Multi Criteria Evaluation of Low Carbon Energy Technologies

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Abstract: Achieving a low carbon energy supply in a future society driven by the impacts of climate change will require huge technological changes. This paper compares the methodological implications of assessing two very different technological solutions – renewable energy and geological carbon sequestration. The UK has high renewable resources, in particular the highest wind resource in Europe. In contrast, atmospheric emissions from fossil fuels could be avoided by storing carbon dioxide in underground geological formations for which the UK has a huge potential capacity. These two technological approaches will have diverse and wide ranging impacts; both inspire views amongst stakeholders that are highly polarised and fiercely held. Each is associated with a wide variety of potential benefits and impacts, some of which can be quantified, others which can not; a systematic framework is needed in order to analyse alternatives with such varying characteristics in a way that allows the involvement of stakeholders from a variety of perspectives. Multi criteria decision analysis (MCDA) has been used to provide a framework under which a number of alternatives can be scored against a series of defined criteria. Here we explore the different methodological challenges introduced by these two technologies under a common assessment framework. In the case of wind energy, there are already tangible and visible examples and stakeholders already have experience of the technology. In contrast, carbon sequestration is invisible, uncertain and relatively untested. Ultimately it is likely that these two technologies will be deployed as complementary solutions, both playing a central role in reaching the goal of a decarbonised society.

Keywords: Renewable energy; Geological carbon sequestration; Multi criteria decision analysis; Stakeholder involvement.

1. INTRODUCTION

1.1. Wind Energy in the U.K

In line with UK climate change policy carbon reduction targets, a target has been set to meet 10% of electricity from renewable sources by the year 2010. With only 2.8% of electricity being supplied by renewable sources at present, this target is highly ambitious. Across all renewable energy technologies, if the current rate of planning application success continues, only 4% of energy needs will be supplied from such sources in 2010 and not the 10% target, RCEP, [2000].

The UK government has devised a two pronged approach, with demand side measures intended to stimulate demand for electricity from renewable sources and changes to the planning system with regional renewable energy targets. Prior to its termination in 1998, the Non Fossil Fuel Obligation (NFFO) provided a protective market to enable new renewable energy technologies to compete with conventional methods of electricity generation. Many authors have commented that the nature of this support mechanism has resulted in an increasingly adversarial planning process with respect to renewable energy schemes and onshore wind in particular, (see for example House of commons, [1994], Mitchell, [1996]). It is hoped that changes to the planning system, with the adoption of renewable energy targets, will improve the planning success of schemes.

1.2. Geological Carbon Sequestration

Geological carbon sequestration has the potential to make a significant contribution to the decarbonisation of the UK - allowing the continued use of coal, oil and gas whilst avoiding the CO_2 emissions currently associated with fossil fuel use. The process involves capturing CO_2 from large point sources - from the flue gases of power stations or by altering the combustion process and extracting CO_2 during combustion, Riemer *et al.*, [1999]. This recovered CO_2 may then be compressed and transported by pipeline to a suitable storage location. The main storage sites for the UK are hydrocarbon fields, in which storage may initially be associated with economic benefits of Enhanced Oil Recovery (EOR), and deep saline aquifers, located several hundred meters below the sea bed. Estimates of the potential capacity of these sites, in the UK alone, indicate that potentially up to 240 $GTCO_2$ could be stored, Holloway [1996].

Thus, in principle, carbon sequestration represents a mitigation option of huge potential. In practice, however there remains a long way to go before it can be adopted on a large scale. Although the use of CO_2 in Enhanced Oil Recovery is routinely used in onshore oil extraction in the US, Stevens and Gale [2000], the application of this technology to long term storage is only currently at a pilot stage (e.g. the Weyburn project) and has not yet been implemented off-shore. The injection of CO_2 into a deep saline aquifer, explicitly for CO_2 emission reduction, is being adopted at an industrial scale in the North Sea at the Sleipner West gas field, Herzog *et al.*, [2000]. CO_2 has been injected into Sleipner at rate of approximately 1 $MTCO_2$ per year since 1996.

