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Incorporating the long term risk for deep emission reduction in near term CO_2 mitigation strategies

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Abstract

The future energy development of a country will differ substantially depending on the level of CO_2 emission reduction that is aimed at. To properly take the long term risk for drastic CO_2 emission reduction targets into account in the analysis of near term energy investment decisions, it is required to apply decision analysis methods that are capable to consider the specific characteristics of climate change (large uncertainties, long term horizon). Such decision analysis methods do exist. They can explicitly include evolving uncertainties, multi-stage decisions, cumulative effects and risk averse attitudes. The methods appear useful to select hedging strategies for CO_2 reduction. Hedging strategies for CO_2 reduction are sets of near term decisions which are most robust for various long term outcomes of climate change negotiations. The result of a hedging analysis gives a balance between the 'present' risk for costly premature emission reduction (when CO_2 reduction appears not needed) and possible 'future' risk for neglected CO_2 reduction in the past (when deep CO_2 reduction appears to be required). A stochastic version of a dynamic techno-economic energy model for the Netherlands was made. This model was used to quantify a CO_2 hedging strategy. Two outcomes of the climate negotiations were forecasted and probabilities were estimated for these outcomes. The results of the examples clearly showed that the calculated near term strategy differs from the results of conventional methods that do not have the capability to include uncertainty. The results of CO_2 hedging analyses indicate that it is better to take concrete action than to wait until uncertainty about CO_2 reduction targets is resolved.

Keywords: CO_2 emission reduction; Decision analysis methods; CO_2 hedging analyses

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1. Introduction

Energy consumption is the main source of greenhouse gas emissions. The choice between one energy technology or another determines to a large extent how much of a specific fuel is used, and thus how large the emissions of CO_2 will be during the active lifetime of the technology. Many energy technologies and the energy infrastructure have long technical lifetimes and long construction times. Therefore, energy is an area where long term planning is of crucial importance.

Since several decades scenario analysis is being used as an important decision support tool in this long term planning process. Various advanced modelling tools have been developed to support energy scenario analysis. In many countries, energy scenario analysis has also been applied to study the possibilities and consequences of reducing CO_2 emissions from the energy system. Such analyses have primarily been made on the national level, as energy policy mainly takes place at this level. Almost without exceptions these scenario studies followed deterministic approaches. This implies that uncertainty in reduction targets for CO_2 was not explicitly considered. Instead, a range of emission reduction targets was analyzed. In such an approach one analysis which measures and investments are required to achieve one or more 'certain' emission reduction targets. As such, scenario analysis remains oriented towards a 'learn-then-act' characterization of the decision problem: the uncertainty about the long term CO_2 reduction target is assumed to be resolved prior to the date at which action is taken [1].

However, the outcome of the international negotiations that take place over the next 10 to 20 years, is uncertain. Therefore, the national emission reduction allowances are also uncertain. They depend on the level of participation of developing countries in the convention, the total level of emission reduction and the use of flexibility increasing instruments. Regarding the current negotiations between countries under the Framework Convention of Climate Change (FCCC), it is hard to predict what the outcome will be. Uncertainty about emission reduction targets is likely to remain for some time. In the meantime the most worthwhile thing to do is to find out what to do in the near term under this long term uncertainty; one has to 'act-then-learn'.

Being faced with the climate change problem, the best a country can do now is to strive for a flexible energy system in the near term at limited additional cost. Such a near term energy system configuration should be a good starting point to realize all possible long term CO_2 emission reduction targets. Such a strategy is called a CO_2 hedging strategy [3].

This paper presents elements of hedging strategies for CO_2 abatements. This is done in two ways. First, in Section 2, some practical ideas for hedging in concrete energy investment decisions are listed and explained. Further, the main body of this paper (Sections 3–5) presents an analysis of how a hedging strategy for an entire country

[3] 'Hedging' means securing oneself against possible losses or keeping one's options open. The term hedging originates from financial analysis and operations research. In financial analysis it implies the diversification of the risks of adverse financial shocks. Hedging is seeking the optimal path in an uncertain world. Implicitly, hedging approaches involve the protection against possible negative consequences by preserving future flexibility in courses of action.

could look like. This latter part includes a model based analysis of a CO_2 hedging strategy for the Netherlands. In Section 6 conclusions about CO_2 hedging analysis are drawn and the main limitations are listed.

