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The potential role of Carbon Capture and Storage, under different policy options

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Abstract

This paper explores the potential role of CCS under different policy options in the Dutch electricity sector. A bottom-up simulation model is used to evaluate different policy scenarios. The results show that CCS plays only a moderate role for gradually rising CO_2 prices. By using the scale advantages in CO_2 transport already for the first CCS plants comparable to the level of large scale transport, the competitiveness of CCS is improved considerably. Furthermore, our results indicate that different policy options stimulate different types of CCS technologies. Finally, stimulating CCS and renewable energy sources simultaneously is more cost effective in the long run than stimulating solely CCS.

Keywords: CO_2 capture, transport and storage; policies, CO_2-price, feed-in tariff, subsidy, CCS obligation, CO_2 transport costs

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1. Introduction

Carbon Capture and Storage (CCS) plays an important role in the climate change mitigation strategy of the Dutch government. The Netherlands is specifically suitable to CCS, because of the availability of sinks, the existing natural gas infrastructure and the relative short distances between large point sources and potential CO_2 storage locations. However, so far no concrete policy has been formulated to stimulate CCS. A few suggestions are made in the Dutch working program 'Schoon en Zuinig' [1], namely co-financing of large scale demonstration plants and a CCS obligation for new fossil fired power plants from 2020 onwards. In the long term CCS may become competitive in the EU Emissions Trading Scheme (EU ETS).

Few studies are available on evaluating CCS stimulation policies. Most studies focus primarily on a CO_2 price. This paper presents the results of a number of scenarios with different policy options. The policy options include a CO_2 price, CCS subsidies, feed-in tariffs for CCS and renewable energy sources, and a CCS obligation. The research question is: What is the potential role of CO_2 Capture and Storage in the Netherlands under different policy options

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on the mid term (2030)? Our analyses focus on replacement of centralized electricity production capacity in the Netherlands.

2. Methodology

2.1. Bottom up simulation model

The analyses are carried out by using a bottom-up simulation model. This model is a newly developed model currently covering the Dutch electricity sector, for the period 1990-2030, with time steps of one year. Twenty-four types of power plants are included, of which seven plants in combination with CCS. Electricity demand is used as a static input to the model. The model simulates the stock turnover of the plants, investment decisions and the related GHG emissions and costs. Figure 1 shows a general overview of the model principles.

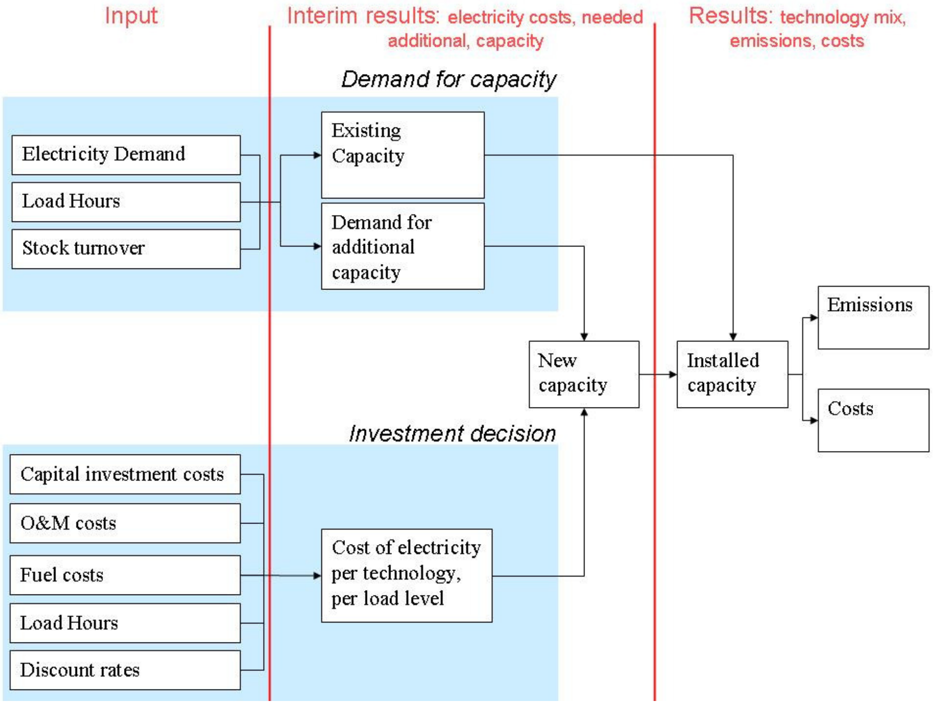

Figure 1: Overview of the model

2.1.1. Main characteristics of the model

For a detailed description of the model is referred to Vrijmoed et al. [3]. This section provides a brief summary. The model can be characterized by seven main elements:

1. Exogenous input of electricity demand and fuel prices: The electricity demand is taken exogenously. Electricity demand and fuel prices are in accordance with exogenous input from the PRIMES 2007 [2] baseline scenario. Electricity demand will be integrated endogenously in future versions of the model.