However, this is a new technology and there remain many uncertainties relating to its viability, effectiveness and acceptability. Further technical and scientific analysis is required to elaborate the economic, geological, engineering, legal and environmental implications of this technology but it is also important to consider the social and political dimensions at this early stage.

2. MULTI CRITERIA METHODS

2.1. Introduction

Multi criteria decision analysis (MCDA) is an umbrella term for a variety of non-monetary evaluation techniques sharing a basic framework under which a number of alternatives can be scored against a series of defined criteria. Despite a growing body of recent work, e.g. Stirling and Meyer, [1999]; Clark et al, [1998] the application of such techniques is only beginning within the environmental field in the UK. This is in contrast to other European countries, Denmark and the Netherlands in particular, where deliberative procedures are well established within the regulatory context.

MCDA provides a good framework for the exploration of both wind energy and geological carbon sequestration, allowing the involvement of stakeholders from a variety of perspectives in a process where they will have the flexibility to explore options against their own criteria, weightings and scores. The method is easily understandable, transparent and does not depend on the technical expertise of the participants, allowing the incorporation of other forms of knowledge. We have chosen the two case studies in order to explore some of their methodological implications and to demonstrate the flexibility of the MCDA method in its application.

2.2. Research Methodology

Wind energy and geological carbon sequestration are both highly relevant case studies within climate change and energy policy in the UK. The UK has significant resources in onshore and offshore wind and has a large capacity for underground storage of carbon dioxide within geological formations. Given the nature of the technologies, both may generate controversy, particularly with regard to their social acceptability. In the case of wind energy, many communities have first hand experience of schemes and perceive that the impacts outweigh the benefits; energy generation is regarded in the same negative light as other ‘unwanted land uses’ such as land fill sites and nuclear waste storage facilities. Public awareness of carbon sequestration technologies is as yet limited and research is only beginning to explore potential reactions to it, Gough et al. [2002], Lenstra and van Engelenburg [2001]. If we look to analogues such as the disposal of nuclear waste or the Brent Spar crisis, despite significant differences, storage of a by-product from large scale power generation for hundreds of years may raise serious ethical questions.

The two case study technologies are at very different stages in their development. Wind energy is well understood, there are visible tangible examples enabling respondents to draw on their own experiences. In contrast, as geological carbon sequestration is both relatively untested and likely to be implemented at remote off-shore sites, most stakeholders will not be able to draw on first hand experience of the technology. In the near term at least, the two technologies could be seen as representing two opposing solutions to low carbon energy generation. Large scale exploitation of renewables may mean a transition to a dispersed pattern of electricity generation, in which a greater number of people will have to bear the impact of its generation (in terms of a perceived reduced amenity). In contrast, geological carbon sequestration may imply a more centralised energy supply regime - based on traditional fossil fuels with an 'end of pipe' approach to carbon reduction.

The first stage of the MCDA involves the generation of the alternatives to be evaluated. These scenarios form the basis of the MCDA which takes place over two, one-to-one interviews with stakeholders. In many scenario building exercises a group process is employed to include a wide variety of perspectives and make the scenarios as rich as possible. However this was felt to be too time consuming for the purpose of this study so the scenarios were developed initially by the researchers based on extensive examination of the literature. It is important that the scenarios used within the evaluation meet a number of objectives:

- as detailed as possible
- understandable to the non-expert
- distinct from each other
- credible
- clear
- substantiated by existing information if possible

From Brown et al, [2001]

In both case studies, interviewees have been selected to cover a range of stakeholders representing a broad cross section of views. In both studies scientists and policy makers, along with representatives of environmental NGO's with supportive and non supportive stances are included in the interviews. For the wind energy study, interviewees also include individuals with direct experience of living with the technology, and implementing it, from both a development and planning perspective. The interviews for the carbon sequestration study were restricted to professional stakeholders – at this stage a more discursive methodology such as Focus Groups or Citizen Panels is considered to be more appropriate for capturing the perceptions of lay participants. Both case studies are conducting an MCDA using a two stage interview process; results of the first round of interviews are presented here, along with a description of the second phase of the methodology, which is still to be completed.

