
- Independence;
- Competitive position or affordability;
- Public acceptance;
- Reliability.

For each criterion, experts and stakeholders have identified a list concerns; in total 36. Each concern poses a possible barrier for the implementation of CCS in a sustainable way. The concerns that were considered as the most worrisome by the experts and stakeholders are:

- Whether or not there will be sufficient public acceptance for CCS;
- The energy system will remain depending on fossil fuels;
- The costs will have negative effects on our standards of living;
- CCS diverts attention away from energy saving and renewable energy;
- Other environmental problems of energy supply are not addressed by CCS like local air pollution;
- The energy system may become dependent on regions with large amounts of storage capacity;
- We may place a burden on future generations because of the CO_2 stored underground;
- (Seen from a Dutch perspective) other countries/regions will not implement CCS.

The concerns related with the criteria **clean**, **flexibility**, **justice**, **competitiveness** and **public acceptance** were considered most relevant in relation to the role of CCS in a sustainable energy system. It was also found that the selection of most concerns was somewhat correlated to the type of organization the respondents work for.

The actions to address the concerns can be categorised in three groups:

- Increase research and development
- Include CCS in a policy portfolio
- Raise public awareness

The role of the stakeholders can be summarized as follows:

The government is generally seen as the most relevant stakeholder for the first phase of implementation of CCS (in a sustainable way). Besides some small niche markets, CCS will add to the costs of energy production and will therefore need a strong policy support. The government should develop standards to safety and monitoring, arrange the inclusion of CCS in legal frameworks and EU ETS system, support research and development and provide in some sense financial guarantees for investment in CCS.

The industrial sector should increase research and development actions into CCS and develop demonstration projects. In addition, it was suggested that they should develop risk assessments and monitoring protocols.

The research Institutions should increase the insight regarding when CCS could be economical and competitive. In addition, they should conduct research to improve the capture efficiency and storage safety, and they should also have a role in the development of risk assessment and monitoring protocols.

The improvement of the public awareness related to CCS was considered a task for all stakeholders, including Environmental NGOs.

The sustainability framework as described in this report can be used for several policy making processes:

- Provide an overview of criteria related to the implementation of CCS in a sustainable energy system;
- Prioritising concerns and prioritising related actions related to these concerns ;
- Provide a framework for further policies and measures related to CCS.

Next steps include the conversion of the criteria into quantifiable indicators that can be used to evaluate possible implementation strategies for large scale deployment of CCS systems.

Content

1 Introduction

1.1 Background

Energy production and use is still the major contributor to the overall greenhouse gas emissions. Reducing greenhouse gas emissions in the energy system is part of an overall policy objective to strive for a sustainable energy system for the longer term.

Currently the global energy system depends for more than 75% on fossil fuels. Energy scenarios estimate that fossil fuels will remain dominant in the coming decades. The reduction of greenhouse gas emissions and the transition towards a more sustainable energy system is therefore a challenging task. Increasing amount of studies[1] indicate that when meeting the EU target on climate change, that is to limit the maximum average global temperature increase to 2^0C at the end of this century, a portfolio consisting of several mitigations options is needed. There is consensus that no one category of mitigation will solve the problem by itself. Measures such as improving energy efficiency, switching from coal to natural gas, afforestation/reforestation and renewable energy applications are all required to meet short- and longer terms goals. But there is a general belief that additional options are also required[2,3].

Since the late 1980s a new concept is being developed which enables to make use of fossil fuels with a considerably reduced emission of carbon dioxide to the atmosphere. The concept is often called ‘Carbon Capture and Storage’ (CCS). CCS involves the recovery of CO_2 from (energy) conversion processes and its disposal outside the atmosphere, e.g. in depleted oil or gas fields, aquifers or into deep-ocean. Figure 1 shows the potential contribution of different options to reduce cumulative CO_2 emissions.

[1] Van Vuuren D.P., M.G.J. den Elzen, P.L. Lucas, B. Eickhout, B.J. Strengers, B. van Ruijven, M.M. Berk, H.J.M. de Vries, M. Hoogwijk, M. Meinshausen, S.J. Wonink, R. van den Houdt, R. Oostenrijk. 2006. Stabilising greenhouse gas concentrations at low levels: an assessment of options and costs, MNP, Report 500114002/2006, 2006, pp 273

[2] Herzog H., Drake E., Adams E., 1997. CO_2 capture, reuse, and storage technologies for mitigating global climate change. Massachusetts Institute of Technology.

[3] International Energy Agency, 2006. Energy technology perspectives 2006. Scenarios and strategies to 2050. EIA, Paris.

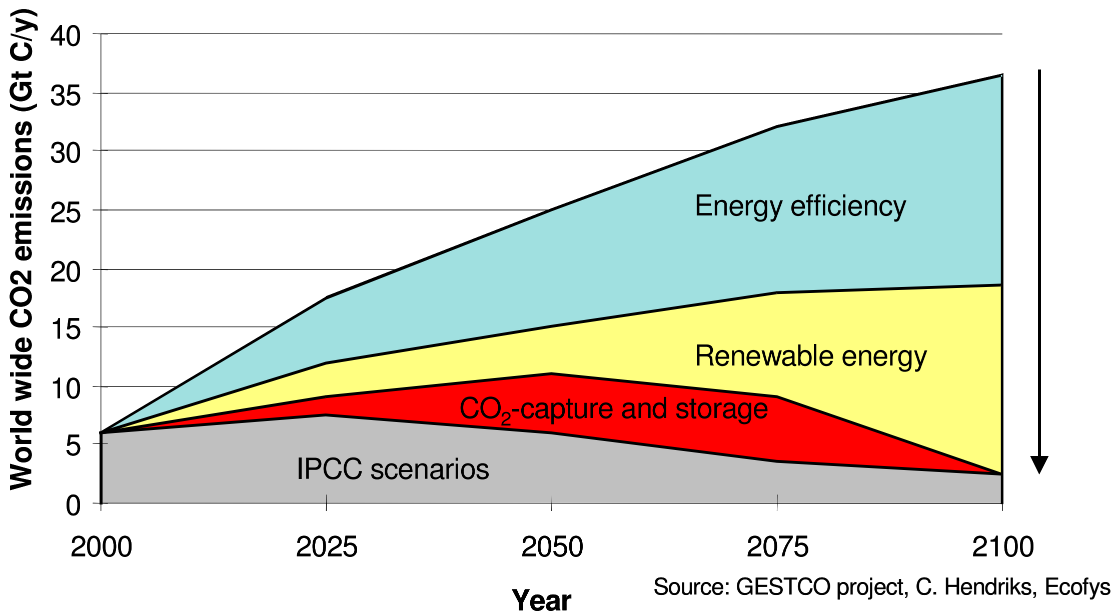

Figure 1: potential contributions of several options for CO_2 abatement.

As shown, the concept of Carbon Capture and Storage (CCS) appears to be a promising option for the medium and long-term abatement of CO_2 emissions. A first quick literature scan indicates that carbon capture and storage systems have a number of attractive features [4,5].

- It can be applied in short and intermediate terms (technology is available);
- The CO_2 storage capacity is large;
- It could be a cost-effective answer to high carbon tax
- It allows for continuing large scale use of fossil fuels giving the time to switch to other forms of energy supply;
- It can be a low cost mitigation option if hydrogen were to become a major energy carrier;
- It could be necessary on longer terms if other options fail (e.g. if energy sources such as wind or nuclear energy cannot gain sufficient market share and/or acceptance);
- It does not depend on local climate conditions, does not compete with agriculture, fishing, other industries and land use.
- Provided that the storage location is chosen carefully, CCS is auditable.

Nevertheless, CCS has a number of less attractive features:

- The system would keep relying on fossil fuels (security of supply issue),
- It may lead to sub-optimal (infrastructure) solutions (lock-in),
- It may diverse attention and resources from renewable energy sources,
- It may lead to long environmental effects associated to fossil fuel use that is not solved by CCS (mining, other pollutants, etc.),

[4] Turkenburg W.C., 1997. Sustainable development, climate change and carbon dioxide removal. Energy conversion and management, Vl 38, Suppl, PS3-S12

[5] Bachu S., 2000. Sequestration of CO_2 in geological media: criteria and approach for site selection in response to climate change. Energy conversion and management 41, 953-970.

- Spin-off of technology may be limited compared to renewables,
- CO_2 may escape gradually to atmosphere when not contained carefully leading to an uncontrolled source of CO_2 and a burden for future generations.

1.2 Objectives of the study

Based on the inventory of attractive features and concerns, an important question is whether Carbon Capture and Storage could effectively contribute to the development of a sustainable energy system. The main objective of this study is therefore to provide an answer to the following question:

"For CCS to play a substantial role in the development of a sustainable energy system in the Netherlands, which criteria should be fulfilled?

To be able to answer this question, we developed a sustainability framework for the implementation of CCS. This framework is built up of a set of clear and unequivocal sustainability criteria that can subsequently be operationalised by indicators. Such a framework has not yet been developed.

The following sub-questions have been posed to address the issue effectively:

1. What kind of sustainability frameworks for energy systems has already been developed?
2. Which criteria determine a sustainable energy system?
3. What concerns should be addressed if CCS is to be part of a sustainable energy system, or a transition towards a sustainable energy system?
4. What do the stakeholders consider as the most important concerns in relation to CCS contributing to a sustainable energy system?
5. Which actor should undertake what action to overcome these concerns?

When developing such a framework it should be realised that:

- There is no one single definition of a sustainable energy system;
- Sustainability assessments consists of various scales in time and space;
- The sustainability criteria are weighted differently among different stakeholders;
- There are several type of stakeholders involved in the decision making process, therefore, a sustainability framework should also be developed together with various stakeholders.

1.3 Setting System Boundaries to CCS

Before focusing on sustainability criteria for CCS, it is important to define the system boundaries of the mitigation option as it is used in this report. The IPCC Special Report on CCS gives the following definition of CCS:

"CCS is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere"[6]

In setting up the framework for sustainability, we expanded the definition of CCS as the influence of capture and storing CO_2 is not limited to the actual separation, transport and storage activities. Also the (continuing) extraction, transport and use of fossil fuel are important elements to take into considerations. The boundaries of CCS as used in this analysis are depicted in Figure 2. The following CCS chain elements are distinguished. Element 1 to 3 represents the fossil fuel or biomass production, transportation and converted to secondary energy carriers, e.g. electricity, heat or hydrogen. During or after the conversion, the CO_2 is captured from the process and compressed (element 4), transported (element 5), and stored or used (element 6). It should be noted that ideally, also the transport and use of secondary energy carriers should be taken into account, as specifically hydrogen has further implications for the system. However, this aspect has been neglected in the present analysis.

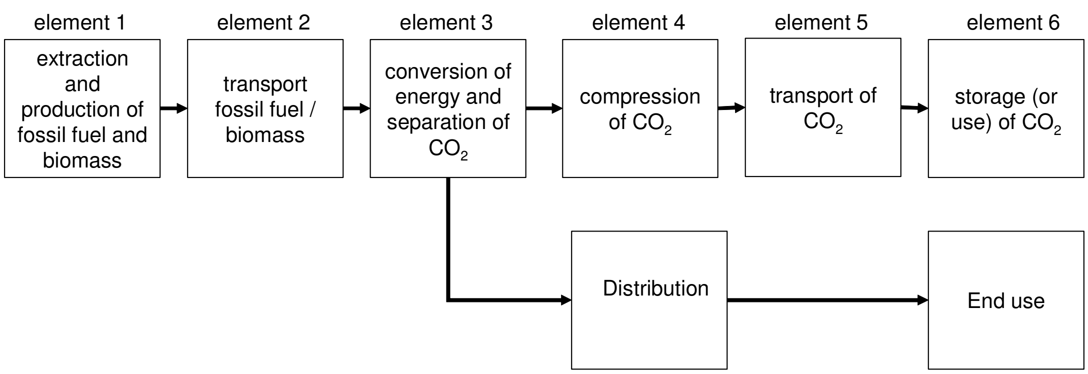

Figure 2: The chain of CCS as used in this study, indicating the different elements

1.4 Structure of the report

The report is structured as follows. In section 2 an introduction is given to sustainable energy systems based on information from literature. Section 3 describes the applied methodology and explains the successive steps to the development of the framework and the interactions and discussion with the involved stakeholders. Section 4 presents the developed criteria, based on literature search and discussions with experts on sustainability and CCS. Section 5 describes the results of a survey of the main concerns among people with some or more involvement in CCS. Finally, section 6 presents the identified actions and responsibilities for the various stakeholders. Conclusion and recommendations are provided in section 7.

1.5 Relation to Other CATO Work Packages

The development of a sustainability framework forms part of Work Package 1 of a Dutch research project called CATO [7]. Within CATO, WP1 focuses on system analysis, infrastructure

[6] Metz B., Davidson O., Coninck H de., Loos M., Meyer L., editors, 2006. IPCC special report on carbon dioxide capture and storage. Intergovernmental Panel on Climate Change, Cambridge University Press.
[7] Information on CATO can be found on www.CO2-cato.nl

and transition management. WP1 consists of several sub-work packages as is presented in Figure 3. The outcome of the sustainability framework will be used in the classification of storage options; in the system scenario analysis and in the transition and policy strategy analysis. The results are all used as a framework for decision making within CATO WP 1.

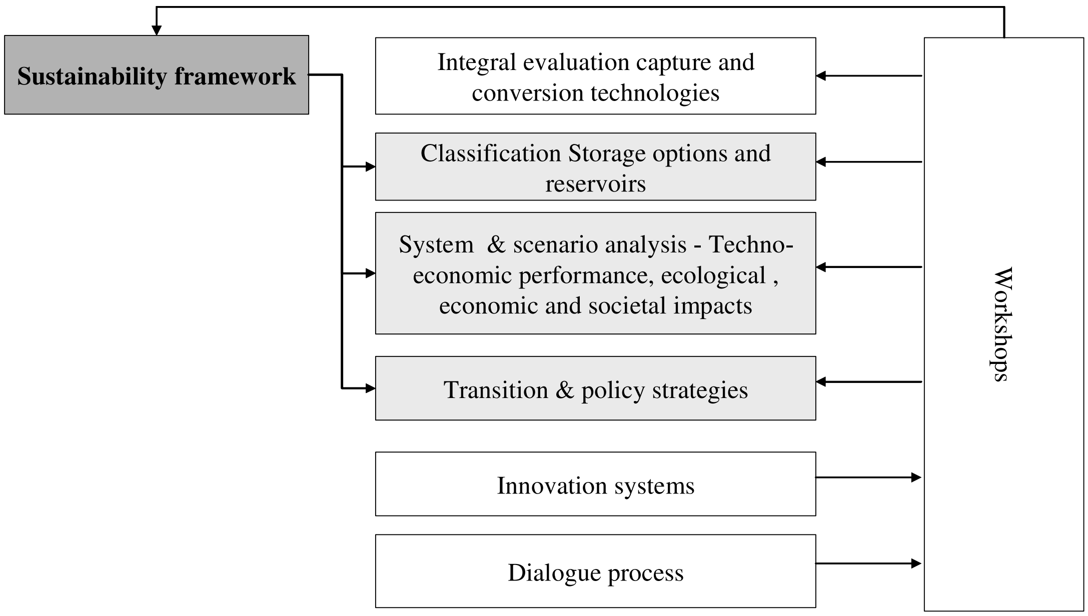

Figure 3: Overview of the sustainability framework within the WP1 of the CATO programme.

2 Sustainable Energy Systems

Sustainable development has become the policy paradigm of the nineties. Sustainability is, however, not a new term. The concept of (ecological) sustainability originated in 1970's in the context of renewable resources such as forests or fisheries and was subsequently adopted by the environmental movement. Sustainable Development, in turn, has embraced ecological sustainability (as promoted by environmental movements) and added social and economic dimensions. The attractiveness of the concept resides on the fact that sustainable development has managed to reconcile the interests of the environmental and the development communities, by rejecting the notion that environmental conservation necessarily constrains development or that development necessarily means environmental pollution. It is, therefore, not surprising that sustainable development has gained increasing relevance in policymaking. Already in the mid-1980s, sustainable development began to be used by agencies such as the World Bank[8], the Asian Development Bank[9] and the Organization for Economic Cooperation and Development [10]. However, it was only in 1992 when sustainable development was officially put on the global political map by the UN Earth Summit in Rio de Janeiro, following the report of the World commission on Environment and Development in 1987 (generally refer to as the Brundtland report).

