Timing is a crucial factor in a CCS development pathway
The case of the Netherlands∗

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Abstract

The analysis presented in this paper is part of a research project which aims to investigate what the *optimal* timing of a CCS implementation trajectory is and how it depends on dynamic factors such as climate policy, electricity demand, life time of existing and new power plants, cost and performance developments of CCS and competing technologies, and availability of sinks. Key criteria are that CCS (in comparison with other CO_2 reduction technologies) has the potential to contribute substantially to CO_2 emission reduction against reasonable costs and that it contributes to energy security. A quantitative analysis of the Strong Europe scenario for the electricity sector in the Netherlands is carried out with MARKAL. This paper gives an outline of the starting points, methodology, and tool which are utilised during the research project. Preliminary results will be presented at the conference.

Keywords: CO_2, capture, storage, system analysis, MARKAL, linear optimisation

Introduction

Timing plays an important role during the development of a Carbon Capture and Storage (CCS) based energy system. It seems that many activities and events need to coincide or at least that they need to be tuned tightly to each other with respect to time:

- Climate policy should be in place at the time investment decisions are to be made,
- learning in capture technology development should be fast enough,
- capture and storage should be affordable compared to other CO_2 abatement options,
- the vintage structure and development of electricity demand determine when there are opportunities to built new power plants with CCS, and
- sinks, where the CO_2 can be stored, must be available in time.

This paper gives an outline of the starting points, methodology, and tool which are utilised during the research project that aims to investigate how these events interact and to what extent planning is necessary. The Netherlands has a number of characteristics that make it a potential interesting country for CCS deployment: it has a high energy use, relatively limited potential for renewable energy, a well developed natural gas infrastructure, good storage possibilities and many large point sources of CO_2 (i.e. chemical industry, power plants). Furthermore, because the Netherlands is small, it is a good case region to study these timing aspects in detail. This paper gives an outline of the starting points, methodology, and tool which are utilised during the research project

Research question

Previous studies that estimated CCS potential in the Netherlands, hardly addressed dynamic aspects. For instance, the fact sheets [1] of the Energy research Centre of the Netherlands (ECN) suggest that the

∗ The CATO programme is the Dutch national research programme on CO_2 Capture and Storage (CCS). CATO is financially supported by the Dutch Ministry of Economic Affairs (EZ) and the consortium partners. (www.CO_2-cato.nl). This paper is part of the CATO system analysis activity which integrates other CATO activities and identifies transition trajectories and strategies to establish an energy system with CCS in the Netherlands.

CCS potential will be 29 Mt CO_2/year at IGCC power plants and 16.5 Mt CO_2/year at NGCC power plants in the year 2050. In a recent ECN study [2] the CCS potential is estimated at 15 Mt CO_2/year in 2020. The research project goes a step further and investigates how the CCS implementation trajectory should look like to reach these targets and if timing of events would be a major bottleneck in the trajectory. The research questions are: what is the *optimal* timing of a CCS implementation trajectory and how does this depend on dynamic factors such as climate policy, electricity demand, life time of existing and new power plants, cost and performance developments of CCS and competing technologies, and availability of sinks? Key criteria are that CCS (in comparison with other CO_2 reduction technologies) has the potential to contribute substantially to CO_2 emission reduction against reasonable costs and that it contributes to energy security. The research will focus on the electricity sector, since this sector is the major candidate for large scale introduction of CCS.

Methodology

In order to investigate timing of CCS implementation pathways, a quantitative analysis of a specific scenario for the electricity sector in the Netherlands is carried out. The concerned scenario is Strong Europe (SE) in which international cooperation and social motivations prevail [3]. Due to globalisation, Europe can not be treated in isolation and definitely not the Netherlands. So the world context of this scenario is taken along by using the B1 scenario of the IPCC. The scenario study is based on a cost minimisation approach within the time horizon 2000 to 2050. Different variants of SE are defined in which one of the dynamic factors is varied. The optimisation model MARKAL is used to find optimal timing of CCS trajectories for each variant. Furthermore, a sensitivity analysis is done for other factors like discount rate and energy prices.

A CCS trajectory is defined by three landmarks. At the first landmark, 10 Mt CO_2 will be reduced by CCS, at the second 20 Mt, and at the third 30 Mt. This study finds out if these landmarks occur in the different variants within the underlying horizon and if they do, when they occur. At these landmarks, it is also assessed how many CCS power plants (with an average capacity of 1000 MW) have been built. The different variants are then ranked based on the total system costs over the entire time horizon, the CO_2 price, and the effects on the primary energy demand and, thus, the energy security. The ranking of the latter is higher the more different sources fulfil the resources need for the electricity production in a substantial amount (> 20%).