In order to ensure the reliability and validity of the scenarios, the first interview with participants provides the opportunity to modify and extend the scenarios and to define possible criteria under which they are to be scored. This gives participants the opportunity to propose additional scenarios if they felt that relevant options are not adequately captured in the initial scenarios.

During the second interview the final scenarios are scored under a set of appraisal criteria. The criteria are selected by the analysts from the full list of criteria identified by respondents during the first interview. Interviewees may also add a small number of their own evaluation criteria should they wish. The number of criteria is restricted to a maximum of thirteen to enable independence to be maintained between criteria and to keep scoring manageable. Scoring is based on the information provided within the scenarios and the expertise and opinions of the respondents. Once the scenarios have been scored, the criteria must be weighted. Participants are asked to weight the criteria according to their perspective and the perceived importance of the criteria within their decision making process.

There are a number of methods that can be used in order to determine the ranking for the alternative scenarios, see for example Stirling and Meyer, [1999]; DETR, [1998]. We will use a simple linear additive weighting model. Since the purpose of the MCDA in these case studies is to map the views of the participants rather than deliver a 'final' ranking or 'best' option, the transparency of the procedure is considered to be vital. Whilst more complex mathematical models may result in a more accurate final ranking this would reduce transparency and detract from the heuristic benefits of the process.

3. SCENARIOS

3.1. Introduction

The outcome of the first stage of interviews is a set of stakeholder reviewed scenarios for the two case studies. This is important to ensure that the MCDA is performed on a scenario set that the stakeholders agree reflects the full range of possible futures and is technically accurate. Whilst the researchers are able to identify many key drivers for change, along with the linkages which exist between different parts of the system, expert input is vital in ensuring that the scenarios are both comprehensive and credible.

3.2. Wind Energy Case Study

The published North West regional wind energy target (1250 GWh by the year 2010) formed the starting point for the design of six alternative visions of wind energy development within the region. They were designed from a bottom up assessment of the resource and the costs and impacts of exploiting that resource. A number of hypotheses concerning wind energy development were incorporated, so the scenarios have different characteristics in terms of development size, turbine characteristics, procurement methods, emission savings, visual impact and so on. For each scenario a description has been produced containing qualitative, quantitative and visual information. Given the very short time horizon (2010) and their shared target, the scenarios were written as caricatures, in order to accentuate the differences between them. The existing tangible examples of wind energy facilitated the quantification of parameters such as costs and the number of turbines required to reach the target. Table 1 summarises the final scenarios and major assumptions.

Although energy efficiency measures play an important role within climate change policy, it is not an area over which local authorities have direct control beyond their own buildings and housing stock. For this reason energy efficiency has not been explicitly included within the scenarios. The new utility bill brings green certificates, new electricity trading arrangements, the renewables obligation and other new factors into play.

Table 1. Wind Energy Scenarios for the NW region to 2010

	Key Assumptions
All at Sea	80% of regional target is met from offshore wind
Bold as Brass	50% of regional target is met from offshore wind. Onshore wind development led by large developers with an emphasis on large schemes on windy sites.
Variety is the Spice	50% of regional target is met from offshore wind. Onshore wind development is led by large developers but with a variety of scheme sizes and locations.
Town and Country	45% of regional target is met from offshore wind. Onshore wind schemes are developed by a variety of interests with many developments close to urban areas.
Community of Interests	50% of regional target is met from offshore wind. Developer led schemes concentrated on windy sites with community involvement via the purchase of shares.
Power to the people	45% of regional target is met from offshore wind. Onshore wind schemes are developed by a variety of interests with many community led schemes.

3.3. Geological Carbon Sequestration Case Study

These scenarios start from national CO_2 emission reduction targets set for four periods up to 2100. Four basic scenarios describing ways in which these targets can be achieved have been designed, each placing different levels of dependence on carbon sequestration as a means of reaching the targets. The design of the scenarios ensures that they have different characteristics in terms of capacity and location of storage sites exploited. For each scenario, a description has been produced containing qualitative and quantitative information. An additional fifth scenario has been included at the suggestion of one of the interview respondents.

None of these scenarios include a reduction in energy use – the reason for this is not that we exclude this possibility but that it would not produce a sufficiently challenging backdrop for a study of carbon sequestration at this stage.