2. Irreversibility and flexibility in the energy system

At the moment when energy technologies, energy infrastructure and buildings are constructed, there is an opportunity to choose a less or more energy efficient type. After the construction has taken place, the energy consumption is more or less fixed for the lifetime of the equipment. One can of course modify or retrofit the original equipment but there are usually relatively high cost involved and there remains a limited potential for efficiency improvements. Thus, the initial construction of energy technologies, infrastructure and buildings create irreversibilities. The irreversibilities are of paramount importance for CO_2 reduction strategies. They determine for a large part the small size of low cost potentials for future emission reduction.

It is possible to reduce irreversibilities in the energy system to a certain extent by allowing more flexibility. This can be done by already anticipating at the moment of construction of the equipment that this equipment will later possibly be adapted. For many retrofit options it is indeed possible to comply with conditions that allow adaptation at relatively low cost, years after the original design. In this way the cost for abatement can be reduced and the potential for emission abatement can be enlarged. Many concrete flexibility increasing measures can be listed. Here, some examples are given to illustrate this concept.

In the built environment many options can be identified with a ‘once or never’ nature. The design and construction of a building largely determines the energy demand for its entire lifetime as the orientation of the building towards the sun, insulation and building mass become more or less fixed. Conditions to allow for a large future potential of efficient devices (such as heat pumps) also require conditions which are determined in the construction phase such as mechanical ventilation systems, low temperature heating systems and access to heat sources.

In industry, the duration of consequences is shorter than the decisions in the built environment except for choices with respect to the location of industry. The choice for a location determines the possibilities to use waste heat from other industries or from electricity generation. Demonstration of new and more efficient industrial processes is also an important hedging option for industry.

The energy infrastructure affects the conditions for CO_2 reduction options in other sectors, e.g. waste heat utilization and the deployment of electric heat pumps. The capacity of electricity grids need to be sufficient to allow for decentralized electricity generation and/or higher electricity use to allow for substitution of fossil fuels.

Location choices are also important in electricity generation as it determines use of waste heat and CO_2 removal. Demonstration and maintenance of knowledge is required to allow for the future penetration of large scale CO_2 free electricity generation based on renewables, nuclear power or CO_2 removal.

The flexibility increasing measures are concrete ‘hedging options’; they are means to keep options open. It is worthwhile to investigate the energy system in detail to identify the most prospective ones.

3. National hedging strategies: A modelling approach

This chapter informs how a CO_2 hedging strategy was constructed for the Dutch energy system. The model applied in this analysis, is a newly developed version of the MARKAL model. MARKAL (acronym for MARKet ALlocation) is a technology oriented model that has already extensively been applied to study the role of technologies in the future energy system, see, e.g. [2]. MARKAL is a cost-minimizing model that becomes most often applied to analyze complete national energy systems. The stochastic model minimizes the expected net present value (NPV) of the energy system over the total time period considered. It is able to determine such a mix of energy technologies that the end-use demand for energy services is met at least cost, while the environmental and reliability conditions are taken into account. The model can calculate cost-effective strategies to abate CO_2 emissions when a dynamic CO_2 reduction path is imposed. The supply and demand side of the energy system are considered simultaneously when cost-effective CO_2 reduction strategies are calculated.

The version of MARKAL that has been applied for this study explicitly contains different uncertain emission targets for the Netherlands. It is hard if not impossible to give an objective assessment of CO_2 emission reduction targets and the probabilities for these reduction targets. Therefore this hedging analysis has based the probabilities on subjective assumptions. The model can be applied to include the time cumulated emission budgets for CO_2. For climate change this is important as CO_2 accumulates in the atmosphere. Within the climate negotiation budget approaches receive more and more attention. It is relevant to learn how a country can best use its emission budget over time under uncertainty.

The model is also capable to analyze multi-stage decisions. Hence, the uncertainty in national reduction targets will reduce over time, and thus more pointed reduction targets for CO_2 in the long term will appear. Multi-stages are also important as alternative energy investments will have different levels of flexibility to reach eventual future CO_2 reduction targets, and this flexibility needs to be valued.

