MSc Program
Renewable Energy in Central and Eastern Europe

Influence of emissions trading design options on investment patterns for electricity generation using real options analysis

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"Master of Science"

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Affidavit

I, **Diego MaximilianoManhard**, hereby declare

1. that I am the sole author of the present Master Thesis, “Influence of emissions trading design options on investment patterns for electricity generation using real options analysis”,38 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

Putting a price on greenhouse gas emissions is a fundamental policy for climate change mitigation. Without adequate policy instruments, it will be significantly difficult and expensive to put the world on track to meet the goal of limiting the temperature rise to 2°C. (OECD 2009)

Emission trading schemes seem to have gained credibility and are being implemented and planned in several countries and regions with the aim to reduce emissions while minimizing the costs of compliance. Organizations involved in the emission trading scheme as liable entities will need to manage their resources appropriately to remain competitive.

The electricity generation sector has particular characteristics that must be taken into account if emission trading systems are expected to be effective in reducing long‐term emissions. The long‐lived nature of the investments in the sector is critical, and inappropriate design choices for emission trading systems can lead to a locking-in of the high-emission infrastructure.

This Master Thesis analyzes how different emission trading design choices influence the decision to invest in photovoltaic technology instead of fossil fuel technology for the generation of electricity based on a real options model that will take into consideration uncertainties both associated with the costs of the generation technology and with the greenhouse gases trading market.

Gaining a better understanding on how such investment decisions are influenced by the modification of the emission trading scheme design choices will help to improve the efficiency of future emission trading schemes and to deliver a low-carbon future.

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List of Abbreviations

BOS	Balance Of System
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
ETS	Emission Trading Scheme
EU ETS	European Union Emission Trading Scheme
GHG	Greenhouse Gas
KP	Kyoto Protocol
kWh	Kilowatt hour
MWh	Megawatt hour
NPV	Net Present Value
NSW	New South Wales
NZIER	New Zealand Institute for Economic Research
NZU	New Zealand Emission Unit
OECD	Organization for Economic Co-operation and Development
PVIFA	Present Value Interest Factor of Annuity
ROA	Real Options Analysis
SME	Small and Medium Enterprise
WCI	Western Climate Initiative

1 Introduction

It is widely accepted within the scientific community that a substantial portion of global warming is being caused by anthropogenic events with greenhouse gases, which triggered about causing the preponderance of this warming (IPCC 2001).

Governments, international organizations and corporations have been seeking ways to address this issue by limiting the emissions generated by industrial and consumer practices.

As part of the international effort, the Kyoto Protocol was introduced in 1997 to reduce levels of GHG emissions at an average of approximately 5% within the period 2008-2012.

Various policy instruments, like command and control, taxes or permit allowance trading have been recommended to help achieve the Kyoto Protocol goals.

Emission trading schemes (ETS) seem to have gained credibility and are being implemented and planned in several countries and regions with the aim to reduce emissions while minimizing the costs of compliance. Organizations involved in the emission trading scheme as liable entities will need to rethink how to manage their resources appropriately in order to remain competitive.

Almost one third of all CO_2 emissions in the world are caused by the generation of electricity. Therefore, the introduction of low-carbon technology, especially in the electricity sector, is crucial to reduce considerable amounts of greenhouse gases. The electricity generation sector has particular characteristics that must be taken into account if trading systems are expected to be effective in reducing long term emissions. The long-lived nature of the investment in the sector is critical and inappropriate ETS design choices can lead to a locking - in of the high-emission infrastructure.

The core objective of this master thesis is to make a contribution to improve the design of ETSs by means of a better understanding on how the ETS design options affect the investment decisions made by electricity generators.

Besides the core objective above, the aim is also to increase awareness among developers of emission trading schemes that the investment behavior of the ETS participants is crucial for the long-term reduction of emissions.

A further objective of the master thesis is to present an alternative investment appraisal analysis to the traditional net present value (NPV) approach. The investment in technology in uncertain and dynamic situations like in an ETS environment is not an easy task. The uncertainty arises from the potential costs of allowances as well as the uncertainties of the costs of various renewable energy technologies. To manage these uncertainties in the investment, a real option analysis methodology, as presented in Joseph Sarkis and MaurryTamarkin's (2008) paper, was adopted.

The information paper "Reviewing Existing and proposed emission trading systems" by Christina Hood (2010) was used as the main source concerning ETS design options and key lessons from existing ETSs, and is the basis for the scenarios created later in the analysis.

Chapter 2 provides a general and brief introduction to emission trading systems.

A general introduction about investment appraisal using real options is presented in Chapter 3.

The method of approach applied for the analysis in the master thesis is described in Chapter 4.

Chapter 5 explains how the scenarios for the analysis were defined and the assumptions taken for the real option model, the photovoltaic technology and the fossil fuel technology, which were later used to run the model.

The outputs from the model for the different scenarios are presented in Chapter 6

Finally, Chapter 7 summarizes a conclusion and provides further research ideas.

2 Basics of emission trading

An emission trading scheme is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants (Stavins, 2001).

The roles and interaction of an environmental regulator and liable entities are the main aspects of an emission trading scheme.

The liable entities – those responsible for emissions (for example electricity generation companies) – must hold allowances to match their emission targets over a given timeframe. A cap on the total number of available allowances sets a limit on the total quantity of emissions. The limit on the total quantity of allowances, the rules to trade and the emissions control in the system are defined by the environmental regulator. Liable entities have the possibility to sell or acquire allowances with the goal to minimizing their cost of compliance. Trading of allowances establish a market price for emissions and promotes least-cost actions to meet the cap.