In the discussion on how to reach sustainability, the central role that energy plays has increasingly being recognized[11] since a) lack of access to diverse and affordable energy services mean that the basic needs of millions of people are not being met; b) energy services are a key motor of economic growth. They are needed to create jobs, develop industries, enhance value added activities and support income-earnings activities, and c) the environmental effects of energy use can occur at many levels, from the household to global and include consequences such as desertification, acidification, air pollution and climate change[12]. Furthermore, the potential of climate change has, in fact, been characterized as one of the main threats for sustainable development due to its severity (current trends on greenhouse gas emissions pose a significant threat to our quality of life and threaten to significantly reduce our stocks of social, environmental and economic assets), time dimensions and irreversibility. For various problems it applies that although it worsens only gradually, it may be very costly or impossible to put right if action is left to a very large scale plus it has a significant inter-generational aspect [13].

[8] Conable B., 1986. Address to the Board of Governors of the World Bank and the International Finance Corporation, 30 September 1986, Washington DC, World bank

[9] Runnalls D., 1986. Factors influencing environmental policy in international development agencies. Manila: Asian Development Bank.

[10] Environmental Committee, 1985. Environmental assessment and development assistance: final report of the Ad Hoc group, 26 November, Paris: OECD.

[11] The role of energy in SD has been affirmed at a number of UN conferences/agreements. For instance: The UN Framework Convention on Climate Change (1992); the Global Conference on Sustainable Development of Small Island Developing states (1994); World summit on social development (1995); the UN Conference on Human Settlements (1996); Kyoto protocol (1997); the Millennium Declaration (2000); the Third United Nations Conference on the Least Developed countries (2001); the Commission in Sustainable Development, 9th session (2001), and the World Summit on Sustainable Development (2002).

[12] WEHAB working group. A Framework for Action on Energy. World submit on sustainable development. August 2002

[13] See for instance, European Commission SP1, sustainable energy systems; UNDP, Energy for sustainable development. A policy agenda. Johansson T, Goldenberg J (eds), 2003; International chamber of

Before considering criteria and indicators that can be used to monitor the sustainability of an energy system (e.g. with CCS), it is necessary to understand what it is meant by a sustainable energy system. A literature scan of about forty papers or books published in the area shows several trends (for the list of the papers reviewed and the definitions of sustainable energy system used see Appendix 1):

1. About one third of the papers revised do not explicitly define what they understand for Sustainable Development or for a Sustainable Energy System.
2. Among the studies that do define Sustainable Development, the most widely quoted definition of sustainable development comes, in fact, from the Brundtland report: "Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[14].
3. There are many interpretations of sustainability, and even with Brundtland's definition, it is clear that there are different views on what is meant with, for instance, "needs". Nonetheless, there is a broad consensus that sustainable development captures two important ideas:
   - Sustainable development is a concept that involves at least three dimensions[15]: economic, social and environmental.
   - There is an obligation from the current generation to future generations so their well-being will be at least as high as our own.
4. When dealing with a sustainable energy system, most authors define it in terms of a system that fulfil at least two characteristics:
   - *Security of supply*: an energy system should be able to supply the basic energy needs of the population (for current and future generations).
   - *Minimization of environmental damage*: the impacts of an energy system should not exceed the capacity of the ecosystems to absorb the effect without permanent damage.

   On addition, two other characteristics are also frequently named:
   - *Resource availability*: an energy system should use resources in such a way that the future generations have at least the same level of access to energy services than current generations.
   - *Price affordability*: there should be equal opportunities to access energy services for all society members and those services should be provided in such a way that it supports economic growth and employment.

6. Compared to the multifaceted visions of sustainable development, the way the concept is framed in most papers places greater emphasis on the environmental pillar (compared with the economic or social pillar).
7. Attempts to operationalise sustainable development assessments of energy systems usually involve a conceptual division of the ecological, economic and social dimensions. There is a lack of a conceptual framework that can reconcile the goals formulated.

---

commerce, energy commission. Briefing paper submitted to the UN Commission on SD, 9th session, New York 16-17 April 2001; EC., A European Union strategy for SD, 2002.

[14] World Commission on Environment and Development, 1987. Our common future. New York: Oxford University Press.

[15] In the literature there are also references to other dimensions, such as cultural, institutional and technological.

8. Frequently, criticisms to implement sustainability strategies are based on desktop exercises without active participation of stakeholders or public perception.
9. The scope of most papers on the sustainability of energy system is on renewables (or renewables combined with efficiency); only a handful of papers include fossil fuel sources or nuclear energy.

In this context, the development of a sustainability framework for Carbon Capture and Storage system for the Netherlands should at least:

- Make explicit what definition of sustainability used.
- Include public participation and stakeholder consultation as an active element.
- Give a balanced attention to the three pillars of sustainable development (economic, social and environment).

3 Methodology

In this project, we depart from the recognition that the formulation of a sustainability framework cannot only be the result of a scientific desktop exercise made by a single institution. The importance of early stakeholder involvement in the formulation of targets to be set for sustainability assessments of complex systems has been pointed out in several studies ([16,17]). There are two main reasons: *i*) a sustainability definition has to be developed context specific and according to the priorities and perceptions of the people towards sustainability (the importance assigned to various criteria may differ depending on specific regional conditions and needs), and *ii*) many sustainability criteria, especially concerning social issues, requires normative decisions which cannot only be made by scientific judgment (e.g. description of criteria which contains aspects such as fair, equitable and justice). Furthermore, for systems such as CCS, where uncertainty is prevalent, information is incomplete and knowledge is diverse, the involvement of different actors allow for a better treatment of information, since it is unlikely that one actor possesses the perfect overview. Taking all these aspects into account, we selected a participatory approach for the development of a national sustainability framework for CCS. According to the literature, a participatory approach should fulfil a series of characteristics [18]:

- The analysis should be decision-oriented and stimulate broad framing of the policy problem;
- A broad overview of available scientific insights should be developed;
- Options should be developed which are creatively different, relevant and internally consistent;
- The method should allow step-by-step learning;
- The method should allow for the participation of the relevant stakeholders;
- The method should facilitate communication in which the judgments of experts and stakeholders are taken into account;
- The method should allow for the integration of scientific data and judgment of experts and stakeholders.

Taking these characteristics into account, the approach selected in this project consists of five main activities:

i) a literature review,

ii) an exploratory workshop,

iii) two interactive meetings,

iv) a survey and,

v) in-depth interviews.

[16] Lewandowski I., Faaij A., 2004 . Steps towards the development of a certification system for sustainable Bio-energy trade. Report NWS-E-2004-31. Copernicus Institute, Utrecht University, the Netherlands.
[17] United Nations, Division for sustainable development, 2001. Indicators of sustainable development: guidelines and methodologies, United Nations, Geneva.
[18] Geurts J.L.A., Mayer I., 1996. Methods for participatory policy analysis. Towards a conceptual model for research and development. Work Organization Research Centre Report 96.12.008/3, Tilburg.

The Dutch stakeholders involved during the development of the sustainability framework were: the government (Ministry of economic affairs, Ministry of environment, SenterNovem), the steel industry (Corus), oil and gas industry (Shell international, NoGePa), the power sector (Electrabel Nederland, Nuon, Delta), research institutions (Clingendael International Energy Programme, the Energy Research Center of the Netherlands, the Netherlands Environmental Assessment Agency, The Netherlands Organization for Applied Scientific Research, the Rathenau Institute, Groningen University, Technical University of Delft, University of Twente, University of Leiden, Utrecht University) and environmental NGOs (Netherlands society for nature and environment, Greenpeace). Table 1 shows the participation of the different stakeholders in the participatory process.

Table 1: Stakeholders involved in the different steps of this project

	Government	Industry	Research institutions	Environmental NGOs
Literature review				
Exploratory workshop				
Interactive meeting 1				
Survey				
Interactive meeting 2				
In depth interviews				

3.1 In Depth-Literature Survey

An in-depth literature survey on how sustainable energy systems are defined and monitored, and the role that CCS can play in the transition towards sustainability, provided the general background from which we departed in this project. Main results of the literature scan have already been summarized in Section 2 and Appendix 1.

3.2 An Exploratory Workshop

The exploratory workshop (held in July 2005) aimed to point out main issues of concern regarding the role of CCS in a sustainable energy system. The workshop was attended by representatives of (energy) industry, NGOs, government and research institutes. The interactive meetings were shaped based on the results of the workshop in combination with the performed literature scan.

3.3 Two Interactive Meetings

Two interactive meetings were conducted in November 2005 and March 2006 using what is generally referred to as a "policy lab". A policy lab is a decision room that has an information technology (IT)-based environment. It consists of a set of hardware (a network system and a computer for each participant involved), software (tools which enable electronic brainstorming and structuring of generating ideas) and process facilitation (preparation and managing the electronic meeting) that support a group of people engaged in a decision-related meeting. This kind of interactive meeting has several advantages since:

- It enables stakeholders to comment on one another's ideas anonymously and parallel,
- The anonymity should encourage participants to speak freely,

- In addition to the electronic exchange of information, 'normal' conversation can also take place.

The agendas of the two policy lab meetings are summarised in Figure 4.

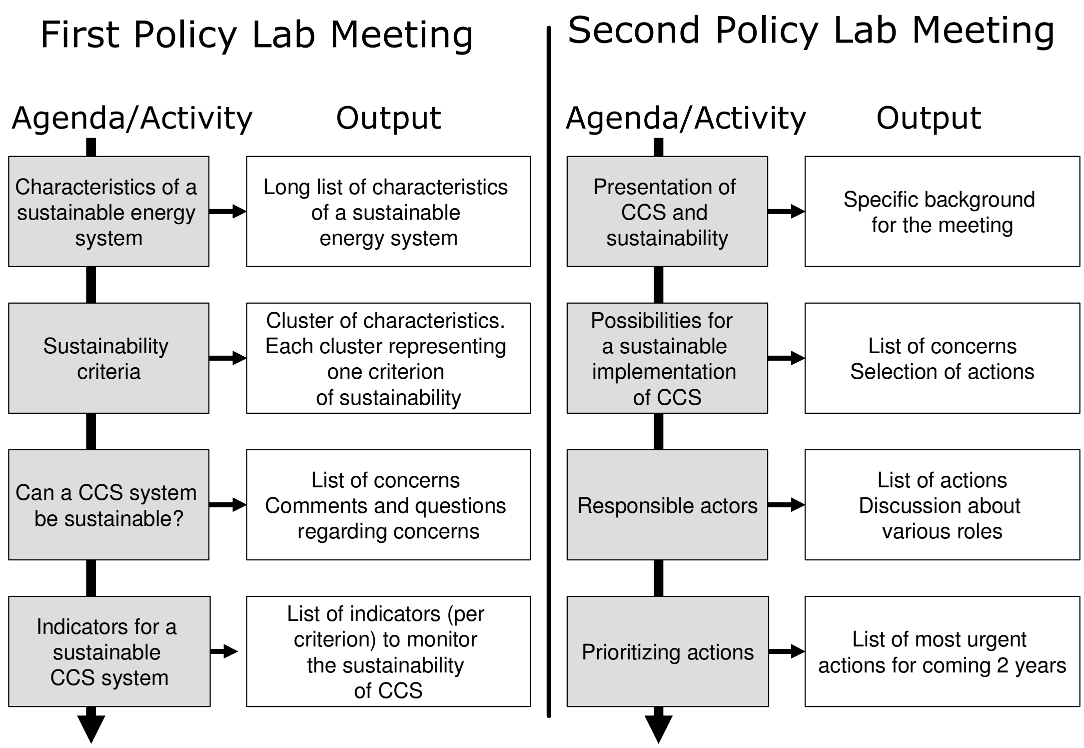

Figure 4. Agenda points and main output expected of the policy laboratories.

In the *first policy lab* fourteen experts in different fields of expertise participated (e.g. pollution, risk assessment, transition management, energy infrastructure, energy economists, public acceptance). The goal of the meeting was twofold. First, to define the criteria an energy system has to fulfil in order to be considered sustainable. Second, to identify the main concerns (by criterion) that would make the implementation of CCS unsustainable.

The *second policy lab* session was designed for stakeholders. Ten participants attended the meeting with representatives from government and from organizations such as power utilities, chemical companies, research institutions, and local associations. Departing from the sustainability criteria and concerns generated in the first interactive meeting, the second policy lab aimed to:

a. Obtain the visions of different stakeholders on the main concerns for the sustainable implementation of CCS, and
b. Identify the responsibilities (which actor(s) is responsible for what) and actions that need to be implemented if CCS is to be deployed in a sustainable way.

An overview of the main agenda points of each session and the expected results is shown in Figure 4. The list of participants of both sessions can be found in Appendix 2 and 3

3.4 The Survey

To obtain a preliminary hierarchy among the criteria (which criteria could be considered more 'important' than others), an (international) survey was conducted between December 2005 and March 2006.The survey was also used to gather data on the visions and preferences of the respondents with respect to the role of CCS in reducing CO_2 emissions. The survey was conducted in both, paper form (during the first Netherlands National Fossil day, November 23rd 2005) and through the Internet. The survey can be found in Appendix 4

The target group of respondents was people working in issues related to climate policy, energy policy, climate change, carbon capture and storage, and development of technologies for carbon dioxide abatement. The group consisted of different types of stakeholders; i.e. government, research instituted, consultants, Environmental NGOs and private companies. It is important to point out that this group already had (some) knowledge of CO_2 related issues and therefore, it is *not* a representative sample of the 'average' citizen in the Netherlands or abroad. To investigate the view of the less informed 'common' citizen on the sustainability of CCS, a different kind of approach needs to be designed since research has shown that 'current public opinions on CCS, assessed by traditional questionnaires, are mostly pseudo-opinions: they are unstable (change within 12 minutes), and are affected by tiny amounts of non-diagnostic information and by the mood of the respondent'[19]

3.5 In-Depth Interviews

Finally, three in-depth interviews (stakeholders from the Ministry of Economic Affairs, the Ministry of Housing, Planning and the Environment, and the Netherlands Society for Nature and Environment) were conducted to address specific issues of concern that were pointed out during the policy lab sessions. The interviews focused on the identification of the most importance concerns, actions and responsible actors for the sustainable implementation of CCS. Of special importance was to obtain a list of actions (together with the responsible actors) that should be implemented in the next two years. Results are included in Section 6.

[19] Best-Waldhober M., Daamen D., 2006. Public perceptions and preferences regarding large scale implementation of six CO_2 capture and storage technologies. Well-informed and well-considered opinions versus uninformed pseudo-opinions of the Dutch public. Centre for Energy and Environmental Studies, Faculty of Social Sciences, Leiden University.

4 Criteria and Concerns for CCS in a Sustainable Energy Systems

This section focuses on the criteria for the use of CCS in a sustainable energy system. As described in the previous section, at first a sustainable energy system is defined by developing a list of criteria. For each of the criteria, main concerns for CCS are identified. The criteria for a sustainable energy system and for CCS are mainly based on the two interactive workshops. See Section 3 for a description of the workshops and see Appendix 2 and 3 for a list of the participants.

4.1 Definition of a Sustainable Energy System

What is the definition of a sustainable energy system? In Section 2 several definitions from the literature of a sustainable energy system have been presented. At first it was concluded that in many studies dealing with the sustainability of energy systems, the definition of what is understood by sustainable is lacking. In addition, the literature scan showed that the definitions of sustainable development and related to that of a sustainable energy system, vary significantly.

To derive to a consistent definition of a sustainable energy system, we focussed on the criteria to which a sustainable energy system has to comply. We addressed this issue by comparing different literature sources and discussing it during an interactive workshop with experts, as described in Section 3. Hence, a sustainable energy system is defined as a system that is clean, safe, reliable, just, affordable (competitive position), is accepted by the public, and guarantees flexibility, continuity and independence. A detailed description of each criterion is found on Table 2.