The database that is applied represents the Dutch energy system in quite some detail for the time period 2000 to 2040 and in nine steps of five years. The energy demand projections for 45 kinds of energy end-use are roughly in line with recent energy demand projections [3]. It is noted that nuclear energy is not allowed as an option. CO_2 removal from coal power plants has been considered. Further, it has been assumed that the technologies considered improve over time. All energy technology data have been taken from a recent technology assessment study [4]. Energy demands and energy prices are exogenous to the model. Their projections have been taken from an earlier scenario study [4]. The discount rate applied amounts to 5% per year.

It has been assumed that until the year 2020 it is uncertain by how much the Dutch CO_2 emissions have to be reduced. In 2020 it is assumed that the countries participating

Table 1
Distinguished states of nature and assumed corresponding CO_2 reduction budgets and probabilities attached

State of nature	CO_2 emission budget for period 1997–2042 [% of 1990 level]	Assumed probability
Unconstrained emissions	unconstrained	50%
Emission reduction	10%	50%

in the FCCC agree on long term national CO_2 reduction budgets. Then it appears that the Netherlands CO_2 emission budget for the period 2000–2040 is unlimited or the CO_2 emissions budget is equivalent to an annual reduction with 10% compared to the 1990 level for the time period 1997–2042. The associated probability assumptions are given in Table 1.

4. Results of CO_2 hedging analysis for the Netherlands

In order to be able to situate the effect of hedging, the results are compared with the results of 2 deterministic MARKAL calculations which correspond to the optimal energy system configuration for each of the 2 individual CO_2 emission reduction targets.

4.1. CO_2 emission levels

Until the period with 2015 as the central year, decisions to invest and/or to use energy technologies and primary fuels are taken without certainty about the time-cumulative CO_2 reduction target. The model will choose one optimal set of decisions which allows to achieve each of the long term emission reduction targets that have been distinguished. This set of optimal decisions is the CO_2 hedging strategy. This strategy has the lowest expected cost and it takes into account that it possibly has to comply with both emission targets. After 2015 it becomes clear which time-cumulated CO_2 reduction target has to be met. The strategy for the period 2017–2042 will depend on the state of nature.

The total effect of the results of the model can be monitored by considering the total emissions of CO_2 over time, see Fig. 1 . The CO_2 emission linked with the calculated hedging path are presented by the solid line between 1995 and 2015 in Fig. 1. After 2015, the CO_2 emission paths diverge from the common hedging path for the different realizations of emission reduction budgets (see the 2 solid lines after the year 2015. With the realization of the unlimited budget, the emissions of CO_2 increase rapidly after 2015 up to the same level as the deterministic unconstrained scenario. In case of realization of the restricted emission budget, CO_2 emissions will strongly decrease after 2015 (see lower solid line). Then the CO_2 emission level goes beyond the level of the deterministic scenario with restricted emissions to compensate the neglected reduction between 2000 and 2020.

The hedging strategy implies to adopt between 2000 and 2015 an emissions level that lies somewhere between the 2 deterministic cases. The emission level in the hedging

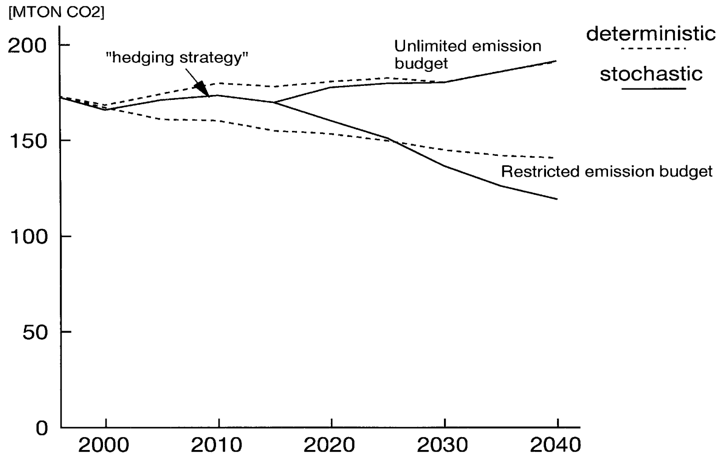

Fig. 1. CO_2 emissions as calculated with stochastic and deterministic calculations.

strategy is closer to the case with unlimited CO_2 emissions than to the deterministic case with restricted emissions. In this example it appears preferable to achieve some emission reduction before 2015 to insure oneself against possible excessive cost after 2015 which would be linked to a strategy of 'waiting too long'.