Figure 1 shows a basic example of an ETS with 4 participants and a cap on the total number of allowances of 50% of actual emissions. After the first period, the emissions target is reached. For participants 1 and 4, it was convenient to invest in emission-reduction infrastructure, lowering their emissions more than the target, and to sell allowances in the market. For participants 2 and 3, it was convenient to buy allowances on the market instead of investing in emission reduction assets.

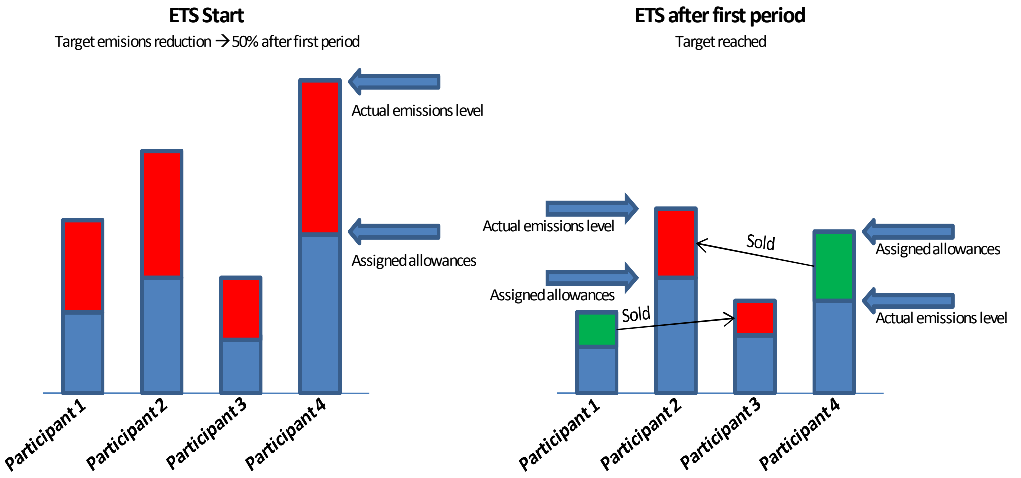

Figure 1. Basic ETS example

At the most basic level, environmental regulators simply need to define emission quotas (i.e. what an “allowance” represents and how it will be measured), determine how these rights will be allocated to participants (liable entities) in the scheme, ensure that rights can be enforced and set rules to enable trading.

Beyond the basic requirements for trading, most schemes include measures that attempt to reduce the impact of introducing carbon pricing on consumers and emissions-intensive sectors, promote investment certainty for clean technologies and support energy efficiency.

Greenhouse gas emission trading schemes (GHG ETS) are expanding world-wide, even in countries without ratification of the Kyoto Protocol. Figure 2 illustrates the current ETSs clustered using two different criteria: first, if the country where the ETS is implemented ratified the Kyoto protocol and second, if the ETS is set in force.

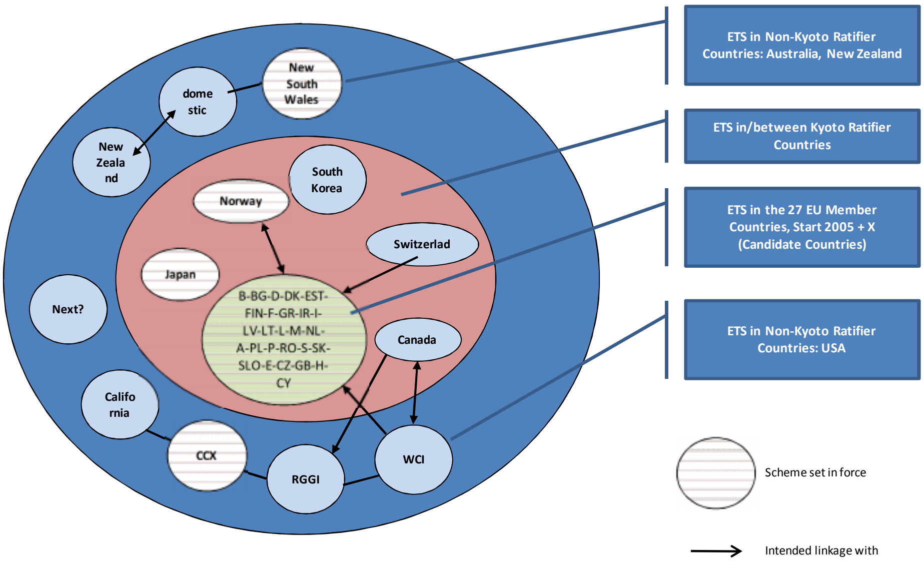

Figure 2. Emission Trading Schemes Overview (Source: Antes et ad (2008))

Some additional schemes (e.g. China) are presently in the design phase, and some of them are already designed but still not in the running phase.

3 Investment appraisal using real options

As mentioned in Sarkis and Tamarkin’s (2008) “Investment appraisal decision and ’business case‘ tools exist to explicitly evaluate various environmental technologies and especially for renewable energies. These tools are available to do organizational technology investment analysis (Austin 2003) and market based analyses from a policy perspective (ECN 2003). They rely on various policy scenarios related to GHG trading and pricing, and provide some insights to both investments and policy. Yet they rely on traditional financial models such as discounted cash flow techniques, e.g., Net Present Value (NPV).”