2. The use of a stock turnover: The model simulates the complete stock turnover of power plants. The stock turnover is derived from assumptions on the operational lifetime of power plants [3] and standing capacity from PLATTS database [4].

3. The use of load level structure. The structure of electricity demand is represented by a normalized load duration curve which is divided into five load levels. The standing stock of electricity generation capacity is divided over the load levels according to a preference order from base load to peak load [3]. In every load level the required additional capacity is determined based on stock turnover and electricity demand. The required new capacity is completed by implementing the technology with the lowest cost of electricity generation. The load level structure allows for the combined modeling of investment decisions and operational strategy. Plants are allocated to a specific load level for their whole lifetime.

4. The use of technological learning. The model simulates technological improvement as a result of increased experience. Investment costs reduce over time according to the capacity growth over time. Table 1 presents the assumptions on progress ratios included in the model.

5. Decision making is based on electricity costs and variation in discount rates. It is assumed that every actor has a critical discount rate against which decisions about technology choice are evaluated. The alternative with the lowest costs (kWh price for electricity from a power plant,) at the critical discount rate is selected. Evaluation is done over the lifetime of the equipment. Within the power sector not all actors will apply the same critical discount rates, because of different preferences. Therefore, a distribution of critical discount rates is used [3]. The main assumptions on electricity generation costs are presented in Table 1.

6. Special approach for intermittent sources. Intermittent energy sources (solar and wind) are not suitable for this load level structure, because their electricity production cannot be planned. Therefore, the costs of generating electricity with intermittent energy sources are evaluated against the average costs of generating electricity in the previous period. With increasing penetration of solar and wind, the costs rise as a result of: increased need for back-up capacity, increased level of discarded electricity and decreasing availability of high quality locations (cost supply curves). The model will install solar and wind capacity up to the level where its costs are equal to average electricity generation costs. The costs included are all based on cost supply curves.

7. Restriction of growth rate. To restrict technologies for rapid growth beyond market-wise feasible levels the costs are assumed to increase if annual growth rates exceed 30%.

2.1.2. Simulation of CCS in the model

Seven types of power plants with CO_2 capture are included in the model. Table 1 shows the type of technologies and main assumptions. The costs over the entire chain of CCS have been included, resulting from capture, transport and storage.

In the calculation of CO_2 transport costs, transport distance is assumed to be 200 km. A distinction is made between onshore and offshore transport costs. We include price differences as a result of economies of scale. Small annual flows of CO_2 go together with small pipeline diameters and high pressure drops. As a result, costs are relatively high for small annual CO_2 flows, and reduce with increasing CO_2 flows. Table 2 shows the assumptions on transport costs, which are adopted from Lysen, Jansen and van Egmond [5].

Table 1: Main data assumptions [3]

Type of plant	Efficiency	Progress Ratio	Sp. Inv. Costs (€/kW)	O&M costs (% of SIC)	Economic Lifetime (year)	Em. Coef. (kg CO_2/ GJ)	Capture efficiency
Nuclear	35%	96%	2400	3%	35	0	
Large hydro	100%	99%	1800	3%	50	0	
Small hydro	100%	99%	2350	2%	50	0	
Wind on-shore	100%	93%	1114	4%	20	0	
Wind off-shore	100%	91%	1856	4%	20	0	
Solar thermal	100%	85%	4336	4%	30	0	
Solar PV	100%	82%	5271	1%	25	0	
Geothermal	100%	95%	2800	7%	20	0	
Conventional Coal, Normal	46%	87%	1100	4%	35	95	
Conventional Coal, normal CCS	36%	98%	1800	5%	35	95	90%
Conventional Coal, Advanced	47%	98%	1163	4%	35	95	
Conventional Coal, Advanced CCS	35%	95%	1600	5%	35	95	95%
Coal gasification/CC	46%	98%	1600	4%	35	95	
Coal gasification/CC, CCS	37%	95%	2350	4%	35	95	90%
Oil Steam Electric	42%	100%	800	3%	30	73	
CC (gas)	58%	90%	500	4%	30	56	
CC (gas) CCS	50%	98%	920	5%	25	56	90%
Gas turbines (small)	30%	87%	610	4%	30	56	
Gas turbines (small), CCS	28%	98%	1852	2%	20	56	90%
Biomass combustion	36%	95%	1800	5%	30	110	
Biomass combustion, CCS	33%	98%	2400	5%	30	110	90%
Biomass gasification	44%	90%	2652	5%	30	91	
Biomass gasification, CCS	38%	92%	3500	5%	30	91	90%

Table 2: Transport costs of CO_2 in the Netherlands [5].