4.2. Capacity expansion for electricity generation

Many energy technologies have technical lifetimes in the order of 30 yr or more. Analysis of the energy investment decisions of long-lived equipment in a CO_2 hedging strategy is therefore very relevant. A few examples of the technology results of the scenario calculations are given in Figs. 2–4. They present the electricity production for 3 groups of technologies (coal fired electricity generation, gas-fired electricity generation

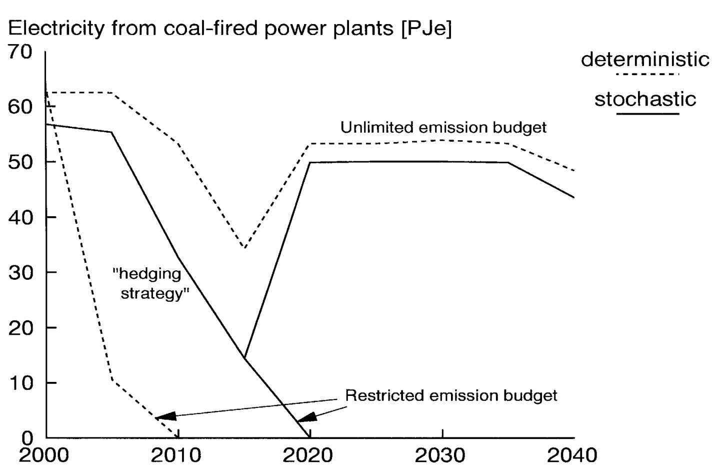

Fig. 2. Electricity generation with coal fired power plants in the deterministic cases and in the CO_2 hedging strategy.

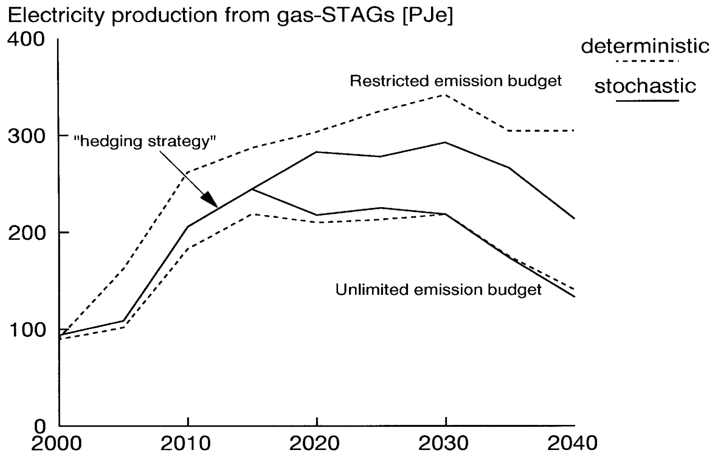

Fig. 3. Electricity generation with gas fired power plants in the deterministic cases and in the CO_2 hedging strategy.

and electricity generation with renewables) between 2000 and 2040. The hedging strategy has different effects for each group, as is illustrated below.

Fig. 2 shows electricity production with coal fired power plants. The difference in results between the 2 deterministic scenarios is striking. With an unlimited emission budget, the production of electricity which is based on coal shows a small drop in 2015 (see upper dashed line) due to the normal retirement of some existing power plants, but after 2020 the contribution of coal to electricity generation is almost back at the same level as in the year 2000. With restricted CO_2 emission budgets, however, coal fired power plants are used with very low annual running hours in 2005 and by 2010 the coal