”Using traditional appraisal investment analysis, only the most likely or representative outcomes are modeled, and the ’flexibility‘available to management is ’ignored‘. The NPV framework (implicitly) assumes that management is ’passive‘ with regard to their Capital Investment once committed. Analysts usually account for this uncertainty by adjusting the discount rate (e.g. by increasing the cost of capital) or the cash flows (using certainty equivalents, or applying (subjective) ’haircuts‘ to the forecast numbers)“ Aswath (2005).

“By contrast, Real Option Analysis (ROA) assumes that management is ’active‘ and can modify the project as necessary. ROA models consider ’all‘ future outcomes and management’s response to these contingent scenarios.”Trigeorgis Lenos, Brosch Rainer and Smit Han (2010).

Because management responds to each outcome - i.e. the option is exercised - the possibility of having a negative outcome is reduced and /or greater profit is achieved. Risk is therefore reduced or "eliminated" under ROA, and uncertainty is accounted for using the techniques applied to financial options. Here the approach is to risk-adjust the probabilities - as opposed to the discount rate, as for NPV - and the cash flows can then be discounted at the risk-free rate.

4 Method of approach

The first step is to define the policy scenarios that are going to be compared throughout the analysis. In order to generate the scenarios, it was first necessary to perform a qualitative analysis on how the design options of the emission trading schemes influence the inputs of the real option model. A reference scenario was then defined and the other scenarios were created modifying only one model parameter each.

After that, the assumptions related to the real options model and the associated restrictions due to these assumptions were documented.

For the real option analysis it is necessary to compare the so called “option”, in this case a solar photovoltaic system as renewable energy technology, with a traditional fossil fuel technology to generate electricity. In order to compare both technologies, the net present value of the costs is used. That means that the best choice will be the technology with lower costs. Such comparison implies that the electricity price in the market is the same for both generators. For the analysis it is assumed that the traditional fossil fuel technology to generate electricity is operating to cover the necessary electricity demand, and the photovoltaic technology system will be installed only if its net present value of the costs is lower than the one for the traditional fossil fuel technology. Otherwise the investment in the photovoltaic technology will be delayed and analysed in the next period and the electricity demand will be covered with the fossil fuel technology further.

For the solar photovoltaic technology, some cost-related figures were estimated and presented in Chapter 5.4.

In the case of the fossil fuel technology electricity generator, the analysis was based on an “average” generator combining coal, natural gas and oil, not only for cost but also for emission figures purposes. Assumptions for the fossil fuel electricity generator are documented in Chapter 5.4.

After having all the necessary figures, the real options model presented in Sarkis and Tamarkin (2008) is run for all the scenarios except for scenario 4. For scenario 4 it was used the ad hoc method to keep the uncertainties separate as outlined in Copeland and Antikatov (2001). In Chapter 5.2 is explained why the scenario 4 needs to be handled differently than the other scenarios. The following steps summarize the method applied to evaluate investment decisions for the analysis:

1. The price of the emission allowances is calculated through a binomial lattice for all the 4 analyzed periods. The current value and the long-term growth rate of the emission allowance price were defined for each scenario in Chapter 5.1.
2. The cost of installing the new technology is calculated through a lattice for all 4 periods as well. The current value and the long term growth for the cost of installation of the new technology were defined for each scenario in Chapter 5.1.
3. The risk-neutral probabilities for up and down moves are calculated for both uncertainties as outlined in Copeland and Antikatov (2001).
4. The lattice is constructed starting from the last period. The NPV here is the value of the **costs** associated with production of 1MWh of electricity for the

next 4 periods. In order to evaluate the execution of the option (meaning to invest in the renewable technology or not), the NPV of the electricity generation using fossil fuels is also calculated for each node of the lattice. If the NPV for the option is higher than the NPV for the traditional electricity generation, then for the calculated node the option will not be exercised and the value of the option will be zero. Otherwise, the option will be exercised and the value will be the NPV of the option.

5. From the final period the lattice will be worked back calculating for all the backward nodes the value of the option to delay the investment in renewable technology, and on the other hand the value of exercising the option (or to invest in renewable). The risk-neutral probability for up and down movements calculated in step 3 is used to calculate the value of the option to delay the investment in renewable technology. The value of the option to invest in the renewable technology for the specific node is the higher value between both alternatives (delay or exercise the option). If the value to delay the option is higher than the value to exercise it, than the best choice will be to delay the investment and wait until the next period to evaluate the investment again. If the value to exercise the option is higher than the value to delay, then the best choice will be to invest in renewable technology.
6. The optimal time to exercise the option (invest in renewable technology instead of in fossil fuels for electricity generation) would be the first period in which the NPV of installation is higher than the values of the option to delay.

The result of the analysis for each scenario is an investment decision matrix with the value of the investment in all the nodes of the lattice. In order to be able to compare the different output matrixes, defined metrics were used, which are presented in the results chapter.

Finally, conclusions were drawn based on the results of the analysis of all scenarios.

5 Scenarios definition and assumptions

5.1 Definition of policy scenarios for the analysis

Modifying design options of the ETS will have direct and indirect effects on the model inputs used in the real options analysis.

The policy scenarios definition was split in 2 steps:

- The first step is to find the qualitative effects in the input of the model changing a design option in the ETS. By qualitative effect it is understood either an increase, no change or a decrease in the input of the model if the design option is changing.
- The second step is to quantify the inputs of the real option model for each scenario.