Table 2: Sustainability criteria of an energy system

Criteria of sustainability	Description
Clean	Minimum burden for the environment in the broad sense; reduction of emissions to the air, soil and water. This includes amongst others emissions that may contribute to the enhanced climate change effect and air pollution. Clean, in addition includes the reduction of transport of (dangerous) waste. The criterion clean has both a time and geographical dimension, no pollution for future generations and other countries.
Safety	Considered to be the minimalisation of the negative health impacts for humans and the prevention of catastrophe occurrences. Special attention should be given to the product of change and impact.
Justice	Implies that there is both equity and manageability between regions and generations. The availability and accessibility of energy should be the same for all regions and current and future generations. Next to this, the risks and possible negative impacts of the energy system should also be equal. There needs to be equity between the benefits and the burdens for everyone. The energy supply of the future should not lead to (increased) poverty.
Flexibility	Implies that the energy system has a diversity of energy sources and carriers to decrease the dependency of other regions for their own current and future energy supply. The choices regarding the energy systems that are made at this moment should not cause any lock-in for future technologies or institutional aspects.
Continuity	Implies that energy sources are available at longer timeframes and that there is sufficient time for and insight in the development of alternative sources.
Independence	Implies that an energy system is not (to) dependent on other regions for its energy supply.
Competitive position or affordable	Implies that energy technologies are available at low generation costs for consumer and that there is a level playing field for industry and power companies.
Public acceptance	Implies that the energy system should be part of the perception of the public. The system should be acceptable for large parts of the society, should be transparent and guarantee the common interest.
Reliability	Implies that the energy system supplies a continue flow of energy. The complexity of the system should not reduce the constant supply of energy.

4.2 Concerns for CCS as Part of a Sustainable Energy System

Can CCS be part of a sustainable energy system? If CCS is to be a part of a sustainable energy system it also should meet the identified criteria listed in Table 2. For that reason, we identify potential concerns of CCS per sustainability criterion. For some criteria, no concern was mentioned.

The concerns of CCS as part of a sustainable energy system were identified and discussed at the first and the second workshop with experts. This resulted in the following list:.

Clean

- With the use of CCS, fossil fuel sources will be still used and only the CO_2 component will be extracted from the system. Other pollutants such as aerosols, NO_x, SO_2, and land related damages will not be reduced.
- During the process of CCS other, potentially pollutant processes, will be introduced e.g. using chemicals during the capture process.
- At different parts of the CCS process, but especially during storage, small losses of CO_2 can occur that still can lead to significant emissions over longer timeframes.
- CCS is less efficient compared to conventional applications and this would lead to accelerated depletion of fossil sources and addition emissions of air pollutants.
- There is a large demand for land area during the mining of coal.

Safety

- The possible consequences of unexpected releases of gas are uncontrollable. Even if there is little change, the consequences for humans and animals might be large.
- It is uncertain if the security of the storage reservoirs can be guaranteed for potential terrorist attacks.
- When CCS is used at large scale, the probability of leakage, especially during transport and transfer, might increase.
- The use of coal on a large scale is unsafe when considering the accidents during mining

Justice

- The final solution for a sustainable energy supply is postponed for future generations when using CCS in combination with fossil fuels.
- CCS is less accessible for less developed countries because of the higher costs involved.

Flexibility

- Because of the remained use of fossil fuels, CCS does not contribute to a less fossil fuel dependent energy supply.
- Investments in CCS could lead to reduced investments in other options or infrastructure for wind and solar energy. It could optimise the current situation further resulting in a suboptimal energy supply system.

Continuity

- Using CCS, fossil fuels will continuously be used. CCS will lower the efficiency of the conversion process which would deplete the fossil fuels earlier.
- For the situation in the Netherlands, the potential for CO_2 storage is limited.
- CCS will probably be implemented on a large scale making it more difficult to implement decentralised supply systems.
- CCS could lead to monopolies of "storage companies", something as an OPEC-like organisation. This could lead to further geo-political instabilities.

Affordability

- CCS increases the electricity costs and prices
- CCS should especially play an important role in countries with significant amount of coal as China and India. In these countries affordability is especially a potential bottleneck.
- Although CCS is more expensive than energy saving measures, it may decrease the necessity of energy efficiency and as a result lead to additional costs.
- There are not many spin-offs expected to other technologies or sectors from CCS.
- If the investments in CCS technologies are not done on an international scale, this might be adverse for the economy. CCS is only possible if there is an international incentive or policy for climate neutral energy supply.

Public acceptance

- CCS could be seen as a centralised, technocratic solution that does not appeal to the sentiment of the public.
- CCS can have large local impacts (compression, transport and storage). This is potential undesirable for local environment and habitants.

When CCS is implemented at large scale as part of a sustainable energy system, these concerns should be overcome. However, there are always trade-offs between concerns and not all concerns are weighted equally among different stakeholders. Therefore, the importance and weighting of the concerns are treated in the following section.

5 Weights and Trade-off of Concerns

Implementing a CCS system that fulfils at once *all* sustainability criteria will be a daunting task to achieve. To implement a system that step-wise fulfils the criteria is a more realistic option. For this reason, it is important to understand which concerns and related criteria are considered a priority. In order to study the weights of each of the concerns two approaches were taken:

- An international survey was developed and filled in by 231 persons with the aim to derive a preliminary overview of the weighting of the criteria and concerns by a broad, international informed audience
- Three in-depth interviews were held with key Dutch stakeholders in the field of CCS

5.1 Survey

As explained in Section 3, a survey was conducted with two goals:

1. Extracting the visions and preferences for CCS among different respondent groups.
2. Obtaining a preliminary hierarchy among the criteria.

5.1.1 Description of the Survey

The survey consisted of three parts. The first part (six questions) aimed to gather data on the background of the respondents. The second part (five questions) addressed the vision on the role of CCS in the energy system during the next century. In the final part (nine questions), respondents were asked to select out of four options, their most relevant concerns regarding CCS and the sustainability of the energy system. The time designed to complete the survey was around 10 minutes. The complete survey can be found in Appendix 4

We use the third part of the survey to obtain a hierarchy among the criteria. As seen from Table 3 and Appendix 4, we did not ask the respondents directly to select between criteria such as clean or social acceptance since each respondent can have a different understanding of what each criterion exactly mean and hence, we will unable to obtain comparable results. Instead, we opted for translate the criteria into concerns (using the results of the first policy lab) and ask the respondents to select among the concerns (four at a time), which would be in their opinion the most relevant. Note that in all cases the respondents were obliged to select one of the concerns over the others since the option 'none of them' was not given. Table 3 shows the correspondence between the questions, concerns and criteria of sustainability. Hence, from the survey it is possible to rank the number of times that each criteria was chosen by developing frequency distributions for each respondent and for the total sample. For instance, respondent X chose concerns linked to the criterion *clean* 3 times, *safe* 2 times, *public acceptance* 1 time, *competitiveness* 3 times (the other criteria were not selected). Note that adding all frequencies will give you a 9. In other words, among 9 points, respondent X has given 3 points to the criterion *clean*, 3 to *competitiveness*, 1 to *public acceptance*, 2 to *safet*y and 0 to the rest. The distribution of 9 points among the different criteria is the way in which the results will be presented and analysed later (see Section 6).

Table 3: Correspondences between Part 3 of the survey and sustainability criteria.

Question	*My greatest concern regarding CCS is:*	*Criteria*
1	That it impedes the implementation of solar and wind energy	Flexible
	That international pipelines are difficult to manage	Independence
	That there is no public acceptance for CCS	Public accept.
	That there is no or little spin-off for renewable energy	Continuity
2	That CO_2 leaks from underground reservoirs counteracting the effect of storage	Clean
	That there is a danger for a large blow-out at the storage site	Safe
	That we stay dependent on fossil fuels	Flexible
	That it impedes poor countries to develop their energy supply	Justice
3	That the storage capacity for CO_2 is insufficient	Continuity
	That CO_2 leaks to an adjacent drinking water reservoir	Clean
	That CO_2 pipelines cross populated areas that may prove to be dangerous	Safe
	That the costs will have negative effects on our standards of living	Competitive
4	That the price of electricity will increase too much	Competitive
	That poor countries do not have access to expensive CCS technology	Justice
	That it stimulates centralized large-scale energy supply (which might be less reliable than decentralized one)	Reliable
	That it diverts attention away from energy saving	Flexible
5	That the development of renewable energy systems will be impeded	Flexible
	That small-scale renewable energy will have little opportunity	Independence
	That other environmental problems of energy supply are not solved	Clean
	That there are not sufficient fossil fuel resources available	Continuity
6	That the balance of competition is disturbed	Public accept.
	That casualties will continue to occur as a consequence of coal mining	Safe
	That companies will not invest in this technology	Competitive
	That we will become dependent on regions with large amounts of storage capacity	Independence
7	That we remain dependent on regions with large fossil fuel resources	Independence
	That power plants will become more complex resulting in more power failures	Reliable
	That it doesn't solve the environmental issue due to the continuing pollution from extracting and transporting fossil fuels	Clean
	That environmental organizations are opposed to it	Public accept.
8	That we place a burden on future generations because of the CO_2 stored underground	Justice
	That the supply of fossil fuels is unreliable	Reliable
	That storage locations will become a target for terrorist attacks	Safe
	That fossil fuels will become expensive	Competitive
9	That future generations have to bear the costs of a transition to an energy supply based on renewables	Justice
	That industrial production processes shut down more often because of the increased complexity	Reliable
	That other countries/regions will not implement CCS	Social accept.
	That climate change is a hype and CCS not required after that	Continuity

The package used to analyze the results of the survey is Sigmastat for windows, version 3.11. In order to decide which statistical tests would be applied to the sample, we tested whether the population follows a standard bell shaped Gaussian distribution. Sigmastat uses the Kolmogorov-Smirnov test (with Lilliefors' correction) to test data for normality. This test compares the cumulative distribution of the data with the expected cumulative Gaussian distribution, and bases its P value on the largest discrepancy. The results pointed out that the population did not show a normal distribution and, therefore, when comparing the differences among variables we selected tests that do not assume the samples to be drawn from normal populations: the Mann-Whitney Rank Sum Test and the Kruskal-Wallis Analysis of Variance on Ranks. A brief description of the two tests follows.

The Mann-Whitney Rank Sum Test is used to test for a difference between two groups that is greater than what can be attributed to random sampling variation. The null hypothesis is that the two samples were not drawn from populations with different medians. This test ranks all the observations from smallest to largest without regard to which group each observation comes from. The ranks for each group are summed and the rank sums compared. If there is no difference between the two groups, the mean ranks should be approximately the same. If they differ by a large amount, you can assume that the low ranks tend to be in one group and the high ranks are in the other, and conclude that the samples were drawn from different populations (i.e. that there is a statistically significant difference). The Kruskal-Wallis Analysis of Variance on Ranks is essentially the same as a Mann-Whitney Rank Sum Test, except that there are more than two experimental groups. The null hypothesis you test is that there is no difference in the distribution of values between the different groups.

5.1.2 Respondents

The total number of respondents was 231 (116 from the Netherlands and 115 distributed among 29 different nationalities). The sample had the following characteristics:

- *Age distribution*: 0 to 30 years (22% total sample, 31% Dutch respondents), 31 to 45 years (32% total sample, 24% Dutch respondents), 46 to 60 years (40% total sample, 41% Dutch respondents), and more than 60 years (6% total sample, 3% Dutch respondents).
- *Employed by*: scientific/research sector (48% total sample, 35% Dutch respondents), the power sector (10% total sample, 14% Dutch respondents); the oil and chemical industry (9% total sample, 10% Dutch respondents), the government (7% total sample, 9% Dutch respondents), consultancy/an engineering company (12% total sample, 13% Dutch respondents), environmental organization (4% total sample, 3% Dutch respondents), and other (10% total sample, 17% Dutch respondents).
- *Work orientation*: technical (52% total sample, 46% Dutch respondents), economic (6% total sample, 6% Dutch respondents), social (5% total sample, 9% Dutch respondents), policy (17% total sample, 18% Dutch respondents), environmental (12% total sample, 9% Dutch respondents), and others (8% total sample, 12% Dutch respondents).
- *Field of expertise*: technology (53% total sample, 41% Dutch respondents), legal issues (2% total sample, 3% Dutch respondents), economic feasibility and finances (9% total sample, 10% Dutch respondents), risk aspects (5% total sample, 3% Dutch respondents), policy (15% total sample, 16% Dutch respondents), management (3% total sample, 5% Dutch respondents), and others (13% total sample, 22% Dutch respondents).

- *Working time spend on CCS issues*: less than 25% time (52% total sample, 67% Dutch respondents), 25 to 50% time (11% total sample, 9% Dutch respondents), 50 to 75% time (11% total sample, 10% Dutch respondents), and more than 75% time (26% total sample, 13% Dutch respondents).

The distribution of the respondents as is described above is summarised in Figure 5.

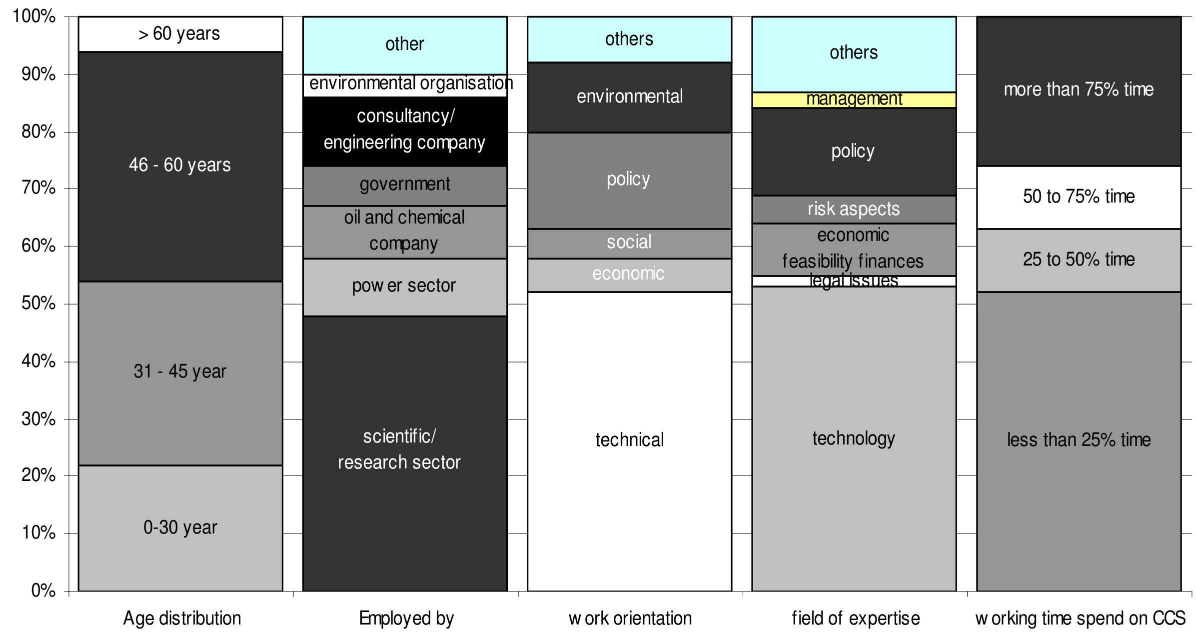

Figure 5: The distribution of the respondents for five different aspects

5.1.3 Visions and Preferences for CCS.

Since perception affects the way in which sustainability is defined and which trade-offs are considered acceptable, a part of the research has focused on extracting the visions and preferences among different groups. We found that:

- *The majority of respondents (58% total sample, 63% Dutch respondents) considered CCS an important option because it creates greater lead-time to develop cost-effective renewables*. 29% of the total respondents (22% in the case of the Dutch respondents) see the importance of CCS on the fact that can be deployed on a large scale, while the minority consider the opportunities to exploit technical know-how at the national level as a key factor (12% of the total sample, 16% of the Dutch respondents).
- *The role of CCS in reducing CO_2 emissions is considered comparable to the role of energy saving and renewables by the majority of respondents* (80 % total sample), while 14% of the total responders consider it THE solution to combat climate change, and 6% see it as a futile solution (the percentages for the Dutch respondents were 76%, 14% and 10% respectively).
- *70% of the total respondents* expect *that in the coming century CCS will play an important role as long as fossil fuels and storage capacity are available*, while 26% of the respondents expect it to play a temporary role and only 4% expect that it will not play an

important role at all (the percentages for the Dutch respondents are 67%, 29% and 3% respectively).

- Interestingly, when asked for how long they hope that CCS will play a role, *only 50% of the total respondents answered that they* hoped *CCS will play an important role as long as fossil fuels and storage capacity are available,* 43% hoped that it will play a temporary role and 7% hoped that it will not play a major role. In contrast with the total sample, the majority of Dutch respondents (58%) hope that CCS will play only a temporary role and only 36% hope that it will play an important role as long as fossil fuels and storage capacity are available.