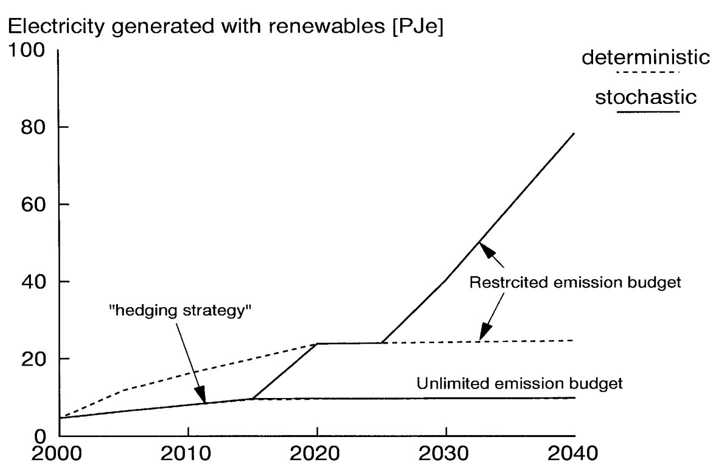

Fig. 4. Electricity generation with renewable technologies (wind turbines and solar PV) in the deterministic cases and in the CO_2 hedging strategy.

plants will even be early depreciated. The hedging strategy is modest in comparison with the 2 deterministic cases. In the CO_2 hedging strategy, shutting down existing coal-fired power plants is not justified due to the existing uncertainty about the stringent reduction target. Instead, the model defers such drastic measures until uncertainty disappears. The existing coal fired power plants are kept in operation until 2015 although the plants are no longer running in base load mode but in intermediate load. New coal fired power plants are not built before 2020. When the emission budgets become certain in 2020, either new coal fired plants are constructed (with unlimited emission budgets) or the remaining coal fired plants are taken out of operation (in the case that restricted CO_2 emission budgets become certain).

For electricity generation with gas-fired STAG power plants the situation is the opposite (see Fig. 3). In the deterministic scenario electricity generation with gas-STAGs is significantly higher with restricted CO_2 emission budgets than with an unlimited emission budget. Again the hedging strategy points at a more cautious strategy with the level of electricity production from gas-STAGs between the levels of the 2 deterministic scenarios. The electricity production from gas-STAGs never achieves the same level as in the deterministic case with restricted CO_2 emissions, also not after 2020. This is due to the fact that other technologies than gas-STAGs, which have lower CO_2 emissions per kWh (such as renewables), are required after 2020 to keep the CO_2 emission within the budget.

For electricity generation from renewables (wind turbines and solar PV systems), the results of the hedging strategy are equal to the results of the deterministic scenario with unlimited emission budgets (see Fig. 4). After uncertainty unfolds in 2020, the contribution either remains low or the role of renewables increases rapidly. The level of electricity production from renewables is ultimately also much higher than in the deterministic scenario with restricted CO_2 budgets.

4.3. Cost for CO_2 reduction

Uncertainty about CO_2 reduction targets is a cause of cost. If there was no uncertainty about the future CO_2 reduction target, it would be possible to make a plan of action for the energy system how the CO_2 emission target can be achieved as cost-effective as possible. The development paths of the energy system as calculated by each of the deterministic model runs follow such strategies. But as uncertainty does exist, the best one can do is to follow a flexible strategy with minimal expected cost, in other words to minimize regret caused by the uncertainties. The expected cost includes a weighting of possible strokes of luck and disappointments. Ex post (after the uncertainty disappears) the strategy is not likely to be optimal, however, ex ante the strategy reduces possible regret. This is always better than ignoring certain possible events. If that would be the case, it can be that a country is caught by surprise and that it faces very high cost linked with adjustment of the energy strategy within a short time span. Such a case can be referred to as an interrupted deterministic scenario. Hedging serves to avoid the high cost that arise from interrupted deterministic scenarios.

The MARKAL model calculates the annual cost of the energy system based on the cost of the technologies and the energy carriers with the application of a discount rate of

5% per year. The cost for CO_2 reduction have been calculated by comparing the annual cost of the energy system with the cost of the energy system in the unconstrained deterministic case.

The annual cost of the hedging strategy between 2000 and 2015 amounts to a few hundred million guilders. After 2015 the annual costs for CO_2 reduction will depend on the ‘state of climate’ that will occur, and are shown to diverge very strongly. For the unconstrained case the costs get less. The annual costs rapidly increase if the stringent emission target has to be achieved. Then, the total costs are higher than in the deterministic stringent reduction case.