The following table summarizes the qualitative effects in the real option model inputs, modifying design options of the ETS based on the key lessons from the existing ETSs presented in Hood (2010):

Table 1. Qualitative effects in the real options model inputs modifying ETS design options

			Inputs to Real option analysis			
			market price of CO2 allowances	**Volatility of allowance price**	**Long term real growth rate of allowance price**	**Non investment specific effects**
ETS design options	**Coverage**	**broad coverage -> designed to deliver external commitment**	↓ (1)	↓		certainty of delivery an external commitment
		Sector specific coverage -> significant emission reduction locally	↑	↑		aim to reduce emissions locally
	Cap setting	**absolut cap**				Focus on achive the specified level of emissions
		output based cap				Focus on tight the cap to the production level or GDP
		high cap -> close to projected BAU emissions	↓	↑ (2)		
		low cap -> tight targets	↑			
		banking of allowances permitted		↓		Risk that overallocation creeps in the following trading periods
		banking of allowances not permitted		↑		
		Ambitious long term cap			↑	
	Long term investment signa	**signal emission caps far in advance**		↓		
		floor price for allowances	higher price certainty (3)			
		Political concensus for the ETS -> scheme repealed or radically changed with change of government	↓	↑		
	Allocation of Allowances	**free**		↑ (4)		
		auctioned		↓		Governemet revenue could be used to reduce consumers impacts from carbon price or subsidize low carbon technology

(1) As presented in Hood (2010) could be also in the opposite way, once cheaper abatement opportunities are exhausted in the power sector, more expensive emission reductions will be implemented elsewhere. The economy-wide emission price will be set by the most expensive

technologies employed across all sectors -> high impact on consumers and windfall profits for electricity generators

(2) High volatility due to risk of oversupply of allowances, when emissions turn to be lower than the level of the cap

(3) As with price caps, the calibration between overall emission caps and appropriate price floors will be difficult to set correctly in advance and may well need adjustment so that allowances trade within the desired price range. Investors will consider the possibility of future political adjustments to the floor price in their risk assessments, rather than taking price floor at face value (Stern, 2006)

(4) Significant free allocation will decrease market liquidity, potentially increasing price volatility

Based on the qualitative analysis, six policy scenarios were created and the model inputs were estimated for each scenario. For all the policy scenarios the decision to invest in photovoltaic technology instead of in fossil fuels to generate energy within the policy framework is being evaluated.

For all scenarios an inflation rate of 2% is expected, which will increase the nominal growth of the emission allowance as well as the costs of the PV technology.

Scenario 1 – Reference scenario:

The emission allowances in this scenario could be acquired either during an auction process at the beginning of the trade period or at the free market. The carbon-free electricity generators do not get any subsidies or green certificates. For this scenario, an absolute cap equal to the cap set for the EU ETS Phase II is taken into consideration, which is 6.5% below the 2005 emission levels.

The price of allowances among Annex B countries has been estimated to be between 5 and 58 Euros per ton of CO2 based on the following models: 1) AIM, EPPA, G-Cubed, GTEM, MS-MRT, Oxford and SGM: Energy Journal (1999). The costs of the Kyoto Protocol: A Multi-Model Evaluation. Special Issue. 2) Green and WorldScan: OECD (1998) Economic Modelling of Climate Change. Report of an OECD Workshop. OECD Headquarters, 17-18 September, 1998 (http://www.oecd.org/dev/news/environment/modelling.htm). 3) Poles: Coherence (1999) “Kyoto protocol and emissions trading: potential cost savings and emission reductions” in Economic Evaluation of Quantitative Objectives for Climate Change (http://europa.eu.int/comm/environment/enveco/studies2.htm). 4) GEM-E3 World: Capros (1999) GEM-E3 Elite research project. Final report to the European

Commission, DG Research. Primes, GEM-E3 and Poles models have been developed through the support of DG Research non-nuclear energy programme.

The allowance prices within the EU ETS have varied between 13 and 16 Euros per ton of CO_2 since mid 2009 until mid 2011. The prices dropped since mid 2011 because of overabundance of permits in the marked caused mainly due to the European financial crisis and the market reaction after Canada, Japan, Russia and New Zealand have decided not to commit the second liability phase of the Kyoto Protocoll defined during the Durban climate change conference in November/December 2011.

Assuming that the reasons of the actual drop of the permits prices is a short term market externality, the initial market price for the allowance in this scenario is assumed at 14 Euros. The long-term real growth rate for the allowances was estimated at 3.3%, which is the same increase used by British Petroleum in its internal trading program.

The lifetime electric power output costs for Photovoltaic assumed for this scenario is 105 Euros per MWh as mentioned in Chapter 5.4, with an estimated long-term cost reduction of 1.1% per year.

Scenario 2 – Green certificates for renewable technology and free allocation of allowances for emitters

The emission allowances in this scenario are allocated for free using "grandfathering" for the fossil fuels electricity generators. The electricity generators using renewable technology get for free 0.767 allowances per Megawatt hour (1 allowance represents 1 metric ton of CO_2), which is the emissions average for the European fossil fuels electricity generators, and are able to get revenues from selling the allowances on the market.

The cap calculated in this scenario is the same cap as in scenario 1. For our calculation it is assumed that the electricity generator using fossil fuels gets individually the same cap than the overall ETS cap of 6.5% below the 2005 emission levels. That means that the electricity generators using fossil fuels are responsible to cover 6.5% of their own emissions with allowances.

All other parameters are the same as in scenario 1.