The two last bullets show an interesting point: there is a significant difference between what the respondents expect and hope the role of CCS will be in the coming century This corroborates the notion that although energy production by using fossil fuels with CCS is considered a necessary option to achieve CO_2 abatement targets, it is far away of being considered an ideal one.

5.1.4 Preliminary Hierarchy of Criteria

Implementing a CCS system that fulfils at once *all* sustainability criteria will be impossible to achieve. To implement a system that step-wise fulfils the criteria is a more realistic option. For this reason, we have used the results of the survey to understand which concerns and related criteria are considered a priority. Table 4 shows the results of the selection of concerns by the respondents of the total sample (third column). It calls the attention that concerns associated with the criteria continuity; reliability and safety were not selected as main concerns when compared with those associated with other sustainability criteria.

Table 4 is in fact, a contingency table which also summarizes the way the concerns were selected according to the type of organization the respondents were working for. Strong conclusions from the table are not easy to be made, and although it is evident that the way participants selected concerns is influenced by the kind of organization they represent, to what level this influenced the selection made is not clear. In order to have a better understanding of the results, we have ‘translated’ the answers to the individual questions into frequencies as has already been described in section 2. This grouping provides a preliminary clustering of the sustainability criteria. It is important to point out that the results of this ‘translation’ can only be used as a guide of the relative importance of each criterion. Try to use the results beyond this (e.g. by applying directly the distribution of weights to a multicriteria analysis) would go beyond a reasonable interpretation of the data[20].

Figure 6 plots how the total respondents of our survey prioritized the criteria. The bars symbolize confidence intervals of 95%. At a first sight, three clusters can be distinguished, with *clean, flexibility, justice, competitiveness and public acceptance* being prioritized the highest, followed by *independence* and *continuity*, and in last place, *safety* and *reliability*.

[20] The way on which the survey was designed implied that each concern statement (indicating a specific criterion) is presented once within the context of three other concern statements and respondents should select their biggest worry (i.e., forced choice of one out of four). Note that each exemplar of this forced choice on his own provides no information on the importance of the chosen criterion; it merely indicates that the chosen worry is “bigger” than the three other worries (for instance all four worries can be totally unimportant in the eyes of a respondent). Hence, although the data allows for a preliminary comparison of the frequency with which certain worried are selected, it is not enough to derive specific weights that could be used in multi criteria analysis.

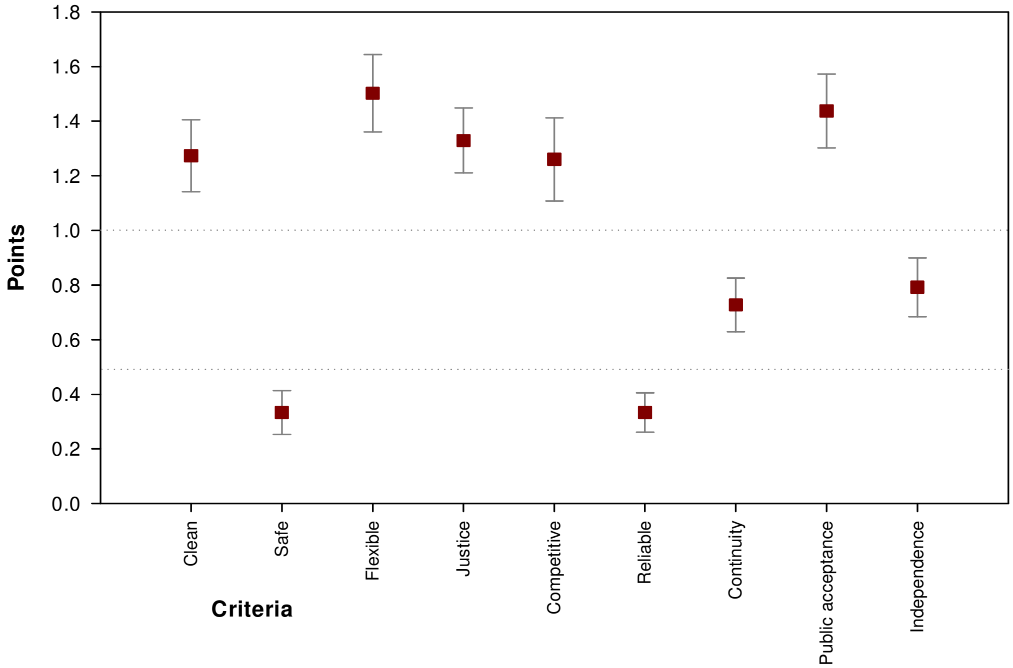

Figure 6: Distribution of points among sustainability criteria by the whole sample of respondents.

Table 4: Results Part III of the survey.

Q	*My greatest concern regarding CCS is:*	*Related Criteria*[a]	*Concern selected [% total sample, n=231]*	*Concern selected by respondents according to the type of organization they work for (in %)*					
				Power sector	*Oil/chemical industry*	*Engineering consultancy*	*Government*	*Scientist*	*NGO*
1	That there is no public acceptance for CCS	1	45	63	71	35	29	47	11
	That there is no or little spin-off for renewable energy	2	28	29	10	15	35	30	33
	That it impedes the implementation of solar and wind energy	3	17	8	5	27	29	13	56
	That international pipelines are difficult to manage	4	10	0	3	6	1	11	0
2	That we stay dependent on fossil fuels	3	49	41	52	46	46	50	22
	That CO_2 leaks from underground reservoirs counteracting the effect of storage	5	27	25	19	23	24	30	56
	That it impedes poor countries to develop their energy supply	6	16	21	19	23	18	15	0
	That there is a danger for a large blow-out at the storage site	7	8	13	10	8	12	5	22
3	That the costs will have negative effects on our standards of living	9	33	58	47	38	24	28	33
	That the storage capacity for CO_2 is insufficient	2	32	13	29	31	46	35	34
	That CO_2 leaks to an adjacent drinking water reservoir	5	22	25	19	12	18	20	33
	That CO_2 pipelines cross populated areas that may prove to be dangerous	7	13	4	5	19	12	17	0
4	That it diverts attention away from energy saving	3	48	33	33	54	59	52	67
	That poor countries do not have access to expensive CCS technology	6	21	13	19	15	29	24	0
	That the price of electricity will increase too much	9	21	50	29	23	12	13	22
	That it stimulates centralized large-scale energy supply (which might be less reliable than decentralized one)	8	10	0	19	8	0	11	11
5	That other environmental problems of energy supply are not solved	5	44	33	47	54	41	43	56

	That the development of renewable energy systems will be impeded	3	36	42	29	38	24	38	33
	That small-scale renewable energy will have little opportunity	4	13	8	24	4	29	12	0
	That there are not sufficient fossil fuel resources available	2	7	17	0	4	6	7	11
6	That we will become dependent on regions with large amounts of storage capacity	4	42	13	13	0	41	22	22
	That companies will not invest in this technology	9	26	25	67	0	53	46	34
	That the balance of competition is disturbed	1	22	58	10	100	0	20	22
	That casualties will continue to occur as a consequence of coal mining	7	10	4	10	0	6	12	22
7	That it doesn't solve the environmental issue due to the continuing pollution from extracting and transporting fossil fuels	5	34	29	14	38	35	37	56
	That we remain dependent on regions with large fossil fuel resources	4	33	38	38	27	47	32	11
	That environmental organizations are opposed to it	1	25	29	43	23	18	24	11
	That power plants will become more complex resulting in more power failures	8	8	4	5	12	0	7	22
8	That we place a burden on future generations because of the CO_2 stored underground	6	58	58	38	58	53	57	56
	That fossil fuels will become expensive	9	26	30	38	27	6	29	44
	That the supply of fossil fuels is unreliable	8	13	8	14	15	29	13	0
	That storage locations will become a target for terrorist attacks	7	3	4	10	0	12	1	0
9	That other countries/regions will not implement CCS	1	52	75	66	30	0	54	0
	That future generations have to bear the costs of a transition to an energy supply based on renewables	6	38	13	24	50	42	39	67
	That climate change is a hype and CCS not required after that	2	6	8	5	8	58	5	33
	That industrial production processes shut down more often because of the increased complexity	8	4	4	5	12	0	2	0

[a]: Related criteria : 1: public acceptance; 2: continuity; 3: flexible; 4: independence; 5: clean; 6: justice; 7: safe; 8: reliable; 9: competitive

We have compared whether the Dutch respondents of our sample would prioritize the criteria differently (see Figure 7). The Mann-Whitney Rank Sum Test[21] shows that, statistically, the differences between the means of the groups ‘Dutch respondents’ and ‘other nationalities’ are not significant for seven of the nine criteria (P values are shown in Appendix 5). In other words, and with exception of *public acceptance* and *independence*, the difference on the means in the distribution of points of the two groups among the criteria can be explained by random sampling variability. The differences in the means for *public acceptance* and *independence* obtained for ‘Dutch respondents’ and ‘Other nationalities’ is greater than would be expected by chance. Nonetheless, despite the statistic difference, the variability of the means is not big enough to change the rank order plotted in Figure 6.

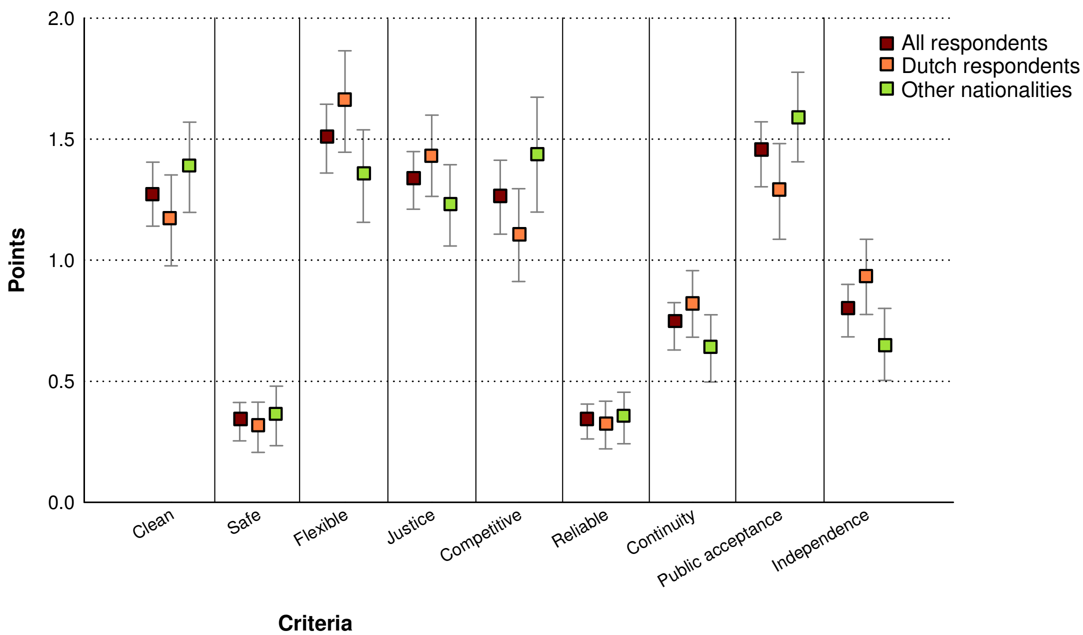

Figure 7 Distribution of points according to the nationality of respondents

To better understand the ranking of the criteria, Figure 8 plots the prioritization of the criteria according to the type of stakeholder. As expected, for those sectors that can implement CCS (the power sector and the oil and chemical industry) *clean*, *competitiveness* and *flexibility* are ranked the highest. Interestingly, among all sectors, it is also in the power and industrial group that *public acceptance* has the highest position. The criteria *independence, flexibility* and *justice* were ranked the highest by the governmental sector while *clean*, *justice*, *competitiveness* and *flexibility* were the criteria ranked in first place by environmental organizations. Note that the confidence intervals are much bigger for the individual groups that for the total sample, which is a reflection of the size of the sample. For instance, only 9 respondents of the total sample work for environmental organizations (4%), while 100 respondents work for the scientific/research sector (48%).

[21] For information on why we perform this test and the parameters chosen we refer to Section 3 of this report.

Since *Public acceptance* and *Independence* are the criteria were statistical differences were present among Dutch and non-Dutch respondents we take a closer look to these two criteria, now according to organization and nationality. Results are plotted in Figure 9. We found that in most cases the weights given to *public acceptance* and *independence* by organization are independent of the nationality of the respondents. The exception being for the criterion *Public acceptance* by the group *Chemical and Oil industry* (Appendix 5 shows all P values obtained), with non-Dutch respondents giving a significant larger weight to this criterion than Dutch ones.

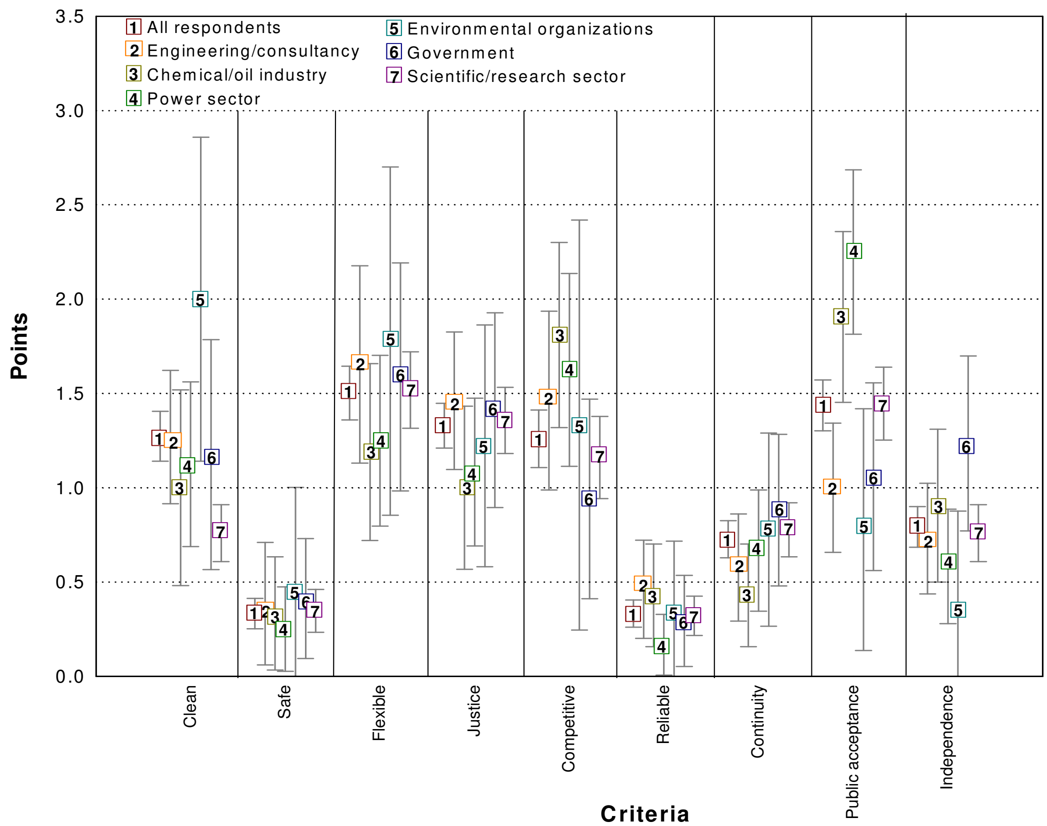

Figure 8: Distribution of points according to organization

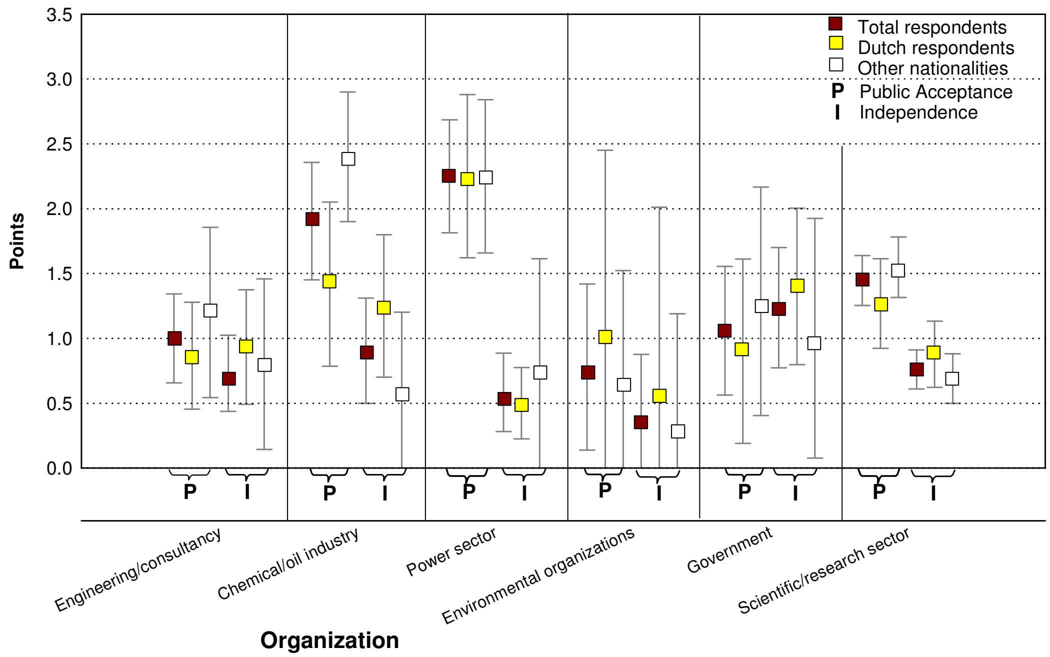

Figure 9 Distribution of points for the criteria public acceptance and independence, according to nationality and organization