Model

MARKAL (an acronym for MARKet ALlocation) is a linear optimisation model of the energy system of one or several regions that provides a technology-rich basis for estimating energy dynamics over a multi-period horizon [4]. This study will use the WEU MARKAL model of ECN as starting point. In this model already the structure of the energy system is implemented and data on costs and performance of energy conversion and demand technologies are specified. The model deals with the pre-2004 EU-15 plus Norway, Iceland and Switzerland. This region is treated as one single region (except for part of the energy system that deals with space and water heating) without import or export of energy resources between countries. The base data in the model is described in several publications of ECN amongst others data on storage of CO_2 can be found in [5].

Because the research focuses on the Dutch electricity sector, this sector needs to be separated from the rest of the region. It is decided to start using the multi-region facility in the MARKAL model and make it a two-region model. The Dutch electricity sector will be transported to the new region. The energy system of the 17 other countries and the remainder of the Dutch energy system will remain in the WEU region. The advantage of this solution is that you can see the effect of changes in the West European energy system in the Dutch electricity sector. Countries like France, Belgium, Germany, Norway, and the United Kingdom play or will play an important role for the import/export of electricity to/from the Netherlands [6]. Since the WEU region includes these countries additional information will be provided on the potential of future electricity exchange to and from the Netherlands.

DEFINITION OF VARIANTS

Variants climate policy: high – very high - stochastic

In order to get CCS into the solution of a MARKAL run, climate mitigation policy measures need to be set. It is chosen to take a CO_2 cap instead of measures such as a CO_2 price or subsidies for clean technology. In a follow-up study, policy measures will be evaluated that can lead to the identified optimal cost-effective trajectories. Within the framework of the Kyoto Protocol it is agreed that the Netherlands has to reduce greenhouse gas emissions with 6% on average in the period 2008 – 2012. Afterwards, the EU Environment Council states that a global GHG emission reduction is necessary of 50-60% in 2050, compared to 1990, and therefore aims to make new agreements that will reduce European GHG emissions with 15% – 30% in 2020 and somewhere around 60% – 80% in 2050.

The research investigates the consequences of a high and very high reduction target in two variants, see Table 1. Also, one variant is added in which the uncertainty to what extent climate policy will be implemented is studied. Because, in this paper, only the CO_2 emissions of the electricity sector are considered, national reduction targets need to be translated to targets for this sector. For the years 2020 – 2050, it is assumed that the electricity sector has to reduce the emissions to the same extent as the national reduction target. However, the industry and energy sector do not need to reduce the CO_2 emissions for the year 2010: the National Allocation Plan states that it may even increase from 92 to 112 Mt/year. The 6% reduction target is instead mainly achieved by acquiring CO_2 rights through Clean Development Mechanism and Joint Implementation projects.

Table 1 CO_2 reduction variants (in % reduction compared to 1990) in the Netherlands

Variant	Description	2010	2020	2050
Base variant	Variant without any CO_2 reduction	0	0	0
Reduction A	A high reduction variant	0	-15	-50
Reduction B	A very high reduction variant.	0	-30	-80
Stochastic variant	This variant addresses the uncertainty of future climate policy and therefore combines the upper 3 variants with each having an equal chance of happening. The eventual cap will only be known by the year 2020.			

Variants electricity demand: low – medium - high

The influence of the electricity demand growth is investigated for a low, medium, and high variant. The demand for electricity and heat from 2000 to 2050 has to be determined outside the model and is based on GDP and demographic developments. SE was quantified by CPB for Europe [7], by CBS and RIVM-MNP for the Dutch demographic developments [8] and by CPB for the Dutch economy [9]. The electricity demand for SE until 2020 is obtained from the Reference Projections [10]. This study assumed growth rates of 1.5% until 2010, and 2.0 and 1.3% until 2020. The medium variant uses this demand as starting point and extrapolates it till the year 2050 with a 1.3% growth per year, resulting in an electricity demand of 200 TWh in the year 2050. The projections are summarized in

Table 2. In the Low and High variants the electricity use grows with 0.3% less and more than in the Medium variant to respectively 175 and 230 TWh in 2050.