Scenario 3 – Absolute cap reduction:

The structure of this scenario is similar to that of scenario 1, where the emission allowances could be acquired either during an auction process at the beginning of the trade period or at the free market. The electricity generators with renewable technology do not get any subsidies or green certificates.

The absolute cap of the ETS is modified from 6.5% to 21% below the 2005 emission levels (the same amount planned for the EU ETS Phase III). According to the qualitative analysis conducted in Section 5.1, the initial allowance price will be increased and is assumed at 18 Euros per ton CO_2. It is also assumed in this scenario that the cap will be reduced 1.74% yearly. The yearly reduction of the absolute cap will increase the long-term real growth rate for the allowances price from 3.3% to an assumed value of 5.1%.

Scenario 4 – Favorable conditions for PV costs

This scenario is defined with the same parameters than for Scenario 1, only modifying the long-term cost reduction for the PV from 1.1% to 6%. For this scenario, the highest estimated long-term cost reduction of 6% as shown in Section 5.4 will be considered.

Due to the fact that in this scenario the nominal growth of the PV costs will be -4% (2 % increase due to inflation rate and 6% decrease due to long-term cost reduction), it is no longer possible to model the uncertainty using a binomial lattice. The PV costs are modeled for this case using a multiplicative or geometric process with a yearly nominal growth of 4% and a volatility of 20% according to Copeland and Antikarov (2001). Although the uncertainty for the real option analysis has to be modeled using another approach than for the other scenarios, the calculated value of the option within the lattice is comparable for all the scenarios. The model used to run this scenario is explained with more details in chapter 5.2.

Scenario 5 – Investment subsidies for renewable technologies:

Within this Scenario all the electricity generators have to acquire emission allowances during an auction process at the beginning of the trade period or at the free market. The carbon-free electricity generators do not get green certificates. Part of the revenue generated from the allowances auction will be used to subsidize 30% of the investment costs for renewable electricity generation technologies.

It is assumed that 30% subsidies for the investment costs of renewable technology allows to reduce 20% the lifetime electric power output costs for the renewable energy technology. Within the lattice, the lifetime electric power output costs for the renewable energy technology will be generated with the same long-term cost reduction of 1.1% as in scenario 1. An additional 20% reduction will be applied to all nodes because of the subsidy.

Scenario 6 – Setting floor prices for allowances:

This scenario is defined with the same parameters than for Scenario 1. The government will set in this case a floor price for the allowance in the market. Price floors are intended to provide greater certainty for investors in low-carbon technologies by guaranteeing a minimum price.

The floor price is assumed at 10 Euros for all 4 periods of the analysis.

The following table shows the scenarios building overview for the analysis:

Table 2. Overview of policy scenarios created for the analysis

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Allowances allocated for free and green certicates for renewables?	No	**Yes**	No	No	No	No
Absolut cap for allowances (percentage of 2005 emissions)	93,50%	93,50%	**79,00%**	93,50%	93,50%	93,50%
Cost average for electricty generated using fossil fules in the EU [Euro/MWh]	45,00	45,00	45,00	45,00	45,00	45,00
CO2 Emissions for an average utility generator using fossil fuels EU [tons/MWh]	0,767	0,767	0,767	0,767	0,767	0,767
Yearly absolut reduction of produced CO2 for an average electricty generator using fossil fuels in EU [tons/MWh]	0,004	0,004	0,004	0,004	0,004	0,004
Initial market price of CO2 allowances [Euro/ton CO2]	14	14	**18**	14	14	14
Long term real growth rate of allowances price	3,30%	3,30%	**5,10%**	3,30%	3,30%	3,30%
Lifetime electric power output costs of renewable option [Euro/MWh]	105,00	105,00	105,00	105,00	105,00	105,00
Long term cost reduction for renewable technologies due to experience and economy of scale	1,10%	1,10%	1,10%	**6,00%**	1,10%	1,10%
Lifetime electric power output cost reduction due to subsidy	0,00%	0,00%	0,00%	0,00%	**20%**	0,00%
Floor price set for allowances (Euro/ton CO2)	No	No	No	No	No	**10%**

5.2 Real options model assumptions and characteristics

The analysis takes into consideration two sources of uncertainty, as described by Sarkis and Tamarkin (2008) in their paper. The first source is the exercise price of the option to invest. This cost is the life cycle costs of the renewable energy technology and the uncertainty in these costs occurs from the uncertainty in the speed of learning or experience effects from greater production (economy of scale). The other source of uncertainty is the price of the emission credits.

To model the NPVs a quadranomial approach is used in all the scenarios except for scenario 4, as outlined in Copeland and Antikarov (2001). In this approach, all outcomes are nodes on a two-variable binomial lattice. It is assumed that both sources of uncertainty follow a multiplicative binomial process and are independent. Due to the fact that in the scenario 4 the lifetime output costs for the photovoltaic technology has a negative nominal growth, it cannot be anymore represented by a binomial process. Thus, the lifetime output costs for the scenario 4 follows a geometric process where the up-movement factor and the down-movement factor are related to the nominal growth and an independent volatility. As outlined in Copeland and Antikarov (2001) the uncertainties for this case cannot be resolved simultaneously as in the case of the quadranomial lattice and with minimum loss of accuracy, the uncertainty is modeled by alternating the uncertainty in the price of the emission credits with the uncertainty in the exercise price of the option. Each period is split in 2 subintervals and within each subinterval is resolved one of the uncertainty using either replicating portfolios or risk-free rate approach. This solution is crude although straightforward and simple. The number of nodes after 4 periods for the scenario 4 is 256 compared with 25 nodes for the other scenarios using quadranomial lattice.