We have also analyzed whether the allocation of weights to the different criteria is affected by the perceptions the respondents have on the role of CCS for the next century (see section 5.1). In other words, does the fact that respondents expect (or hope) that CCS will play an important role as long as fossil fuels and storage capacity is available (hereafter refer to as 'important role'), a temporary role or that it will not play an important role in the next century, affect the way they distribute the weights among the different criteria? The results are plotted in Figure 10 and Figure 11 while results of the statistical tests are shown in Appendix 5. We found that:

- to the frequency with which concerns related to the criteria *clean*, *safe*, *independence* and *reliable* were selected, is independent of whether the respondents hope/expect the role of CCS to be important, temporal or no important.
- The frequency with which concerns related to the criteria *continuity* and *public acceptance* are dependent of their hopes/expectations for the role of CCS. For the criterion *continuity* there are significant statistical differences between the groups 'important role' and 'temporal role'. In both cases, respondents who hope/expect CCS to play a temporal role selected concerns allocated to this criterion more frequently than those who hope/expect CCS to play an important role. On the contrary, for the criterion *public acceptance*, respondents who hope/expect CCS to play an important role selected more frequently concerns related to this criterion than respondents who hope/expect a temporary role. Additionally, we also found a significant difference in the way weights are allocated for the criteria *public acceptance* between the groups 'important role' and 'non-important role', with the former group showing a higher frequency to this parameter (this is only the case when participants were asked about

their hope for the role of CCS, when asked for their expectations, no significant differences are found between the groups).

- For the criteria *justice* and *competitiveness*, there are only differences in the way the criteria are prioritized when respondents were asked about their hopes on the role of CCS for the next century (when asked for their expectations, no differences are found among the groups). The difference is found between the groups 'hoping that CCS will play an important role' and 'hoping that CCS will play a temporal role'. For the criterion *justice*, respondents who hope CCS will play a temporal role allocated a higher weight to this criterion than those respondents hoping for an important role. For the criterion *competitiveness*, a highest weight is allocated by those respondents hoping for an important role.

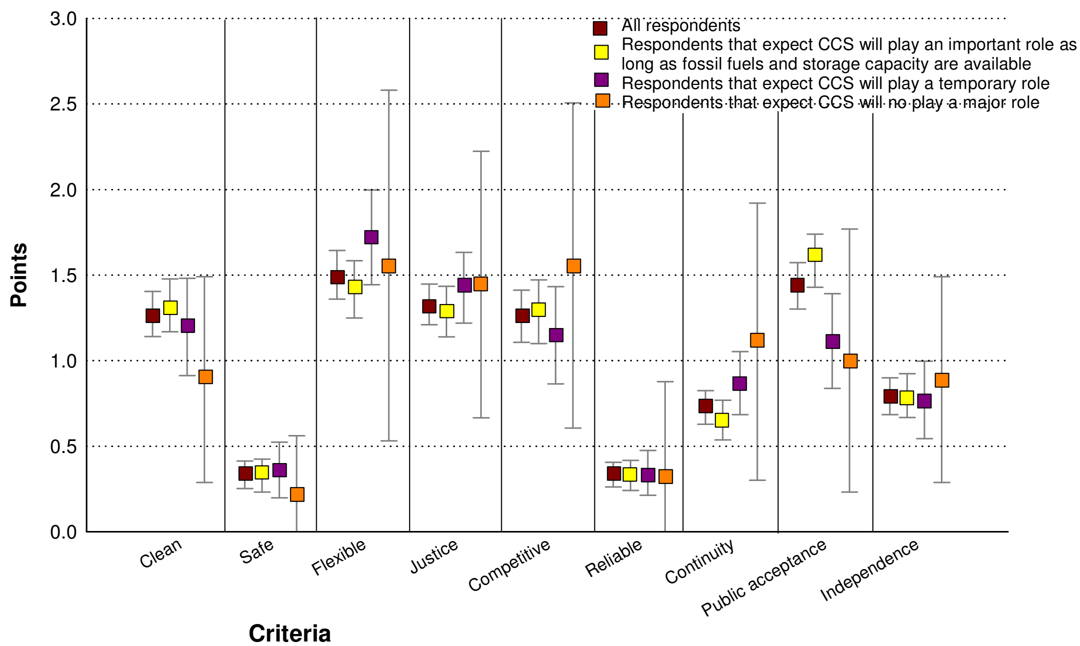

Figure 10: Distribution of weights according to the role that respondents expect CCS to play in the next century.

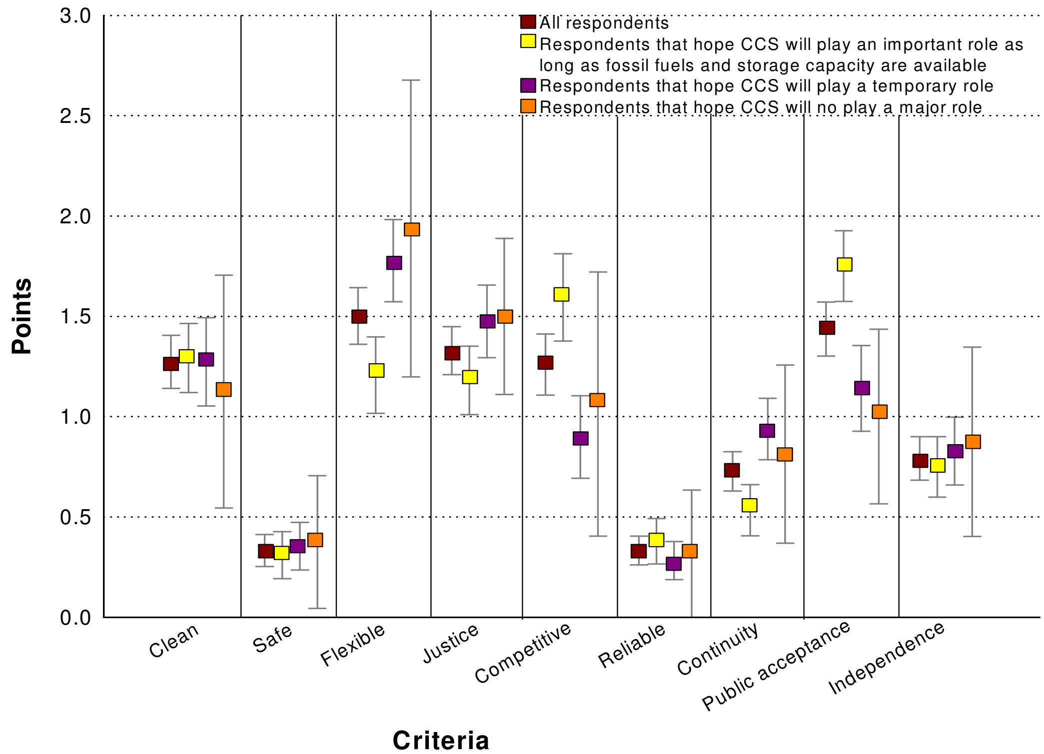

Figure 11: Distribution of weights according to the role that respondents hope CCS to play in the next century.

6 Actions and Responsibilities for Different Stakeholders

The main aim of the next step in the project was to identify actions to overcome the main concerns for the implementation of CCS as part of (a transition towards) a sustainable energy system and the actors responsible for these actions.

This was done using two main sources of information.

- The second interactive policy lab meeting. Stakeholders from four different groups have been included: government, research institutions, environmental NGOs and industry. See Section 3 for more information on the approach and list of stakeholders.
- The in-depth interviews with some additional stakeholders (Ministry of Economic Affairs, Ministry of Housing, Spatial Planning and the Environment and the Netherlands Society for Nature and Environment), that were not present at the policy lab meeting.

6.1 Visions of Stakeholders Concerning CCS

Before continuing to the actions and the responsibilities, we first summarise the views concerning CCS of the four different stakeholders identified in this project.

- *Government*. It recognizes the importance of advanced technologies, including CCS, in addressing climate change. However, there is not a unified vision about the role that CCS can play. Different views are observed between e.g. the Ministry of Environment vs Ministry of Economic Affairs (which in the Netherlands is the responsible for designing and implementing energy policy).
- *Environmental NGOs*. Their role is to critically examine the option and the conditions under which CCS would be implemented in order to guarantee that the energy system will develop into a sustainable one. NGO's perceive CCS as an option that may be necessary in a transition phase in order to obtain a significant share of the CO_2 emissions reduction necessary for the medium term (e.g. 2020-2030), but stress than in the long term (2050-2100), the energy system should be based in efficiency and renewables[22]. CCS should not hinder in any way the (further) development and implementation of renewables and energy efficiency.
- *Scientists/research centres*. Recognize the potential role that CCS can play in addressing greenhouse gas emissions. Highlight the need for further research on economics, development of monitoring systems and technologies for CO_2 capture.
- *Oil and power companies*. Important because it is expected that they will play a major role in the implementation of CCS. They are cautious to take any definitive decision about CCS as long as there is no clarity on the CO_2 policy (at the national and Euro-

[22] Typical examples of the NGOs position can be found on: Climate Action Network Europe, 2006; Friends of the Earth et al. 2005; Froggatt and Teske 2005.

pean level) and the value of CO_2 reduction in the post Kyoto period. There is also a strong need to obtain and evaluate results from demonstration projects.

6.2 Actions and Responsible Stakeholders to Overcome the Concerns

All stakeholders involved were asked to define actions to overcome the concerns and to add responsible stakeholders to these actions. In general three groups of actions have been defined:

- Increase research and development;
- Include CCS in a policy portfolio national and international and include CCS in current or new legal frameworks;
- Raise public awareness.

6.2.1 Increase Research, Demonstration and Development

It was mentioned that to reduce the energy efficiency penalty and high investment costs, more research and development is required. Demonstration projects are required as well as more academic research. All individual parts of the CCS chain are known and tested, but a complete chain has never been proven on a larger scale. Increase experience with testing the complete chain is considered important.

In addition, since experience with storage is limited, monitoring and on site testing during demonstration project are needed to improve the insights into the storage capacities and the safety of storage sites.

Summarising this group of actions would focus on the following criteria:

- Clean: efficiency improvement;
- Safety: testing storage sites and develop monitoring systems;
- Competitiveness: reduce the high investment costs, improve efficiency entire CCS chain.

Research institutions need to define and develop required research proposals, (partly) funded by the national government. Demonstration/pilot projects need to be carried out by the market players, industry but financed (partly) by the government.

6.2.2 Include CCS in Policy portfolio

The next action identified was to include CCS in a policy portfolio national and international and include CCS in current or new legal frameworks. CCS is only implemented at a large scale when there is a price for CO2. An incentive for the investment of the market players for CCS needs to be created. The inclusion of CCS in the EU Emissions Trading Schemes is therefore indispensable. The current ETS system is not yet clear on the inclusion of CCS and this need to be changed. One of the main requirements is the development of monitoring, reporting and verification standards for CCS project which needs to be accepted at the European level. Similar remarks apply for the inclusion of CCS in the Clean Development Mechanism.

At a national scale it was mentioned that a subsidy like a feed in tariff needs to be implemented. These subsidies should be guaranteed at the longer term to create security for market players. However, it is important to note that subsidies of this kind will most likely be opposed by environmental NGO's. In fact, one of the main points that has been made by NGOs such as Greenpeace and the Netherlands Society for Nature and Environment is that subsidies should not be given for the implementation of CCS (with exception of subsides for R&D and demos). This is based on the principle that the polluter should bear the financial weight (i.e. energy and chemical companies), and subsidies should be set aside for sustainable energy initiatives (i.e. primarily low-impact renewable energy, energy efficiency and conservation) for which public investment is needed to mobilize large-scale deployment across the economy.

The Netherlands Society for Nature and Environment also mentioned that CCS should be presented as one option within a portfolio of greenhouse gas mitigation options next to renewable energy sources. This portfolio (and not CCS as such) should be the main framework of the greenhouse gas mitigation policy.

In current legislation on waste or treatment of offshore areas, storage of CO_2 is not included. This needs to be included. In addition, to guarantee safety and storage over the longer period of time, monitoring is of high important. This needs to be institutionalised including the development of standards. The responsibilities related to the impacts of CO_2 leakage should also be clear before starting.

Summarising this group of actions would focus on:

- Competitiveness: provide some kind of financial guarantees to lower the threshold for investment in CCS and reduce vulnerability to the political decision making.
- Safety: develop and implement (regulate) a reporting, monitoring and verification system for CCS systems, in particular for storage of CO_2.
- Justice: increase technological development by means of CDM projects.

The implementation in EU ETS, CDM, subsidies and a legal approval as well as the standards for monitoring is the responsibility for the national and international governmental bodies.

6.2.3 Raise Public Awareness and Improve Public Acceptance

The potential acceptance or rejection of CCS by the public was considered crucial for the long term large scale implementation of CCS. It was mentioned that CCS might be considered as a technocratic option to reduce greenhouse gas emissions. When communicating CCS to a broader public, the most important message should be that all options and measures are required when combating climate change.
It was also mentioned that a stepwise introduction of CCS might be an approach to gradually get more acquainted with the technology.

Local resistance can be encountered related to infrastructural impacts. When starting implementing CCS (including demonstration projects), attention should be paid to reduce spatial impacts. When informing the public an open communication is important,

Who should play what role in public awareness of CCS? The focus was put at the awareness of the general public, not stakeholders involved in a specific CCS project. For awareness of the general public, it was concluded that all stakeholders are important and there is not one single stakeholder to be mainly responsible. However, stakeholders from the government and scientific community have highlighted the importance of NGO support when informing the general public. The support position of different actors could induce but it could also minimize conflicts[23]. Environmental NGOs have a crucial role in the public debate and they need to be actively involved in the decision making process from the start.

6.3 Most Urgent Actions

So far, the list of actions and responsible actors obtained during the policy labs has a rather general character. In order to get a more concrete list of actions, we used the in-depth interviews to obtain a list of actions that needs to be undertaking in the coming two years. The results are shown in Table 5. Interestingly one of the most important concerns named during the policy labs and survey ("CCS is only reducing CO_2 emissions and other environmental problems as emissions of NOx, SO_2, aerosols, particulate matter, are not addressed") was not further discussed in terms of actions. This may be due to the fact that the option is designed to capture CO_2 and hence this concern is perceived as a necessary trade-off.

It can be seen that for an efficient implementation and for increased competitiveness of CCS, mainly policy makers and research institutions should take early actions. Policy makers need to come up with better guarantee for a sufficient high price for CO_2 and are considered responsible for the standards and guidelines for risk management and monitoring. There is a task for research institutions to improve the efficiency of CCS and conduct analyses on the costs and cost reduction potential for CCS. There is a role for industry to increase their knowledge on the implementation of the entire chain by starting demonstration projects. The improvement of public acceptance is seen as an action that involves all stakeholders.

[23] A typical example of the distrust of the citizen on a technology is found in the Nuclear energy debate.