Table 2 Characteristics Strong Europe

	Population growth per year(%)		GDP growth per year (%)		Projected: final electricity growth per year (%)
	Projected	Historic	Projected	Historic	Medium variant
World	0.83 (1990-2050)	1.86 (1950-1990)	3.1	4.0 (1950-	

		1.42 (1990-2000)		1990)	
EU-15	0.3 (2000-2040)	0.3 (1980-2000)	1.6	2.2 (1980-2000)	
NL	0.5 (2005-2020) 0.3 (2020-2040)	0.6[4] (1980-2000)	1.6	2.6 (1971-2001)	1.5 (2005-2020) 1.3 (2020-2050)

Variants - vintage structure: normal – prolonged

In order to assess when new power plants are needed, the capacity and age of current power plants and cogeneration units in the Netherlands are traced. This vintage structure can be found in Figure 1. Data for the assessment of the vintage structure in the Netherlands were obtained from [11] and energy companies. Since plans for new power plants are only preliminary, these are not included. The 11 decommissioned large units (>200 MWe) had an average life time of 25 years. The average life time of 20 current large units in the Dutch electricity park of which the planned capacity is known, is on average 31 years (excluding the nuclear power plant). For the other units, an average is assumed of 25 years. In North America lifespans of power plants tend to be 10 to 15 years longer [12]. Since the electricity market in Europe is liberalising, a variant with a prolonged lifespan of up to 40 years of the existing capacity is also included. The same approach is taken for new power plants.

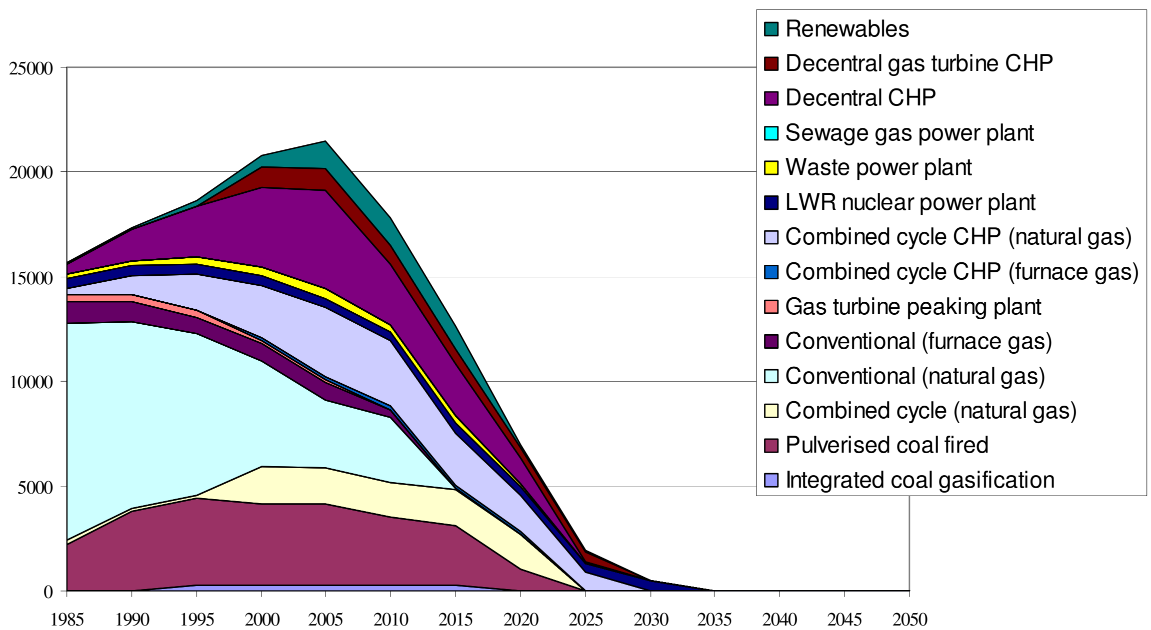

Figure 1 Vintage structure of the electricity sector in the Netherlands (in MW)

Variants – technologies: pessimistic progress – neutral - optimistic progress

The results of the optimisation depend very much on the techno-economic data of capture and competing technologies in MARKAL. Therefore, it is important to get insight into how the results depend on more optimistic versus more negative assumptions about advances in technologies. For this purpose three variants are defined. One with reference values for all technologies, one with pessimistic assumptions for capture technologies and optimistic ones for competing technologies, and one where it is exactly the other way around. In the next two paragraphs this approach is further elaborated upon for capture technologies and competing technologies.