A one-year time step is used and because of this large time step the model is not exact. That is, the model used for the analysis is only close to being exact if the terms in Δt^2 and higher powers of Δt are ignored. If $\Delta t = 1$ in years, error creeps in because Δt is not small. Furthermore, the lattice is carried out only for 4 periods. Although the quadranomial lattice is recombining, with two sources of uncertainty the number of nodes grows quickly (at a rate of $(t+1)^2$). The number of nodes growths even faster (at a rate of 2^{2*t}) if the uncertainty is resolved by alternating both uncertainties as in scenario 4. The purpose of the analysis is to compare the outputs of the real option analysis for different policy scenarios rather than to get exact values for the option, and policy implications might still be inaccurate.

Since there is no a priori reason to assume any particular probability for an up or down move through the lattice, a probability of 0.5 is assumed for both uncertainties and for all scenarios.

It is estimated that the risk-free interest rate is the approximate current yield on 20-year U.S. Treasury bonds and is equal to 4.5%. It is also assumed, that whenever the technology is installed, its cost will not vary during the following 4 years and the amount of offsets it can generate will not change. Thus, for valuation we need to find present values of 4-year annuities, the present value factor of which is $PVIFA_{4,r}$ where 4 is the number of periods and r is the appropriate discount rate.

Assuming that the uncertainty follows a multiplicative binomial process implies that the volatility is a function of the long-term growth rate. By fixing the long-term growth rate, the volatility is determined automatically. This is another reason why for scenario 4, where the volatility and the long-term growth rate for the costs of the photovoltaic technology were independently estimated, it is not possible to model the uncertainty with a multiplicative binomial process.

5.3 Assumptions for fossil fuel technology

The amount of GHG reduction from introducing renewable energies is based on the trade-off of marginal improvements of renewable energy technologies when compared with fossil-fueled generation of electricity.

Table 3 shows for the average life cycle emissions for the different electricity generation technologies.

Table 3. Lifecycle greenhouse gas emissions estimates for electricity generators (Source: Sovacool 2008)

Technology	Description	Estimate (g CO2e/kWhe)
Wind	2.5 MW offshore	9
Hydroelectric	3.1 MW reservoir	10
Wind	1.5 MW onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW run-of-river	13
Solar thermal	80 MW parabolic trough	13
Biomass	various	14-35
Solar PV	Polycrystaline silicon	32
Geothermal	80 MW hot dry rock	38
Nuclear	various reactor types	66
Natural gas	various combined cycle turbines	443
Diesel	various generator and turbine types	778
Heavy oil	various generator and turbine types	778
Coal	various generator types with scrubbing	960
Coal	various generator types without scrubbing	1050

According to the data published by the European Commission Statistics Office (EUROSTAT nrg_105a) in 2007, 3.9%, 20.1% and 28.6% of the electricity in Europe was generated using oil, natural gas and coal as fuels, respectively.

Using the average amount of emissions for coal, gas and oil from Table 3 and the share of the electricity production by fuel in the European Union, a weighted average was calculated in order to estimate the emissions for an average electricity generator using fossil fuels in the European Union.

Thus, the emission generated by an average electricity generation using fossil fuels used in the analysis is estimated at 0.767 metric tons of CO_2 emissions per MWh.

Due to the fact that the technology for the fossil-fuel electricity generation is being continuously improved, it will be assumed that the emissions of the average electricity generator using fossil fuels will be reduced 0.004 tons CO_2/MWh per year.

In order to be able to compare the net present values for the electricity generation costs of fossil fuel and renewable technology, it is necessary to estimate average costs for the electricity generators using fossil fuels. The analysis will be based on the figure presented in the study performed by the Joint Research Center of the European Commission (Tzimas et al. 2009), making a cost average of 45 Euro/MWh for electricity generated from fossil fuels in the European Union.

5.4 Assumptions for the PV technology

A PV Module is an array of packaged solar cells that convert solar energy directly into direct-current (dc) electricity. There are two major types of solar cells, Crystalline Silicon and Thin-Film PV. The solar cells are the core elements and costs for the PV system. Additional equipment referred to as the balance-of-system (BOS) is necessary to run the PV system and need to be included in the costing. BOS requirements are site-specific due to power, reliability, environment, and power storage needs. BOS components may include: mounting equipment, tracking systems to follow the sun, DC/AC power inverters, power storage batteries, and protective electrical hardware (Notton et al. 1998).

Thus there are no truly representative costs for this system since these may depend on the alternatives and characteristics of the installation and PV technology chosen and their efficiency. The BOS may represent 2/3 of the costs of a system according actual estimations. But this ratio may not remain the same since there are differences in the “learning curves” for PV modules and BOS, where learning for PV modules is global and BOS learning is local (Shaeffer and de Moor 2004).

The German Federal Association of Solar Industry (BSW-Solar) raises quarterly price data for photovoltaic systems. The institute EUPD Research surveyed on behalf of BSW-Solar 100 representative PV system installers and thus determines the photovoltaic Price Index.

The average prices for turnkey installed PV system with a maximal peak power of 100KW for Q3 2011 will be used as a base for our calculations.