Table 5: The most urgent actions for the coming two years including the responsible actor as mentioned in the in depth interviews.

Actions	Responsible actor	Related criteria
Inclusion of CCS in EU ETS system	Government (international)	Competitiveness
Insight when CCS could be competitive under what CO_2 price regime	Research institutions	Competitiveness
Develop standards related to safety and monitoring as well as institutionalised responsibilities and liabilities.	Government (international)	Safe
Demonstration projects	Industry	Clean, Safe, Competitiveness
Include CCS in legal frameworks (national and international ,e.g. London Convention, ETS, CDM)	Government (international)	Safe, Competitiveness, Justice
Public awareness	All stakeholders	Public awareness
Research on efficiency improvements	Research institutions (academic, national, industrial)	Clean

7 Discussion, Conclusions and Recommendations

Carbon Capture and Storage is a mitigation option that has gained increasing interest over the past years. It is believed to be an interesting option because it can be applied in short and intermediate terms, i.e. the technology is available; the CO_2 storage capacity is large and it can be applied cost-effectively. Nevertheless, there is also some debate on CCS as it is considered to bear less attractive features, The energy system would keep relying on fossil fuels (security of supply issue), CCS may diverse attention and resources from energy efficiency improvement and renewable energy sources or may lead to (sub)optimal (infrastructure) solutions (lock-in).

Whether CCS can contribute towards development of a sustainable energy system is an important but complex policy question. In this study a start has been made to develop a sustainability framework. Using the framework a (more objective) consideration can be made if and how CCS can contribute to a sustainable energy system. The framework has been developed in close discussion with experts on sustainability, and with the relevant experts and actors with respect to CCS.

In the study the following steps were performed:

- Compilation of a set of criteria, which form the basic elements of the framework;
- Identification of the concerns for implementation of CCS with respect to its contribution to a sustainable energy system. This has been done per criteria;
- Prioritising the criteria, and the concerns;
- Identification of required actions to address the concerns. For each action also the actors have been identified who should be the principal responsible to initiate the action.

Based on literature search, discussion, interviews and workshops the following comprehensive set of criteria was developed:

- Clean;
- Safety;
- Justice;
- Flexibility;
- Continuity;
- Independence;
- Competitive position or affordable;
- Public acceptance;
- Reliability.

For each criterion, experts and stakeholders have identified a list with, in total, 36 concerns. Each concern poses a possible barrier for the implementation of CCS in a sustainable way. The concerns that were selected as the most worrisome by the respondents of the survey are:

- Whether or not there will be sufficient public acceptance for CCS;
- The energy system will remain depending on fossil fuels;
- The costs will have negative effects on our standards of living;
- CCS diverts attention away from energy saving and renewables;
- Other environmental problems of energy supply are not addressed by CCS like local air pollution;
- The energy system may become dependent on regions with large amounts of storage capacity;
- We may place a burden on future generations because of the CO_2 stored underground;
- (Seen from the Dutch perspective) other countries/regions will not implement CCS.

Analysis shows that concerns related with the criteria **clean**, **flexibility**, **justice**, **competitiveness** and **public acceptance** were considered most relevant.
The selection of concerns depends on the organization the respondents work for. This is an important point since it implies that for balanced and unbiased evaluation of sustainability of energy supply systems with CCS, heterogeneity in the stakeholder group that participate in the decision-making process should be guaranteed.

In stakeholder consultations and through interviews, we have discussed the actions required to overcome the concerns. These actions can be categories in three groups:

- Increase research and development;
- Include CCS in a policy portfolio;
- Raise public awareness.

The government is generally seen as the most relevant stakeholder for the first phase of implementation of CCS (in a sustainable way). Besides some small niche markets, CCS will add to the costs of energy production and will therefore need a strong policy support. Early actions should include (per stakeholder group):

Government
- Arrange the inclusion of CCS in EU ETS system;
- Support research, development and demonstration to increase environmental performance and reduce costs of CCS;
- Develop standards related to safety and monitoring ;
- Include CCS in legal and regulatory frameworks (e.g. London Convention, ETS, CDM) and adjust current legislation to make CCS possible, especially regarding storage;
- Provide (financial) guarantees for investment in CCS, especially in the start-up phase of the implementation.

Industry:
- Increase research and development into CCS and develop demonstration projects (including the entire CCS chain)
- Develop risk assessment and monitoring protocols

Research Institutions:
- Increase the insight regarding when CCS could be economical and competitive;
- Conduct research to improve the capture efficiency and storage safety, and develop risk assessment and monitoring protocols.

All stakeholders:
- Improve the public awareness related to CCS.

The sustainability framework as described in this report can be used for several policy making processes:
- Provide an overview of criteria related to the implementation of CCS in a sustainable energy system;
- Prioritising concerns and prioritising related actions related to these concerns ;
- Provide a framework for further policies and measures related to CCS.

So far, we made an inventory to the position of different stakeholders respect to CCS, defined sustainability criteria, identified main concerns for CCS and provide a list of actions that should take place in the next years. Next steps include the conversion of the criteria into quantifiable indicators that can be used to evaluate possible implementation strategies for large scale deployment of CCS systems. Further research is also necessary to establish weights that can be assigned to the different sustainability criteria and indicators and which are necessary when performing any kind of dynamic system analysis.

Appendix 1: overview of studies on sustainable energy system

Author	Year	Scope	Definition of SD/SES	Aspects emphasized	Additional comments
Afgan et al.	1998	Overview of SED and its important aspects	*Based on Brutland's. *In addition: SD focuses on the role and the use of science in supporting the prudent management of the environment and for the survival and future development of humanity.	*Optimal energy design. *Knowledge dissemination. *Science and technology development. *Exploration of new resources.	*The design of a sustainable energy system should: -Mix the energy concept with the optimization of local resources, urban and industrial planning with transport optimization, and the use of renewable sources. -Select the structure and design parameters to minimize the energy cost under conditions associated with available materials, financial resources, protection of the environment and governmental regulations, together with safety, reliability, availability and maintainability of the systems. -Design the energy system, plant and equipment with optimal use of information technology in order to prevent duplications, prevent operational malfunction and assure rational maintenance schedule. *This is one of the few studies which focus a whole section on the development of education as a basis requirement for the development of a SES.
Afgan et al.	2000	Development of sustainability indicators for an energy system using a small island as case study.	No specified.	*Resource aspect. *Environmental aspect. *Social aspect. *Economic aspect.	*The definition of sustainability indicators for energy should reflect the following aspects: -It should reflect the sustainability concept. -It should be defined with indicators which can be measured as physical parameters. -It should be based on timely information. -It should be based on reliable information.

					-It should reflect a strategic view. -It should give the possibility to perform optimisation of the system and it should reflect longevity of design.
Afgan et al.	2004	Multi-criteria assessment of hydrogen energy systems.	No specified.	*For evaluating the hydrogen system the following indicators were used: -Performance indicator: composed of efficiency, total energy cost, capital cost and lifetime. -Market indicator: refers to the market penetration. Composed of euro market for the perspective system and world market for the same system.	*The development and selection of indicators require parameters related to the reliability, appropriateness, practicality and limitation of measurement. *This study shows that the decision making process strongly depends on the priority give to the specific indicators used. *Calls the attention that although specifying the need for education as a basis for SED (article of 1998) when looking at a specific energy system such as hydrogen, education is not taken into account at all.
				-Environmental indicator: CO_2, N_2O and Kyoto indicator -Social indicator: area and new jobs.	
Bradley	1999	Analysis of the sustainability of conventional energy sources in comparison with renewables.	No specified.	*Technological infrastructure. *Energy supply security. *Price affordability.	*The wakening scientific case for dangerous climate change makes the global warming issue a transient political problem for fossil fuels rather than a death warrant.
Bruggink and van der Zwaan	2001	Potential role of nuclear energy in establishing sustainable energy paths.	An energy system can be viewed as sustainable if it succeeds in providing the energy to allow sufficient and equitable economic growth without seriously compromising the	*Risks management. *Market performance. *Energy supply security. *Resource availability. *Environmental impacts. *Technological infrastructure.	*The sustainability of a particular energy system or energy path is in principle not an objectively measurable qualification of an empirical nature. Measuring the sustainability of a particular energy technologies with a set of economic, environmental and social indicators is not an objective, empirical task but a normative, subjective task involving weighting indicators

			environment.	*Public opinion.	that are based on unrelated units of measurement or similar qualitative assessments. *Indicators of sustainability are characterized by fundamental uncertainties. SD has therefore to do a lot with choosing for one kind of risk rather than another.
European Commission	?	Indicators for sustainable energy systems.	Brundtland' definition.	*Reducing greenhouses and pollutant emissions (Kyoto). *Increasing the security of energy supplies. *Improving energy efficiency. *Increasing the use of renewable energy. *Enhancing the competitiveness of the European industry. *Improving the quality of life of both within EU and globally.	*Criteria for selecting indicators: -An indicator should capture the essence of the problem and have a clear and accepted normative interpretation. -An indicator should be robust and statistically validated. -An indicator should be responsive to policy interventions but not subject to manipulation. -An indicator should be measurable in a sufficiently comparable way across Member States, and comparable as far as practicable with the standards applied internationally by the UN and the OECD. -An indicator should be timely and susceptible to revision. -The measure of an indicator should not impose on Member States, on enterprises, nor on the Union's citizens a burden disproportionate to its benefits.
Frey and Linke	2002	Hydropower as a sustainable energy resource.	What sustainability addresses is the need for society to consider energy consumption in a way that does not exceed the environmental	*Preservation of the resource for future use. *The environment's absorptive capacity of negative impacts.	*Sustainability of hydropower would depend on whether sustainability is seen as an absolute concept, where a process is either sustainable or not, or whether it allows for a more flexible definition, where a process can have some positive and negative
			capacity to absorb the effects, without permanent damage.		sustainability characteristics, and what counts is the balance of the two.
Frische and Matthes	2002	Analysis of a global energy strategy for SES.	*Based on the following principles: -At a minimum, a sustainable	*Energy services should be sustained and expanded by energy efficiency improvements, renew-	*Some conclusions on a global level regarding sustainability: -Sustainability in the energy sector can only be achieved if energy efficiency is increased significantly

			energy policy must sufficiently supply the basic energy service needs of a growing world population and future generations. -Equal opportunities to access basic energy services must be guaranteed for all society members. -Environmental burdens must be limited to a level ensuring the life-support functions of nature in the long-term.	able and low polluting/low risk technologies. *Utilization of renewable energies should not exceed their regeneration rate. *Environmental burdens should be limited to levels no exceeding the regeneration and/or adaptation capabilities of ecosystems. *Utilization of energy technologies with high risk should be minimized *Energy services should be supply at the least cost, taking into account their externalities. *Conflicting management should follow democratic principles.	-Renewable energy sources must play a much bigger role in the decades to come. -Fossil fuel energy sources must be substituted with zero emission options in this century. A large step in this direction must be made during the next five decades -High-risk technologies, like nuclear energy, do not meet the requirements of a sustainable energy system, and should be phased out in the transition period * A global energy strategy will require: -The definition of targets for energy related emission limits, future contribution of renewables, development of energy productivity and performance standards. -The establishment of guidelines for the assessment of environmental and social effects for all energy systems. -The obligation to develop global, regional, local strategic plans for energy efficiency improvements, safety controls, waste management and emission reductions for all energy carriers and their production chain. -The promotion of exchange of technology, know-how, education, information, data. -The improvement of existing and the development of new financial instruments and investment mechanisms.
German Council for SD	2003	Coal policy and SD.	*SED is defined in terms of the following goals: -A reliable supply of energy (and energy services) without supply disruptions must be secured. -The energy services must be provided in a competitive way	*Medium and long term requirements for climate protection.	*The biggest challenge in coal is to meet the long-term climate protection goals in order to prevent dangerous climate change. Coal can only make an important contribution to the sustainable energy industry, if the CO_2 released during its consumption is minimised or does not reach the atmosphere at all. * In all probability, renewable energies will still not supply the necessary volume of energy service by the mid 20's. Therefore, the capture and storage of CO_2 could be an important bridge in

			that supports the momentum of economic growth and employment. -Sustainable energy consumption		the transition from the age of fossil fuels to that of renewable energies. *Factors that particularly need to be guaranteed for large-scale
			and supply protects human health, helps slow down climate change, protects the environment and safeguards the ecological foundations for life on earth.		CO_2 storage are: -High storage security for several tens of thousands of years and no leakages. -No counterproductive consequences on ecological systems and groundwater. -No security risks, such as the sudden release of large amounts of CO_2. -No conflicting uses (storage locations, further exploitations of deposits).
Giampetro et al.	2006	Quality assurance of multi-criteria analysis.	No specified.	*Science and governance.	*The article provides guidelines for the development of sustainability criteria in the context of normal and post-normal science. *Multi-criteria analysis of sustainability should be obtained through participatory procedures of integrated assessment *The new role of scientists should be that of facilitating the negotiation among stakeholders by clarifying the nature and possible consequences of trade-offs in relation to non-equivalent criteria of quality, and in face of uncertainty on predictions.
Gosselink	2002	Sustainable hydrogen	No specified.	*Diminution of the ecological footprint.	*Emphasises the role of innovation. Focus attention on the development of sustainable energy chains based on sunlight.
Graβl et al.	2004	Sustainability of energy systems.	A sustainable energy systems should: -Protect natural life-support systems (compliance with ecological guard rails). -Secure access to modern en-	*Guard rails: minimum requirements that need to be meet if the sustainability principle is to be adhered to: -Climate protection (a temperature rise of no more than 0.2ºC per	*In this book the minimum requirements (guard rails) are used to evaluate the sustainability of future energy paths. *Principles for a transformation towards sustainability: -Promote good governance. -Assume common but differentiated responsibility. -Obey the precautionary principle.

			ergy worldwide for all (compliance with socio-economic guard rails).	decade). -Sustainable land use (no more than 3% of the global land surface should be used for bio-energy crops or terrestrial CO_2 sequestration). -Protection of rivers and their catchments areas (10-20% of riverine ecosystem should be reserved for nature conservation, hydroelectricity can only be expanded to a limit extent). -Protection of marine ecosystems	-Observe the subsidiary principle (competences for tasks must in principle first be developed to the lowest level). -Pursue regional approaches. -Create a level playing field for all energy carriers. -Shape energy liberalization sustainably. -Tap transformation potentials swiftly. -Harness social and economic forces.
				(use of ocean to sequester CO_2 is not tolerable). -Prevention of atmospheric air pollution (critical levels of air pollution are not tolerable). -Access to advance energy for all. -Meeting the individual minimum requirements for advance energy (by the year 2020 at the latest, everyone should have at least 500 kWh final energy per person. By 2050 at least 700 kWh). -Limiting the proportion of income expended for energy. -Minimum macroeconomic development. -Keeping risk within a normal range.	