Annual CO_2 flow (onshore and offshore)	Transport cost: €/ton CO_2 (200 km)	
	Onshore	Offshore
< 1 Mton/year	13.6	21.1
1 to 4 Mton/year	6.8	10.5
> 4 Mton/year	3.4	5.1

The potential for CO_2 storage is derived from Simmelink et al. [6]. The assumptions on costs are derived from Hendriks et al. [7] and shown in Table 3. The costs of storage in coal seams are derived from Hamelinck et al. [8] and Wildenborg and van der Meer [9].

Table 3: Costs of CO_2 storage [7, 8, 9]

Storage type	Storage costs (€/ton CO_2)	Storage potential in 2030 (Mton CO_2)
Aquifer onshore	2.7	400
Aquifer offshore	7.3	300
Gas fields onshore	1.6	1620
Gas fields offshore	5.7	1150
Oil fields	1.6	40
Coal seams	15	400

2.2. Policy options included

A wide range of policy options is available in the bottom-up simulation model used. In this research, we use four policy options:

- CO_2 price
- Subsidies on investment costs for CO_2 capture facilities
- Feed-in tariffs for CCS and renewable energy sources
- CCS obligation to new coal fired and/or gas fired power plants

Feed-in tariffs are implemented as subsidies for electricity production, at the expense of the government. Feed-in tariffs for renewable energy sources are assumed to stay constant at the level of the Dutch SDE subsidy scheme. Emissions stored through biomass plants with CCS are, unless stated differently, accounted as negative emissions in a CO_2 price system. In this study we did not take nuclear energy into account.

2.3. Different modeling experiments

Different modeling experiments are done:

i) In different scenarios an annual increase of CO_2 price is assumed, varying from 0% to 10%. The starting value in 2008 is €25 per tonne of CO_2. The scenarios are examined under four different conditions:
  a) CO_2 stored from biomass is accounted for as negative emissions and transport costs for small annual CO_2 flows are high compared to large scale transport
  b) CO_2 stored from biomass is not accounted for as negative emissions
  c) CO_2 stored from biomass is not accounted for as negative emissions and transport costs for small CO_2 flows are at the same low level as large scale transport

ii) CCS subsidies are applied to capture investment costs
iii) The feed-in tariff for CCS is €0.03/kWh
iv) CCS standards represent a CCS obligation in new coal and gas fired power plants from 2020 onwards

3. Main findings

3.1. At moderate increases of carbon prices, the share of CCS is modest

The maximum share of CCS in 2030 in the total installed electricity generation capacity in the CO_2 price scenarios (i) is 17%. This high share is reached if the CO_2 price increases from €25 in 2008 to €204 in 2030. At low CO_2 prices rising up to €90 in 2030, the share is less than 15%. The limited implementation of CCS is a result of the gradually rising CO_2 prices. In the first years a lock-in of conventional fossil fuel fired capacity is induced, mainly due to a switch to natural gas fired plants. We do not take into account early retirement or retrofit of conventional plants with CCS. As a result, our scenarios reflect a situation which is favorable to lock-in. However, the costs of retrofitting a plant with capture facilities are higher than implementing CO_2 capture in a new power plant. In addition, critics point at uncertainties related to the possibilities for retrofit in existing power plants.

3.2. Reducing initial transport costs has a significant positive impact on the implementation of CCS

Reducing the transport costs of small scale transport to the level of large scale transport has considerable effect on the competitiveness of CCS. The CO_2 price at which CCS becomes competitive is reduced from €66/ton CO_2 (case b) to €37/ton CO_2 (case c). The results indicate that the initial costs of transport form a hurdle to the implementation of CCS and that policy aimed at reducing the initial costs of transport is possibly an effective option.

3.3. Different policies stimulate different CCS technologies, biomass CCS may become important

We find that different policy options stimulate different types of CCS. Figure 1 shows a distinction between fuel types: biomass, coal and natural gas. Figure 1 shows the capacity of CCS implemented in 2030, for a selection of policy scenarios.