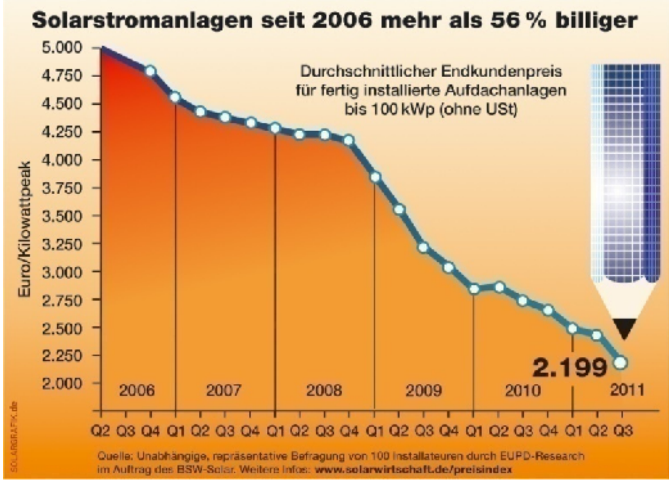

Figure 3. Average price for turnkey installed PV systems with a maximal peak power of 100 kW

The conditions of the yearly full load hours of a PV system for Denmark (840 hours per year) and Spain (1400 hours per year) are taken into account to calculate the lifetime electric power outputs of the PV system.

A solar irradiation database and software PV tool for the european territory are available in the Photovoltaic Geographical Information System[1] developed by the European Commission.

The following parameters were considered for the full load hours calculations:

Table 4. Parameters applied for PV system full load hours calculations

Parameters	Denmark	Spain
Radiation Database	**Classic PVGIS**	**Classic PVGIS**
PV technology	**Crystalline silicon**	**Crystalline silicon**
Optimized slope for solar panels	**38°**	**32°**
Estimated system losses	**14%**	**14%**
Estimated losses due to temperature	**8.4%**	**11.9%**
Estimated loss due to angular reflectance effects	**3.1%**	**2.7%**

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[1] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php; visited 17.9.2011

It is also assumed that the lifetime of the PV system is of 20 years due to the fact that most PV panels are guaranteed for over 20 years.

So their lifetime electric power output costs about $2199 \frac{\text{Euros}}{\text{KWp}} / \left(840 \frac{\text{hours}}{\text{year}} . 20 \text{ years}\right)$ = $0.13 \frac{\text{Euros}}{\text{KWh}}$ = $130 \frac{\text{Euros}}{\text{MWh}}$ for Denmark and $79 \frac{\text{Euros}}{\text{MWh}}$ for Spain. An average in the lifetime electric power output costs for the PV system of $105 \frac{\text{Euros}}{\text{MWh}}$ will be assumed for the analysis.

Based on the estimations from Schaeffer and de Moor (2004), the cost reductions are expected to be anywhere from 1% to 6% per year over the next few years.

6 Analysis results

Each scenario was introduced in the real option model and the output of the model is the investment decision lattice. Each node of the lattice shows the following investment decision information:

1. The value of the option to invest in renewable energy technology instead of a fossil fuel technology.
2. The investment choices for each node:
    a. Exercise the option: In this case the net present value of the investment in renewable energy technology is greater than the value of the option to delay the investment. For the last period the option will be exercised only if the net present value of investment in renewable technology is greater than the net present value to invest in a fossil fuel technology.
    b. Delay the option to invest in renewable technology: In this case the value of delaying the option is greater than the net present value to invest in the new technology.
    c. Do not exercise the option: In this case the value of delaying the option is zero or, for the last period, the net present value of investment in renewable technology is lower than the net present value to invest in fossil fuel technology.

The investment decision lattices for each scenario are presented in Annex I.

The following metrics were defined in order to be able to compare the output of the model for the different scenarios:

Metric 1 - Value of the option to delay the investment of renewable technology at period zero:

This is the value of the option in the first node of the lattice at period zero. The reason why the value at period zero is relevant for the scenarios comparison is because the value of all the nodes in the lattice and their risk-neutral probabilities are considered in its calculation and could be interpreted as the overall value of investment in renewable technology within the analyzed period.

In the real option analysis, this value could be also interpreted as the upper limit of a potential partial investment in an initial phase of the project in order to ensure the investment opportunity (i.e. some licenses or governmental permits for the renewable installation in a specific place).

The results are presented in Figure 4:

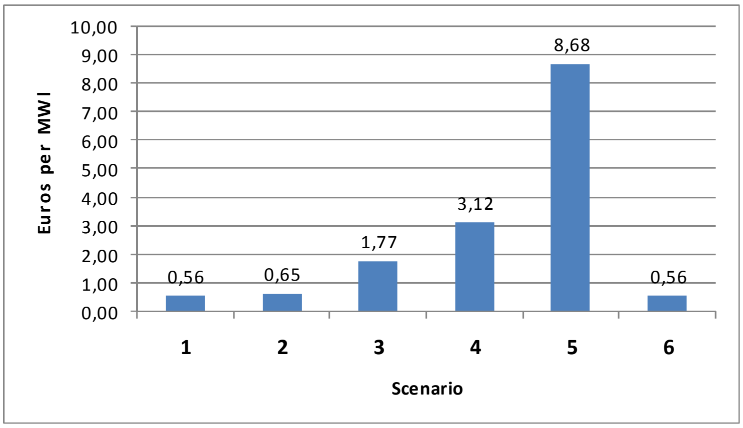

Figure 4. Value of the option to delay the investment in photovoltaic technology for electricity generation at period zero

Metric 2 – Investment decision distribution for each period:

For each period and each scenario the share of the investment choices will be calculated (exercise the option, delay the option or do not exercise the option).