				-Preventing disease caused by energy use.	
Hammond	2004	Link between thermodynamic analysis and SD.	*Brundtlands definition plus 'the Nature step' conditions: -Finite materials (including fossil fuels) should not be extracted at a faster rate than they can be redeposited in the Earth's crush -Artificial materials should not be produced at a faster rate that they can be broken down by nature -The biodiversity of ecosystems should be maintained -Basic human needs must be met in an equitable and efficient matter.	*Resource productivity (the technology element). *Environmental pollution.	
Hennicke and Fischedick	2006	Role of hydrogen in long run sustainable energy scenarios.	Defined on terms of the following principles: -Access to energy services for all and fair partnerships with developing countries.	*Decoupling the increase of living standards and energy services as much as possible from the use of non-renewable and risky energy supply.	*The article focuses on the German situation based on backcasting scenarios. *It points out that: -Sustainable energy systems presuppose advance efficiency. -Substantial change of electricity supply is needed.
			-Effective conservation of resources and protection of environment, climate and health. -Social acceptability now and in accordance with the needs of later generations. -Low risks, fault tolerance and contribution to mitigate inter-		-Economics make hydrogen based on renewables a long-term option.

			national conflicts. -Cost-effectiveness (including external costs).		
Hui	1997	Renewables as a leading option for sustainability.	Brundtland's definition.	*Social sustainability: equity, empowerment, accessibility, participation, cultural identity, institutional stability. *Environmental sustainability: Eco-system integrity, carrying capacity, bio-diversity. *Economic sustainability: growth, development, productivity and trickle down.	
IAEA	2005	Development of energy indicators for SD.	SD is essentially about improving quality of life in a way that can be sustained, economically and environmentally, over the long term supported by the institutional structure of the country.	*Aspects emphasised by dimension: -Social dimension: equity and health. -Economic: use and production patterns and security. -Environmental: atmosphere, water and land. -Institutional.	*Institutional questions are largely considered to be responses and not readily quantified as indicators: therefore this aspect is not further dealt with in the article. *Most pressing issues (also identified at CSD-9): improving affordability and accessibility to modern energy services for the rural and urban poor as well as promoting less wasteful use of energy resources by the rich.
ICC	2001	Importance of energy for SD-climate change challenges.	Brundtland's definition.	*Development, commercialization, and wide spread dissemination of technologies.	*Achieving a 'sustainable energy future' should be understood to embrace economic /commercial sustainability as well as environmental and social concerns. This is not an ultimate destination, but rather a journey of continuous improvement. It should be understood as a flexible objective, with different pathways depending on local and national circumstances and priorities.
IEA	2001	Sustainability of future energy	Economic sustainability encompasses the requirements	*The balance of the three dimensions of sustainable development	*Globalisation and the increasing interconnectedness between countries are important aspects of several sustainability-related

		systems.	for strong and durable economic	is explored by considering it in relation	energy issues. Globalisation also poses the question of the scale
			growth, such as preserving financial stability and a low and stable inflationary environment. Environmental sustainability focuses on the stability of biological and physical systems and on preserving access to a healthy environment. Social sustainability emphasises the importance of well functioning labour markets and high employment, of adaptability to major demographic changes, of stability in social and cultural systems, of equity and of democratic participation in decision-making. SD emphasises the links among these three dimensions, their complementarities and the need for balancing them when conflicts arise.	to three policy options: -The maintenance of per capita incomes through time. -The internalisation of energy externalities. -The removal of energy subsidies.	on which SD in the energy sector should be pursued. *There are two kinds of sustainability: -Weak sustainability: when trade-offs between competing sustainability objectives are acceptable. Sustainability can be viewed as enhanced if the gain in one dimension more than offsets the loss in another. -Strong sustainability: when the potential for substituting one goal for another is absent. In general where strong sustainability applies, minimum benchmarks need to be set (e.g. a country can decide that a certain percentage of the population must have access to electricity). The principle of weak sustainability can be helpful in clarifying the nature of choices available in certain situations. Where it is acceptable, weak sustainability allows for arrangements that can advance SD efficiently and consistently. *Large-scale risk in the energy sector can lead to irreversible effects that would constrain the economic, social and environmental options of future generations. To avoid or limit such risk, the energy system should be robust and resilient in response to shocks and errors. In the medium and long term, diversification is the key measure to reducing risks and to maintaining economic activity. *Pursuing "zero risk" in relation to many objectives would imply impossibly high costs and thus endanger the economic dimension of sustainability.
Jaccard	2005	Analyses of the fossil fuels' role in the quest for a SES.	To be sustainable, an energy system must meet two conditions: -First, the energy system must	*Resource availability. *Capability of ecosystems to assimilate waste (materials and energy).	*The sustainability of an energy system depends on its ability to be clean and enduring. *The definition of sustainability refers to the energy system, not individual primary energy resources. Individual compo-

			have good prospects for enduring indefinitely in terms of the type and level of energy services provided. Moreover, given the significant energy use that will be required to improve human well being in much of the developing country-the size of the global energy system would ideally grow substantially over this century.	*Prevention of emissions. *Extreme event risk to the environment and humans. *Path dependence. *Projected costs.	nents of that system need not endure as long as the system as a whole does. *The definition focuses on the type and level of services provided, including the expanded services that are needed to improve dramatically the lives of the less-well-off people on the planet. *Four common indicators of the environmental and human sustainability of an energy system are: indoor air quality, urban air quality, regional acid emissions and greenhouse gas
			-Second, extraction, transformation, transport and consumption of energy must be benign to people and ecosystems. Both, the known, cumulative impacts of the energy system must be negligible and any extraordinary risks it poses must be extremely unlikely, and ones from which the system could recover within a reasonable period of time, perhaps aided by rehabilitation efforts.		emissions.
Jeffersson	2006	Sustainable energy development.	Development that manages to balance present and future needs	*Four key elements: -Sufficient growth of energy supplies to meet human needs (including accommodating relatively rapid growth in developing coun-	*Article examines this fourth points. *Trends of the last 20 years point out no change in the development path.

				tries). -Energy efficiency and conservation measures, in order to minimize waste of primary resources. -Addressing public health and safety issues where they arise in the use of energy resources. -Protection of the biosphere and prevention of more localised forms of pollution.	
Kessler	2002	Nuclear energy as a sustainable energy source.	Brundtland's definition.	*No short time depletion of resources. *Extremely low emissions of noxious or radioactive substances. *Extremely low risk of the energy system for the population	*For the nuclear energy system sustainability is translated into: -Almost zero release of radioactivity from the nuclear power and from the plants of the fuel cycle during normal operation. -Extremely low release of radioactivity from the nuclear plant during e.g. a core melt down accident. No emergency measures shall be necessary outside the plant in such cases. -The present issue of a very long term high active waste disposal problem should be transformed into a few hundred years problem.
Li	2005	Diversification as a key component	Even though each energy system has its own adverse impact on a	*Energy diversity *Ecological damage	*Problem with current energy systems: dominance of a single-energy system. Hence, energy diversity is the key for SD and
		of SED.	particular aspect of the environment, if that impact is small enough to allow for the environment to tolerate or withstand the impact, then that particular energy system may be considered sustainable.		energy security.
Ludwig	1997	Development of a methodology	No specified.	*Duration (resource availability, level of technology, social fac-	*The authors propose the use of fuzzy logic to assess technologies in terms of sustainability.

		to compare energy conversion technologies, taking into account entire environmental impacts.		tors). *Ecological relevance (climate impact, area demand and risks).	
Maldonado and Marquez	1996	Analysis of technology assessment for disconnected energy systems and organization structures in the context of SED.	No specified, defined in term of aspects.	*An energy strategy consistent with SD entails: -Reliable, timely and cost-effective supply. -Reducing system vulnerability. -Minimum environmental impacts. -Equity oriented energy supply.	
Matson and Carasso	1999	Ethics as an imperative for energy technologies.	Based on Brundtland's definition.	*Intergeneration equity. *Intra-generational equity.	*The term technology includes all processes from initial exploration, research and development, through the economic life of the conversion process, to the disposal of the conversion plant and any remaining waste. *Discounting is a fundamental assumption to the workings of the neoclassical economic model, but it is diametrically opposed to the idea of sustainability, because it favours the present.
Matthes and Cames	2002	Future sustainable energy policy paths for Germany.	No specified.	*Security of supply (technical and organization dependability and susceptibility to disruption). *Fair pricing. *Environmental compatibility (atmospheric contaminants, greenhouse gasees and risks of nuclear power).	*The central challenge from the ecological perspective is the development of a strategy of risk minimization (warming of the earth's atmosphere is kept within tolerable limits and, at the same time, the renunciation of the use of nuclear power).

Pop-Jordanov	2003	Inclusion of negentropic perspective when looking at SES.	Based on Brundtland's.	*Scientific and technological knowledge.	*Introduction of 'mental indicators' to the traditional set of indicators for SES. The authors propose to introduce indicators for: mental resources and capacities; information overflow and organizational attention deficit; occupational psychosomatic disorders; transparency and morality and brain-drain.
PowerClean et al.	2004	Sustainability of fossil fuels.	No specified.	*Security of supply (fuel flexibility). *Reduction of greenhouse gas emissions. *Competitiveness.	*A strategy for the continued used of fossil fuels should: -Consider time frames from now to 2030 and beyond -Be broad in nature (embrace fuel flexibility and increase efficiency). -Embrace all aspects of technology development and deployment. -Include the non-technical issues linked to the deployment of the technology.
Scalon et al.	2004	Guidelines to promote the sustainability assessment of new wind projects.	Brundtland's definition.	*Sustainability aspects in assessing new wind projects: -Need for the project. -Economic viability and planned monitoring of economic performance. -Availability and costs of resources over the projected life of the facility. -Appropriateness of the technology. -Energy payback ratio. -Distribution and sustainability of economic benefits. -Poverty reduction through flow on benefits to local communities. -Community support. -Safety issues and hazards.	*Good governance within each country, and at the international level, is an essential prerequisite for SD. *National and regional policies should include a Strategic Assessment Process, which should incorporate assessment of cumulative impacts, the determination of marine and land use effects and environmental priorities, as well as goals for economic growth. *Policies should be framed in the context of the global needs to reduce greenhouse gas emissions, security of domestic supply, public and social participation and promotion of clean renewable options. *The following considerations should be taken into account when determining the social aspect of sustainability: - Impacts on the communities, stakeholder and the environment are identified. -Stakeholders are informed about the project and the implications for them. -The proposal project is the best alternative, following the con-

				-Environmental impact assessment. -Waste products, land use. -Regulatory compliance.	sideration of relevant stakeholders. -A negotiated and agreed outcome is achieved wherever is possible. -The community and environmental resources are managed in a sustainable way, and on-going monitoring and liaison with local community groups continues through the life of the project.
Spalding-Fecher et al.	2003	Development of indicators for	Brundtland's definition.	*Access to energy. *Global and local environmental	
		sustainable energy systems using South Africa as case study.		impacts. *Relisence to external trade imports. *Burden of energy investments on the public sector.	
Spalding-Fecher et al.	2005	Analysis of the World Summit on Sustainable Development (WSSD) on relation with energy.	No specified.	*Access to modern energy: most critical energy use for developing countries *The need for cleaner energy.	* Challenge for the energy sector is twofold: first, to dramatically increase access to affordable, modern energy services in countries that lack them, especially for poor communities; and secondly, to find the mix of energy sources, technologies, policies and behavioural changes that will reduce the adverse environmental impacts of providing necessary energy services. *In order to carry out the goals and time-frames of WSSD, there is a need for a programme that would take charge of 4 groups of functions: i) agreeing on goals and time-tables and monitoring them; ii) disbursing funds for investment in clean energy and energy access; iii) providing additional technical support-capacity building; iv) co-ordinating and/or sharing information about the activities of existing institutions.
Tasdemiroglu	1988	Sustainability of fossil fuels in Turkey.	No specified.	*Sustainability of production (based on the comparison of production vs reserves).	
Turkenburg	1996	Sustainability of	Based on Brundtland's. A SES	*More efficient use of energy and	

		energy systems.	should not endanger the quality of life of present and future generations, and should not exceed the carrying capacity of supporting ecosystems.	energy-intensive materials. *Increased use of renewable sources of energy. *More efficient (and clean) production of fossil fuels. *Fuel substitution, from high-carbon to low-carbon and no-carbon based fuels.	
Turkenburg	1997	Characteristics of a SES and the role of CCS.	A SES should not endanger the quality of life of present and future generations and should not exceed the carrying capacity of supporting ecosystems.	*Costs. *Social acceptance. *Environmental soundness.	*It is important that the development of short term options to fulfil out energy needs in an environmental sound way does not hinder the development options that in the longer term contribute better to sustainability.
UNDP	2003	Policy agenda for SED.	Brundtland' definition.		*The challenge of sustainability is to address the following issues: -Modern fuels and electricity are not universally accessible.
				*Increase the efficiency of energy; increasing reliance on renewable sources of energy and/or developing new technologies.	-The current energy system is not sufficiently reliable or affordable to support widespread economic growth -Negative local, regional, and global environmental impacts of energy production, and use threaten the health and well being of current and future generations.
UNDP	2004	World energy assessment.	By definition, a sustainable energy systems must support both human and ecosystem health over the long term. Thus, goals on tolerable emissions should be long term and take into account the public's tendency to demand more health and environmental protection as prosperity increases.	*The key issues for energy availability from a resource point of view are: -Whether technologies to extract, harvest and convert the vast energy stocks and flows can be developed in time to meet growing demand for energy. -Whether the technologies have adverse implications.	*The context for sustainable energy: increasing globalisation; shifting governmental responsibilities; restructuring and liberalising energy markets; the emerging information technology revolution; increased public participation in decision making. *Fossil energy technologies should evolve toward the long term goal of near-zero air pollutant and GHG emissions without complicated end-of-pipe control technologies if sustainability goals are to be met. *A prerequisite for achieving an energy future compatible with sustainable development objectives is finding ways to acceler-

				-Whether the energy services generated from threes resources will be affordable.	ate progress for new technologies along the innovation chain.
Vellinga	2000	Sustainability of the energy system.	To explore the ways on which energy needs can be met in a way that does not cause serious and/or irreversible environmental degradation.	*The article focuses on three perspectives: consumer, producer's and the governmental (incentives).	* The article emphasises the need for a pluralistic approach (introduction of a broad set of options).
Weidou and Johansson	2004	Energy for SD in China.	No specified.	*Four key objectives: -To deliver the power needed for economic growth and sustainable development. -To ensure security of energy supply. -To ensure that energy supply and use are conducted in ways that safeguard public health and the environment. -To achieve an equitable distribution of energy services throughout the nations.	*Elements of the strategy to achieve SD of the energy system are: -Continued strong emphasis on energy efficiency in all sectors. -Push away from smoke-generating direct combustion towards cleaner energy carriers. -Modernization of coal conversion through oxygen-blown gasification with CO_2 sequestration. -Increase supply of energy of sources such wind, solar and biomass. -Find commercially viable alternatives to import oil and products for transportation.
Wellmer and Becker-Platen	2002	SD and exploitation of mineral and energy	On addition to Brundtland's definition, SD also requires the maintenance, rational use and	*Regeneration of resources. *Efficiency. *Ecological damage minimization.	*General rules for implementing sustainability: -The rate of consumption of renewable resources should not exceed the rate at which they can be regenerated.
		resources.	enhancement of the natural resource base that underpins ecological resilience and economic growth, and that implies progress towards international equity.		-The consumption of non-renewable resources should not exceed the amount that can be replaced by functionally equivalent resources or by other solutions. -Material and energy input into the environment should not exceed the capacity of the environment to absorb them with minimal detrimental effects. -The rate of anthropogenic input and environmental interfer-

					ence should be measured against the time required for natural processes to react to and cope with environmental damage -Hazards and unacceptable risks to human health caused by human activities are to be avoided.
World Energy Council	2005	To examine the challenges and opportunities of delivering energy sustainably.	A SES should deliver sufficient energy for equitable and secure social and economic development while avoiding environmental impacts, which would compromise the capacity of future generations to enjoy the fruits of that development.	*Energy diversity and energy efficiency. *Access to energy worldwide (energy infrastructure investment and cost-reflective prices). *Supply reliability. *Addressing climate change. *Technological innovation and development. *public understanding and trust.	*The keys to delivering energy sustainability are: -Keep all energy options open. -Ensure the necessary investment in energy infrastructure. -Adopt a pragmatic approach to market reform. -Place priority on the measures needed to ensure reliability of supply. -Promote regional integration of energy supply systems. -Exploit the win-win opportunities of emerging climate change. -Ensure technical innovation. -Foster and sustain public understanding and trust.

Bibliography of the appendix 1:

-Afgan N.H., Al Gobaisi A., Carvalho M.,G., Cumo M., 1998. Sustainable energy development. Renewable and sustainable energy reviews 2, 235-286.

-Afgan N.H., Carvalho M.G., Honavov N.V., 2000. Energy system assessment with sustainability indicators. Energy Policy 28, 603-612.

-Afgan N., Carvalho M.G., 2004. Sustainability assessment of hydrogen energy systems. International Journal of Hydrogen Energy 29, 1327-1342.

-Bradley R.L., 1999. The increasing sustainability of conventional energy. Policy Analysis 341, 1-40.

-Bruggink J.J.C., van der Zwaan B.C.C., 2001. The role of nuclear energy in establishing sustainable energy paths. ECN-C-01-109. ECN, Vrije Universiteit Amsterdam.

-European Comission, SP1, sustainable energy systems, Brussels.

-Frey G.W., Linke D.M., 2002. Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. Energy policy 30, 1261-1265.

-Fritsche U.R., Matthes F.C., 2002. Changing course. A contribution to a global energy strategy. An Öko institute policy paper. World Summit paper No 22, Berlin.