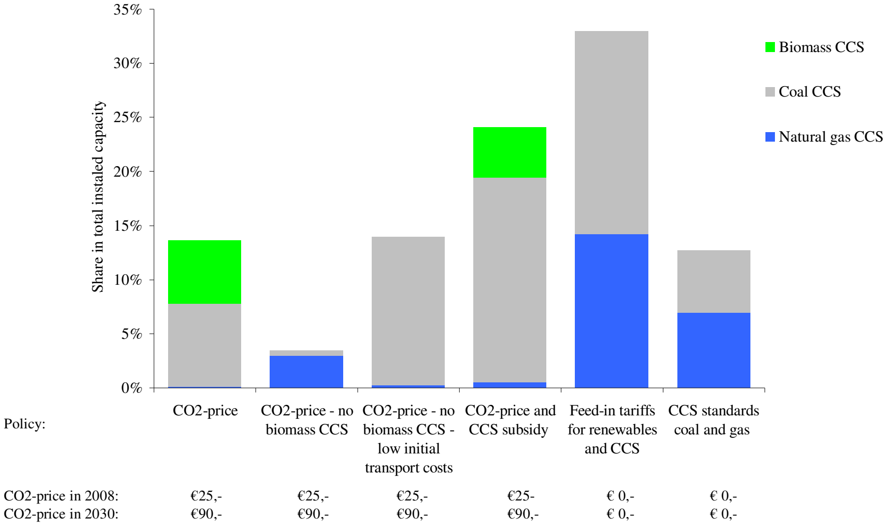

Figure 2: Share in installed capacity of different types of CCS in different policy scenarios.

The first column in Figure 2 shows a CO_2 price, when biomass CCS is included as an option. In this case biomass CCS plays a role in CO_2 mitigation. In the next column, negative emissions as a result of biomass CCS are not acknowledged. In this case gas plants dominate the CCS capacity. When the low scale transport costs are reduced, coal becomes the dominant CCS fuel (third column). The high initial transport costs influence mainly the share of CCS coal. The transport costs of coal plants are relatively high, because they have larger emissions and therefore more CO_2 to transport. The considerable share of CCS coal in the first column (with biomass CCS and high small scale transport costs) can also be explained through this argument. The implementation of biomass CCS upscales

CO_2 transport. As a result transport costs for coal fired CCS plants decrease as well and coal CCS becomes competitive. CCS subsidy (fourth column) is most beneficial for plants in which investment costs form the largest share in total electricity generation costs, in particular coal fired CCS plants. Feed-in tariffs and CCS standards impose about equal incentives to coal and gas fired power plants. The preference for coal or gas-fired power plants depends on the discount rate used and fuel prices.

3.4. It is most cost-effective in the long-term to stimulate both renewable energy sources and CCS.

Figure 3 shows the societal costs (discount rate 6%) and CO_2 emissions in 2030 for a selection of policy scenarios. The different scenarios are divided into three categories. Scenarios with one single policy option lead to the lowest annual costs in 2030, but also the highest emissions. The policy combinations are categorized as scenarios leading to a large role for CCS only or to a large role for renewable energy sources and CCS. In scenarios where renewable energy sources are stimulated, this is done through feed-in tariffs. The results in Figure 3 show that policy combinations with a large role for both CCS and renewable energy sources result in lower emissions, but cost about equal to policy combinations that stimulate CCS only. This is a result of the larger potential for technological learning of renewable energy sources. The results indicate that it is more cost-effective in the long-term to stimulate both renewable energy sources and CCS, than stimulating just one option, either CCS or renewable energy sources.

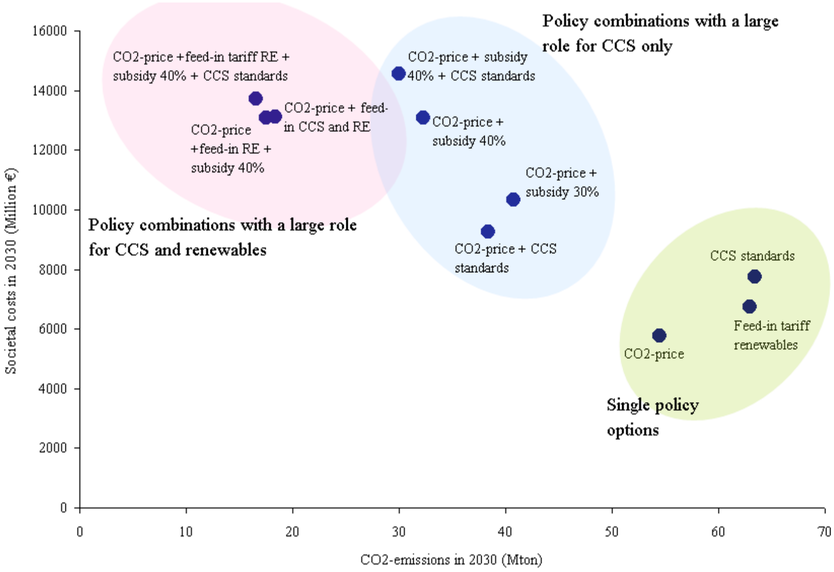

Figure 3: The societal costs in 2030 and CO_2 emissions in 2030 for a selection of policy scenarios (RE = renewables).