Capture technologies - A portfolio of CO_2 capture technologies is included so that the total potential of the Dutch electricity sector is covered. The criteria for the selection of CO_2 capture technologies are:

fuel type, state-of-the-art versus advanced technologies, large scale versus small scale technologies, and distinct characteristics with respect to cost or performance. The basis of the selection was provided by the study 'A comparison of hydrogen and electricity production systems with CO_2 capture and storage' [13], because it gives a normalised dataset of the different technologies. However, this study provides the O&M costs as percentage of the investment costs. For MARKAL it is necessary to go to back to the original data to be able to split the O&M costs into a variable and a fixed cost part. To obtain pessimistic and optimistic values for the variants, the cost and performance ranges in the IPCC Special Report on Carbon Dioxide Capture and Storage [14] are used. According to this report, it is difficult to use learning rates since CCS is in an early stage of development in which costs are very uncertain.

Competing technologies – For competing technologies more information is available about learning rates and expected growth of cumulative capacity in the world. In this research project the results are used from the study 'Wind energy on the North Sea, a social cost-benefit analysis' in which costs of wind energy as a function of time are estimated for the SE scenario [15]. These are given for both a fast and a slow learning rate. A similar approach is taken for a selection of the main competing technologies, in particular nuclear and biomass power plants.

Variants sinks availability: optimistic - pessimistic

For a successful introduction of CCS in the Netherlands, sufficient suitable sinks should be available. Of course, data for the sinks in the Netherlands are relevant for this study. Also, sinks in other countries such as Norway may also be relevant if these are very large or if CO_2 could be used for enhanced oil recovery. In this study the timing when sinks become available, is especially considered. For this purpose the following assumptions are taken:

- In the Netherlands CO_2 will be mainly stored in empty gas fields and acquifers. The potential in oil fields can be neglected. Ultimately, there is a capacity of 11 Gt CO_2 available in empty gas reservoirs and 300 Mt in onshore aquifers (a recent, unpublished update of total onshore capacity performed within TNO-NITG comes to this amount when considering aquifer traps with a minimal storage capacity of 10 Mt). Part of the gas reservoirs should probably be discarded because these are either too small or do not fulfil safety requirements.
- With around 7.5 Gt CO_2 [16], the Groningen field accounts for more than half of the CO_2 storage potential. The annual Oil and Gas report states that in this field still a little gas will be left by 2040 [17], which would imply that it cannot yet be used for CO_2 storage. However, if CCS would be a serious option in 2040, there might be efforts to make it available for CO_2 storage from 2040 and maybe earlier.
- Between 2005 and 2020 most of the other suitable gas reservoirs will become gradually available. Specific data on the current availability still needs to be obtained from other partners within the CATO project.

Two variants are run. One with an optimistic and one with a pessimistic perspective concerning the availability of sinks.

Expected results

The Dutch electricity sector will be separated from the rest of the energy system in the WEU MARKAL model and a base case will be established. Subsequently it is assessed with MARKAL how sensitive the timing of a CCS trajectory is by varying the dynamic factors as follows:

- A strict versus a very strict climate policy.
- Slow versus fast learning of CCS technologies in comparison with competing options.
- A low versus a high electricity demand growth
- A slow versus a high replacement rate of power plants

- An optimistic and pessimistic view with regard to suitability of sinks

The results will be presented as shown in Figure 2. From this figure it will turn out how the time dependent factors influence the implementation rate of CCS in the Netherlands and how they influence costs and energy security. Preliminary results will be presented at the conference.

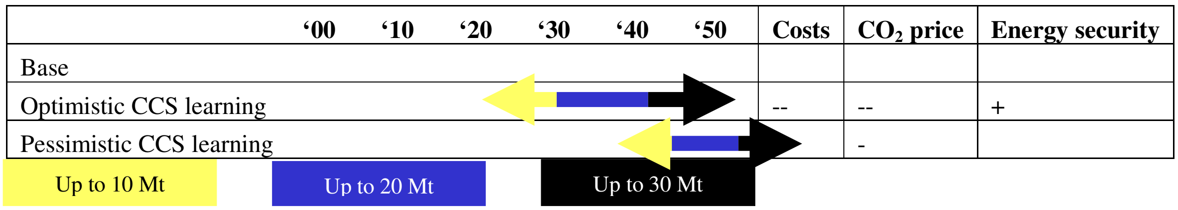

Figure 2 Example of one of the result graphs

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