5. Sensitivity analysis

The results of the calculations are sensitive to the assumptions that had to be made. Several assumptions that affect the size of the CO_2 hedging have been analyzed.

(a) Selection of the range of possible outcomes of uncertainties.

(b) Probability assumptions. The probabilities assigned to the ‘states of climate’ determine the relative weights of the discerned states of nature in assessing the CO_2 hedging strategy.

(c) Technological progress and/or availability of technologies. The assumptions about the availability and maximum potentials of energy technologies affect the cost and boundaries for emission reduction. If a technology like CO_2 removal is available, flexibility increases to achieve far-reaching emission reduction targets in the long term. If additional policies would be assumed, like Joint Implementation (JI) or research and development (R and D) for energy technologies, the flexibility for CO_2 reduction would also increase and the optimal CO_2 hedging strategy may change.

(d) Annual emission constraint vs. emission budgets for periods. In the discussion on targets and timetables for CO_2 reduction targets under the FCCC, the main focus is still on annual emission targets although emission budgets increasingly receive attention.

(e) Discount rate. The level of the discount rate determines the comparison of current and future financial flows.

(f) Moment in time that uncertainty about the emission budget disappears.

Sensitivity analyses have been reported in [5]. Table 2 summarizes the sensitivity of the hedging results to the list of assumptions. The results appeared most sensitive to the assumptions to substitute emission budgets for annual emission constraints. If, after

Table 2
Summary of results of sensitivity analysis

Issue for which assumptions were made	Size of impact on the results
Annual CO_2 constraints vs. CO_2 budgets	Very high
Range of possible reduction targets	High
Availability of new technology	High
Moment that uncertainty disappears	Medium
Probabilities of constraints	Medium

uncertainty has disappeared, one does not have to make up for neglected reductions before uncertainty about the target, the hedging strategy is much closer to the unconstrained emission case. The results are also highly sensitive to assumptions about the range of uncertain budgets under consideration and technology availability. Less sensitive are the results to assumptions on probabilities of targets and the moment in time that uncertainty unfolds.

6. Conclusions and recommendations

The following conclusions about the hedging approach can be drawn from the analysis presented in this paper:

CO_2 hedging strategies provide a comprehensive way to analyze CO_2 abatement strategies while properly accounting for uncertainties in future emission budgets.

Analysis of CO_2 hedging strategies helps to define policy strategies for CO_2 reduction with minimum regret.

The results of CO_2 hedging analyses suggest that it is better to take concrete actions soon than to defer them until uncertainty about CO_2 reduction targets is resolved.

Four kinds of action cover the relevant elements of CO_2 hedging strategies:

- not investing in energy technologies with relative high CO_2 emissions;
- not investing in the short term in expensive CO_2 abatement technologies;
- increasing flexibility of the energy system; many ways are available to do this at low cost;
- research and development (R and D) for new low CO_2 energy technologies to facilitate long term emission reduction.

Analysis of CO_2 hedging strategies allows to make a trade-off between these kinds of action and to design an optimal portfolio of actions.

It is important to note that the hedging analysis represented in this paper can certainly not give the ultimate answer about CO_2 reduction strategies. The limitations need to be considered.

For the application of the CO_2 hedging approach some critical assumptions need to be made. When a hedging method is to be explored, e.g. different CO_2 reduction targets need to be discerned and the probabilities of these targets need to be estimated and the process of unfolding of uncertainty over time has to be estimated. Currently, these assumptions can only be based on subjective judgements.

Until now, hedging methods have only to a limited extent been applied to address climate change considerations in energy investments. Applications of the hedging methods to more examples will increase insight in critical assumptions. One interesting direction will be to extend or replace the climate uncertainties with other uncertainties, e.g. uncertainties in energy prices or in energy technology development. Further, a more thorough analysis of national CO_2 hedging strategies, guided by policy makers, can provide a more pointed answer to the question what actions should be taken now to prepare for uncertainty in long term CO_2 reduction. For such studies, it is recommended to also quantify the benefits of CO_2 hedging strategies.

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