Again these scenarios have been written as caricatures to expose the major tradeoffs between different routes to achieving significant CO_2 emission reductions. The context of these scenarios, however, is quite different from that of the wind energy case study; here we are exploring the main issues, in very general terms, of long-term pathways (to 2100). We refer broadly to other (non carbon capture and storage) aspects of the scenarios by way of illustration. A substantive and detailed analysis of the alternative energy policies over this time period would be both over ambitious and inappropriate, we refer the reader to two long term analyses of UK energy futures RCEP [2000]; PIU [2002]. The four scenarios are summarised in Table 2; the fifth additional scenario was introduced as a variation on the ‘Spreading the load’ scenario, exploiting lower levels of carbon storage.

Table 2. Carbon sequestration scenarios for the UK to 2050

Energy use	Low carbon storage	High carbon storage
Growth (0.5% pa)	*Nuclear Renaissance* Carbon storage is adopted as an interim measure to enable emission reduction targets to be met during a gradual transition to a high nuclear energy future	*Fossilwise* Carbon storage is adopted as the major component of the emission reduction strategy, allowing the UK to continue its dependence on fossil fuels
No growth (from 1998)	*Renewable generation* Carbon storage is necessary to achieve emission reductions as the UK moves towards a renewables based hydrogen economy, nuclear power is abandoned	*Spreading the load* High levels of carbon storage within a diverse energy regime, large centralised power stations coexist with decentralised networks of new and renewable energy technologies

4. CRITERIA

4.1 . Introduction

In both case studies, stakeholders were asked about the criteria they would use in order to evaluate the scenarios. Respondents were asked to comment upon those on an initial list, and to suggest additional ones to reflect their priorities or concerns in evaluating the scenarios.

4.2. Wind Energy Case Study

Initially, many of the stakeholders expressed difficulty with the concept of evaluation criteria and found it easier to discuss suggested criteria than to define new ones. A number of the organisations, in particular those concerned with landscape, had a narrow remit and only considered a small number of criteria to be important within the objectives of their organisation. Although at the regional planning level, sustainability objectives were important, this was not the case at the local planning level, where the overriding concern were land use objectives.

Respondents will be asked to weight and score the scenarios against the top ten criteria from the first interview, as shown below. In addition, two further appraisal criteria can be specified if it is felt that those on the list of 'core' criteria do not fully describe those issues important to them.

- Visual impact
- Impact on designated areas
- Emission savings
- Involvement in the development process
- Costs
- Jobs created and lost
- Level of community ownership
- Distribution of schemes around the region
- Contribution to sustainability objectives
- Location onshore/offshore

4.3. Geological Carbon Sequestration Case Study

As for the wind energy case, we found respondents initially reluctant to define their own criteria but more able to engage in discussion over a pre-prepared list. The multi criteria evaluation of carbon sequestration will be implemented in two steps. The first step explores in detail the various carbon storage reservoirs included in the study, a set of evaluation criteria have been defined for this purpose. In the second step scenarios are assessed – using an aggregate score from step one according to the scores and weights of participants and the relative use of each reservoir type in each scenario, in conjunction with a set of criteria relating to the scenarios. This approach allows us to identify and assess the key issues associated with different reservoir types and then to explore the use of carbon sequestration in the context of other climate mitigation strategies and the tradeoffs associated with different pathways. For each step, participants are presented with a basic list of criteria, as shown below, with the option of specifying additional criteria. As this assessment represents an initial scoping exercise – mapping out possible trade-offs and issues associated with carbon sequestration - and given the uncertainty associated with many of the parameters, these criteria were all evaluated on a relative scale - by allocating 100 points to each criterion across the options. A set of 'optimistic' and 'pessimistic' default values are available for reservoir criteria should respondents not feel comfortable assigning scores (all weights and scenario criteria scores must be user-defined however).