-German Council for Sustainable Development, 2003. The perspectives for coal in a sustainable energy industry. Guidelines for a modern coal policy and the promotion of innovation, September.

-Giampetro M., Mayumi K., Munda G., 2006. Integrated assessment and energy analysis: Quality assurance in multicriteria analysis of sustainability. Energy 31, 59-86.

-Gosselink J.W., 2002. Pathways to a more sustainable production of energy: sustainable hydrogen- a research objective for Shell. International Journal of Hydrogen energy 27, 1125-1229.

-Graβl H., Kokott J., Kulessa M., Luther J., Nuscheler F., Sauerborn R., Schellnhuber H.J., Schuber R., Schulze E., 2004. World in transition. Towards sustainable energy systems. German Advisory council on global change, Earthscan: UK.

-Hammond G.P., 2004. Towards sustainability: energy efficiency, thermodynamic analysis and the two cultures. Energy Policy 32, 1789-1798.

-Hennicke P., Fischedick M., 2006. Towards sustainable energy systems: the related role of hydrogen. Energy policy 34, 1260-1270.

-Hui S.C., 1997. From renewable energy to sustainability: the challenge for Hong-Kong. In: proceeding of the POLMET '97 Conference, 25-25 November, Hong Kong Institution of Engineers, Hong Kong, 351-358.

-International Atomic Energy Agency (IAEA), 2005. Energy indicators for sustainable development: guidelines and methodologies. IAEA, UNDP, IEA, Eurostat, European Environmental Agency, Vienna.

-International Chamber of Commerce (ICC), Energy Commission, 2001. Briefing paper submitted to the UN Commission on SD, 9th session, New York 16-17 April.

-International Energy Agency (IEA), 2001. Toward a sustainable energy future. Highlights. IEA-OECD, Paris.

-Jaccard M., 2005. Sustainable fossil fuels. The unusual suspect in the quest for clean and enduring energy. Cambridge university press, UK.
-Jefferson M., 2006. Sustainable energy development: performance and prospects. Renewable energy 31, 571-582.
-Kessler G., 2002. Requirements for nuclear energy in the 21st century. Nuclear energy as a sustainable energy source. Progress in nuclear energy 40, 3-4, 309-325.
-Li X., 2005. Diversification and localization of energy systems for sustainable development and energy security. Energy Policy 33, 2237-2243.
-Ludwig B., 1997. On the sustainability of future energy systems. Energy Conversion Management 38, 15, 1765-1776.
-Maldonado P., Marquez M. Renewable energies: an energy option for sustainable development, WREC, 1996, 1072-1075.
-Matson J., Carasso M., 1998. Sustainability, energy technologies, and ethics, Renewable Energy 16, 1-4, 1200-1203.
-Matthes F.C., Cames M., 2002. Energy turn round 2020. The path to a sustainable energy system in Germany. Heinrich Boll foundation, Berlin.
-Pop-Jordanov, 2003. Indicators for sustainable energy development from a negentropic perspective. Clean technology environment 5, 273-278.
-PowerClean, CO_2NET and CAME-GT, 2004. Strategy for sustainable power generation from fossil fuels. PowerClean, CO_2NET and CAME-GT.
-Scalon A., Gsanger S., Davier R., Brandshaw J., Kile R., Howamn A, Blumstein B., 2004. Sustainability and due diligence guidelines. World Wind Energy Association.
-Spalding-Fecher R., 2003. Indicators of sustainability for the energy sector: a south African case study. Energy for Sustainable Development, vol II , 1, 35-49.
-Spalding-Fecher R., Winkler H., Mwakasonda S., 2005. Energy and the World summit on sustainable development: what next? Energy policy 33, 99-112.
-Tasdemiroglu, E., 1988. Sustainability of fossil fuels and alternative energies for Turkey. Energy 13, 10, 761-765.
-Turkenburg W., 1996. Energy and sustainable development. Report on phase I of the JOULE-project ‘Energy RD&D strategies for a sustainable future’. Department of Science, Technology and Society, Utrecht University.
-Turkenburg W., 1997. Sustainable development, climate change and carbon dioxide removal. Energy Conversion Management 38, supp. s3-s12.
-United Nations Development Programme (UNDP), 2003. Energy for sustainable development. A policy agenda. Johansson T, Goldenberg J (eds), London: UK.
- United Nations Development Programme (UNDP), 2004. World energy assessment, overview 2004 update, London, UK
-Vellinga P., 2000. Industrial transformation towards sustainability of the energy system. Integrated assessment 1, 157-163.
-Weidou N., Johansson T.B., 2004. Energy for sustainable development in China. Energy Policy 32, 1225-1229.
-Wellmer F.W., Becker-Platen J.D., 2002. Sustainable development and the exploitation of mineral and energy resources: a review. International Journal of Earth Sciences, 91, 723-745.
-World energy council, 2005. Delivering sustainability, challenges and opportunities for the energy industry. WEC statement, London, UK.

Appendix 2. Participants of the first Policy Lab

The First policy lab meeting was held 2nd November 2005 in Utrecht.

1. Jos Bruggink
ECN- Policy Studies
Badhuisweg 3, 1031 CM Amsterdam

2. Dancker Daamen
Universiteit van Leiden, Fac. der Sociale wetenschappen
Postbus 9555, 2300 RB Leiden

3. Sander de Bruyn
CE
Oude Delft 180, 2611 HH Delft

4. Wouter de Ridder
Milieu en Natuur Planbureau, Luchtkwaliteit en Europese Duurzaamheid
Postbus 303, 3720 AH Bilthoven

5. Bert de Vries
Milieu en Natuur Planbureau, Klimaat en Mondiale Duurzaamheid
Postbus 303, 3720 AH Bilthoven

6. Louis H.J. Goossens
TU Delft, Fac of Technology, Policy and Management, Safety Science
Jaffalaan 5, 2628 BX Delft

7. Peter Hofman
TU Twente, Centre for Studies of Science, Technology and Society
Postbus 217, 7500 AE Enschede

8. Daniel Jansen
ECN, System Assessment Group
Postbus 1, 1755 ZG Petten

9. Anne Kets
Rathenau Institute
Postbus 95366, 2509 CJ Den Haag

10. Karel Mulder
TU Delft, Technology Dynamics & Sustainable Development
Postbus 5015, 2600 GA Delft

11. Jos Post
RIVM, Centrum voor Externe Veiligheid
Postbus 1, 3720 BA Bilthoven

12. Marko Hekkert
Copernicus Instituut- Natuurwetenschap en Innovatiemanagement
Heidelberglaan 2, 3584 CS Utrecht

13. Christoph Tönjes
Clingendael International Energy Programme
Postbus 93080, 2509 AB Den Haag

14. Eise Spikers
Universiteit van Groningen JIN Foundation

Appendix 3. Participants of the Second Policy Lab

The second policy lab meeting was held 29 March 2006 in Utrecht.

1. Mart van Bracht
TNO Bouw en Ondergrond (TNO-NITG)
Postbus 80015, 3508 TA Utrecht

2. Maarten Gnoth
Electrabel Nederland
Concept- & Projectontwikkeling (CPO)
Postbus 10087, 8000 GB Zwolle

3. Hans Hage
Corus
Postbus 10000, 1970 CA Ijmuiden

4. Jos Maas
Shell International Exploration and Production B.V.
Volmerlaan 8 2280 RI Rijswijk

5. Jan Maas
Delta N.V.
Postbus 5048, 4330 KA Middelburg

6. Huub Paes
Electrabel Nederland
Concept & project ontwikkeling
Postbus 10087, 8000 GB Zwolle

7. Bert Stuij
SenterNovem
Postbus 17, 6130 AA Sittard

8. Chris te Stroet
TNO Bouw en Ondergrond (TNO-NITG)
Postbus 80015, 3508 TA Utrecht

9. Wim Turkenburg
Universiteit Utrecht-Copernicus Instituut

Sectie Natuurwetenschap en Samenleving
Heidelberglaan 2, 3584 CS Utrecht

10. Bram Van Mannekes
NoGePa
Postbus 11729, 2502 AS Den Haag

Appendix 4. The Survey

PART 1: Background information (question 1 out of 6)

The survey comprises three parts:

- Six questions about your background
- Five questions about your vision on the role of CCS in the energy system
- Nine questions about points of concern regarding CCS with respect to a sustainable energy system

In the survey we will use the abbreviation CCS for Carbon dioxide Capture and Storage.

Question 1 (out of 6)

My age is between

- 0 - 30 years
- 31 - 45 years
- 46 - 60 years
- > 60 years

Question 2 (out of 6)

I work for

- the power sector
- the oil industry
- the chemical industry
- an engineering company
- the government
- scientific/research sector
- a consultancy
- environmental organization
- other

Question 3 (out of 6)

On average my time spent working on CCS issues is

- less than 5%
- between 5% and 25%
- between 25 and 50%
- between 50% and 75%
- between 75% and 100%

Question 4 (out of 6)

My work is mainly

- Technically oriented
- Economically oriented
- Socially oriented
- Policy oriented
- Environmentally/ecologically oriented
- Other

Question 5 (out of 6)

Mine most relevant field of expertise regarding CCS

- Technology (capture, storage, etc.)
- Legal issues
- Economic feasibility and financing
- Risk aspects
- Policy aspects
- Management
- Other

Question 6(out of 6)

During the last national election I voted

- Christian Democrats
- Liberal party
- Green Party
- Nationalist party
- Socialist party
- Other left wing
- Other right wing
- Other / didn't vote / not applicable

PART 2: Your vision on the role of CCS in the energy supply (question 1 out of 5)

This part is about your vision on CCS with respect to a sustainable energy system.

I expect that CCS will play an important role

- for a short period of time (at the most for 30 years)
- for a medium period of time (between 30 en 80 years)
- for a long period of time (more than 80 years)

Question 2(out of 5)

I expect that in the coming century CCS

- will not play a major role
- will play a temporary role
- will play an important role as long as fossil fuels and storage capacity are available

Question 3(out of 5)
I hope that in the coming century CCS
- will not play a major role
- will play a temporary role
- will play an important role as long as fossil fuels and storage capacity are available

Question 4 (out of 5)
I see the role of CCS in reducing CO_2 emissions as
- THE solution to combat climate change
- Comparable to the role of energy saving and renewables
- Futile

Question 5 (out of 5)
CCS is an important option because it is
- Applicable on a large scale
- Gives national industries opportunities to exploit technical know-how
- Creates greater lead-time to develop cost-effective renewables

PART 3: Your concerns with respect to CCS in a sustainable energy system (question 1 out of 9)
This part comprises nine questions with four corresponding statements. Each statement formulates a possible concern with respect to the role of CCS in (the development to) a sustainable energy system. Please choose the statement that best describes your opinion.
My greatest concern regarding CCS is
- That it impedes the implementation of solar and wind energy
- That international pipelines are difficult to manage
- That there is no public acceptance for CCS
- That there is no or little spin-off for renewable energy

Question 2 (out of 9)
My greatest concern regarding CCS is
- That CO_2 leaks from underground reservoirs counteracting the effect of storage
- That there is a danger for a large blow-out at the storage site
- That we stay dependent on fossil fuels
- That it impedes poor countries to develop their energy supply

Question 3 (out of 9)
My greatest concern regarding CCS is
- That the storage capacity for CO_2 is insufficient
- That CO_2 leaks to an adjacent drinking water reservoir
- That CO_2 pipelines cross populated areas that may prove to be dangerous

- That the costs will have negative effects on our standards of living

Question 4 (out of 9)

My greatest concern regarding CCS is

- That the price of electricity will increase too much
- That poor countries do not have access to expensive CCS technology
- That it stimulates centralized large-scale energy supply (which might be less reliable than decentralized one)
- That it diverts attention away from energy saving

Question 5 (out of 9)

My greatest concern regarding CCS is

- That the development of renewable energy systems will be impeded
- That small-scale renewable energy will have little opportunity
- That other environmental problems of energy supply are not solved
- That there are not sufficient fossil fuel resources available

Question 6 (out of 9)

My greatest concern regarding CCS is

- That the balance of competition is disturbed
- That casualties will continue to occur as a consequence of coal mining
- That companies will not invest in this technology
- That we will become dependent on regions with large amounts of storage capacity

Question 7 (out of 9)

My greatest concern regarding CCS is

- That we remain dependent on regions with large fossil fuel resources
- That power plants will become more complex resulting in more power failures
- That it doesn't solve the environmental issue due to the continuing pollution from extracting and transporting fossil fuels
- That environmental organizations are opposed to it

Question 8 (out of 9)

My greatest concern regarding CCS is

- That we place a burden on future generations because of the CO_2 stored underground
- That the supply of fossil fuels is unreliable
- That storage locations will become a target for terrorist attacks
- That fossil fuels will become expensive

Question 9 (out of 9)

- That future generations have to bear the costs of a transition to an energy supply based on renewables

- That industrial production processes shut down more often because of the increased complexity
- That other countries/regions will not implement CCS
- That climate change is a hype and CCS not required after that hype

Appendix 5: Statistical results

Table A: Mann-Whitney Rank Sum Test – differences in hierarchies among criteria by nationality

Criteria	P value for the comparison between the groups: 'Dutch respondents' and 'Other nationalities'
Clean	0.094
Safe	0.835
Flexible	0.058
Justice	0.141
Competitive	0.090
Reliable	0.836
Continuity	0.058
Public acceptance	0.015*
Independence	0.012*

* Failed the test (P<0.05). The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference.

Table B: Mann-Whitney Rank Sum Test – differences in hierarchies among criteria by organization

Organization	P value for the comparison between the groups 'Dutch respondents' and 'Other nationalities'	
	Criterion: Public Acceptance	Criterion: Independence
Engineering/consultancy	0.436	0.597
Chemical/oil industry	0.029*	0.122
Power sector	0.927	0.830
Environmental organizations	0.714	0.905
Government	0.405	0.493
Scientific/research sector	0.150	0.237

* Failed the test (P<0.05). The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference.

Table C: Kruskal-Wallis One Way Analysis of Variance on Ranks-Differences in hierarchies among criteria according the role that respondents hope/expect CCS to have in the next century.

	P value for the comparison between the groups:	
Criteria	'*hoping* that CCS will play an important role as long as fossil fuels and capacity are available', '*hoping* that CCS will play a temporal role' and ' *hoping* that CCS will no play a major role'	'*expecting* that CCS will play an important role as long as fossil fuels and capacity are available', '*expecting* that CCS will play a temporal role' and '*expecting* that CCS will no play a major role'
Clean	0.682	0.317
Safe	0.604	0.879
Flexible	<0.001*[,1]	0.167
Justice	0.023*[,2]	0.498
Competitive	<0.001*[,3]	0.566
Reliable	0.669	0.830
Continuity	0.020*[,4]	0.049[*,6]
Public acceptance	<0.001[*,5]	0.002[*,7]
Independence	0.717	0.817

* Failed the test (P<0.05). The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference. A multiple comparison procedure has been performed using the Mann-Whitney Rank Sum Test to show in which groups the difference among the means can be found. [1]: The difference in the means is found between the groups 'important role' and 'temporal role' (P<0.001). The P values for the comparison "important role vs. no-important" and " temporal role vs. no important:" are 0.061 and 0.799 respectively. [2]: The difference in the means is found between the groups 'important role' and 'temporal role' (P=0.017). The P values for the comparison "important role vs no-important" and " temporal role vs no important:" are 0.113 and 0.811 respectively. [3]: The difference in the means is found between the groups 'important role' and 'temporal role' (P<0.001). The P values for the comparison "important role vs. no-important" and " temporal role vs. no important:" are 0.088 and 0.790. [4]: The difference in the means is found between the groups 'important role' and 'temporal role' (P=0.026). The P values for the comparison "important role vs. no-important" and " temporal role vs. no important:" are 0.236 and 0.566 respectively. [5]: Differences in the means are found between the groups 'important role' and 'temporal role' (P<0.001) and the groups 'no-important' and 'important role' (P=0.004). The P value for the comparison 'temporal role vs. no important:" is 0.821. [6]: The difference in the means is found between the groups 'important role' and 'temporal role' (P=0.046). The P values for the comparison "important role vs. no-important" and " temporal role vs. no important:" are 0.206 and 0.604 respectively. [7]: The difference in the means is found between the groups 'important role' and 'temporal role' (P=0.002). The P values for the comparison "important role vs. no-important" and " temporal role vs. no important" are 0.097 and 0.840 respectively.