4. Discussion

The role of CCS in scenarios with a CO_2 price is small in our results, compared to a study performed by Van den Broek et al. [10]. This can be explained by two main differences. First, Van den Broek et al. [10] use an optimization model with perfect foresight, while we use a simulation model without foresight. Second, Van den Broek et al. [10] include the possibility of early retirement and retrofit. We do not include those possibilities. As a result, our scenarios easily lead to a lock-in of conventional technology. Especially with high CO_2 prices early retirement and retrofit might become feasible options. Nonetheless, the possibilities of retrofit are uncertain and questioned by critics.

In our analyses we assume that nuclear energy is not an acceptable option in the Netherlands. However, recently the discussion on nuclear energy has been restarted in the Netherlands. The most recent development in this field is the application for a concession to built two new nuclear power plants by the Dutch power company Delta. Extensive sensitivity analyses for nuclear energy are therefore recommended. The results show that CCS in combination with biomass has potential when the CO_2 stored is accounted as negative emissions. Other factors, which are not included in the analysis, might reduce this potential. First, biomass CCS is accompanied with high risks. Second, a societal discussion on the sustainability of biomass is ongoing and might affect the public and political support for biomass with CCS. Third, there is no system yet in the EU emissions trading scheme (ETS) to acknowledge negative emissions. Fourth, biomass with CCS is an expensive option and it will increase overall costs of electricity generation. Therefore, it is questionable whether stimulation of this option is desired.

5. Conclusions

If policy makers aim to stimulate CCS, specific policies should be put in place. This paper has analyzed the potential role of CCS in the Dutch electricity system, under different policy options. It was found that biomass energy in combination with CCS might be interesting, provided that negative emissions could be accounted for within the ETS. Further, reducing the initial transport costs may be effective. In addition, it was found that different types of policies stimulate different types of CCS. Finally, policy combinations that stimulate both CCS and renewable energy sources are most cost effective in the long run. Therefore, it is recommended to stimulate both CO_2 mitigation options simultaneously.

References

[1] VROM, 2007, Werkprogramma Schoon en Zuinig. Nieuwe energie voor het klimaat. VROM 7421, The Hague, September 2007

[2] National Technical University of Athens, 2007, PRIMES baseline scenario

[3] Vrijmoed S., Hoogwijk, M. Hendriks, C., 2008, The potential role of Carbon Capture and Storage, under different Policy Options. Simulating the Dutch Electricity Market by a Bottom-up model, Ecofys, Utrecht

[4] PLATTS, a division of the McGraw-Hill companies, Inc., 2006, UDI World Electric Powerplants Data Base

[5] Lysen, E.H., Jansen, D. and van Egmond, A., 2006, Afvang en opslag van CO_2: Vermindering van de CO_2 uitstoot van fossiel brandstoffen om klimaatverandering tegen te gaan, UCE and ECN

[6] Simmelink, H.J., Lokhorst, A., Vandeweijer, V., Rijkers, R., Benedictus, T. And van Eijs, R., 2007, Options for CO_2 storage in the Netherlands- time dependent storage capacity, hazard aspects, and regulations, TNO report 2007-U-R0564/B

[7] Hendriks, C., Graus, W. and Van Bergen, F. 2004. Global Carbon Dioxide Storage Potential and Costs. Ecofys Report Number EEP-02001, Utrecht

[8] Hamelinck, C.N., Faaij, A.P.C., Turkenburg, W.C., van Bergen, F., Pagnier, H.J.M., Barzandji, O.H.M., Wolf, K.-H.A.A. and Ruijg, G.J., 2002, CO_2 enhanced coal bed methane production in the Netherlands, Energy, Volume 27, pp. 647-674

[9] Wildenborg, A.F.B. and van der Meer, L.G.H., 2002, The use of oil, gas and coal fields as CO_2 sinks, TNO-NTG, IPCC workshop on carbon dioxide capture and storage

[10] Van den Broek, M., Faaij, A. and Turkenburg, W., 2008, Planning for an Electricity sector with carbon capture and storage, Case of the Netherlands, International Journal of Greenhouse Gas Control, Volume 2, pp. 105-129