Step One - Reservoir Specific Criteria

- Storage timescale
- Rate of leakage of CO_2
- Adverse impacts - ecosystems
- Adverse impacts - human health
- Proven storage security
- Costs
- Planning or legal barriers

- Public opposition
- Monitoring / verification
- Storage potential (capacity)

Step Two - Scenario specific Criteria

- Reservoir performance (within each scenario, calculated from results of step one)
- Costs of carbon capture and transport
- Costs- energy supply and use
- Infrastructure change
- Lifestyle changes
- Security of energy supply
- Environmental impact

5. DISCUSSION

In both case studies, MCDA has proved a useful format for the exploration of stakeholder perceptions, with the capacity to include a number of perspectives and the divergent values and assumptions inspired by the technologies. Since information can be included in the various qualitative or quantitative formats in which it occurs, non commensurable factors are not forced into a single format; this allows the representation of the multi dimensional aspect of the problem in a flexible manner. The scoring of each option under each criterion is a simple and easily understood methodology, in particular the inclusion of a wide variety of information allows the involvement of both experts and the lay public. The involvement of a variety of stakeholders ensures analytical breadth. The weighting of criteria enables the participants' perceptions and values to be incorporated into the decision making process in a systematic way. Manipulation of weightings allows the exploration of how different perspectives affect the performance of options under different criteria and serves to enhance the understanding of the problem rather than come up with a single 'best' option. The method is simple, transparent and this makes it easy to apply.

The two case studies are distinctly contrasted in terms of scale, maturity of the technology, their interpretation within long-range and short range futures, general awareness and familiarity with the technology. In the case of wind energy the weightings assigned to the criteria are particularly interesting; reliable quantitative information is available to score criteria with reasonable confidence and hence consensus. In the case of the carbon sequestration, the scoring of criteria provides a framework within which we can explore the uncertainties associated with the technology – participants can see the effects of optimistic or pessimistic estimates, for example. MCDA also serves to identify key factors, and through the weighting procedure, their perceived relative importance in the debate and the manner in which they relate to the viability, effectiveness and acceptability of the technology. This helps point to areas in which future research should be focused.

We have illustrated, through two diverse case studies, the flexibility with which the MCDA methodology can be applied, exploring very different types of scenario, or technology options, from detailed developments of particular wind energy proposals, up to macro-level descriptions of long term energy pathways.

6. REFERENCES

Brown, K. Tompson, E. and Adger, W. N., Trade Off Analysis for Participatory Coastal Zone Decision Making, ODG, UEA, 2001.

Clark, J,A. and Burgess, J., Prioritising the Issues in Local Environment Agency Plans Through Consensus Building with Stakeholder Groups, Technical report W114, 1998.

Department of the Environment, Transport and the Regions, Multi-Criteria Analysis: A manual, DETR, 1998.

Gough, C., Taylor, I. and Shackley, S., Burying Carbon under the Sea: An Initial Exploration of Public Opinions, *Tyndall Centre Working Paper* 10 and submitted to: *Energy and Environment*, 2002.

Herzog, H. Eliasson, B. and Kaarstad, O., Capturing Greenhouse Gases, *Scientific American*, Vol 282 (2), 2000.

Holloway, S. (Ed.), The Underground Disposal of Carbon dioxide, Final Report of the Joule II Project CT92-0031,1996.

House of Commons Select Committee of Welsh Affairs, Wind Energy, Vols. 1,2, &3, HMSO, 1994.

Lenstra, W. and van Engelenburg, B., *'Climate Policy, CO_2 storage and public perception*', Ministry of Housing, Spatial Planning and the Environment, The Netherlands, 2000.

Mitchell, C., Future support of renewable energy in the UK – options and merits, *Energy and Environment*, Vol. 7 (3), pp267-283, 1996.

Performance and Innovation Unit, The Energy Review, The Cabinet Office, UK, 2002.

Riemer P., Audus, H. and Smith, A., CO_2 Capture from Power Stations, IEA GHG R&D Programme, Cheltenham, UK, 1999.

Royal Commission on Environmental Pollution, Energy –The Changing Climate, HSMO, 2000.

Stevens, S. H. & Gale, J., Geological CO_2 sequestration, *Oil and Gas Journal*, May 15^{th} 2000.

Stirling, A. and Meyer, S., A novel approach to the appraisal of technological risk: a multi-criteria mapping of a genetically modified crop, *Environment and Planning C: Government and Policy*, 19 pp529-555. 2001