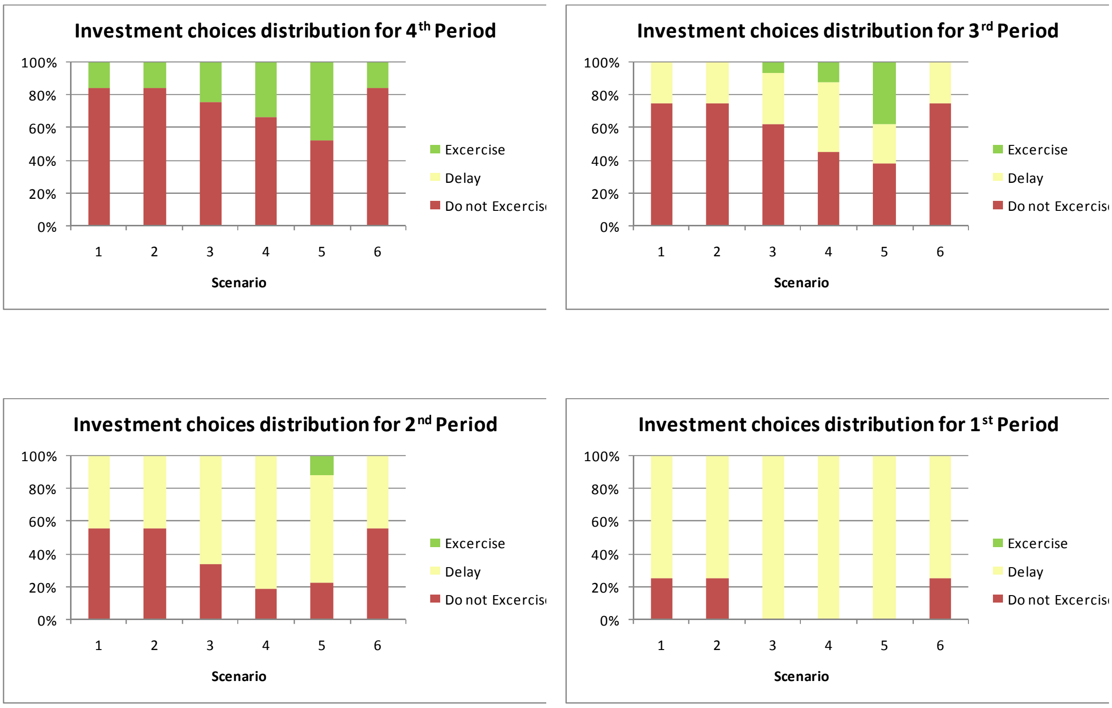

Figure 5. Investment choices distribution for the different scenarios

For scenarios 1, 2 and 6 in more than 80% of the nodes for the fourth period and more than 70% of the nodes for the third period investment in fossil fuels technology generates a higher value than to invest in PV technology. The comparison of the option value at time zero shows for these 3 scenarios a value close to 0.6 Euros per MWh.

For scenario 2, the free allocation of allowances for the fossil fuels technologies using grandfathering (meaning that the fossil fuels technology do not need to buy the allowances on the market as in scenario 1) almost compensates the additional revenues generated at the photovoltaic technology due to green certificates.

In scenario 6, setting a price floor of 10 Euros for the emission allowance (which represents more than 71% of the market price for the allowance in this scenario) did not bring any change in the investment appraisal compared with scenario 1.

An improvement in the value of the option at time zero compared to scenario 1 is first shown in scenario 3. The investment choice of exercising the option is increased from 16% to 25% for the fourth period. In the third period of the analysis there is even one case in the lattice where exercising the option is higher than the value to delay it (after 3 increases in the allowance price and 3 decreases in the cost of the PV).

In this scenario, an initial reduction of the ETS absolute cap plus a yearly planned reduction of the cap were assumed, compared with scenario 1. This modification of the cap leads to an estimated increase of the allowances price from 14 to 18 Euros per ton CO_2, as well as an estimated increase in the long-term growth for the allowance price from 3.3% to 5.1%. The increase in the price and the long-term growth for the allowances enhances the chance to introduce the photovoltaic technology for electricity generation.

Scenario 4 shows an improvement in the value of the option at time zero higher than 5 times the value at scenario 1, assuming that the long-term cost reduction for photovoltaic will be increased from 1.1% to 6%. The percentage of the nodes to exercise the option increases from less than 20% in scenario 1 to more than 30% in the fourth period. In the third period of the analysis, the “positive” investment choices (exercise the option and delay the option) increase from 25% to 54%.

A detailed comparison of scenarios 3 and 4 shows the difference in the sensitivity of the value of the option at time zero to the price of the allowance and to the costs of the PV. The price of the allowance was increased more than 28% at period zero (from 14 to 18 Euros) and also the long-term growth of the price allowance was increased from 3.3% to 5.1% per year between scenarios 1 and 3. Between scenarios 1 and 4, the long-term cost reduction was increased from 1% to 6%, keeping the costs of PV at period zero at the same level for both.

Figure 6 shows the relative delta increase of the allowance price at the fourth period between scenarios 3 and 1, and the relative delta decrease of the PV costs at the fourth period between scenarios 4 and 1. The delta increase in the price at period 4 between scenarios 3 and 1 is higher than the relative delta decrease of the PV costs at period 4.

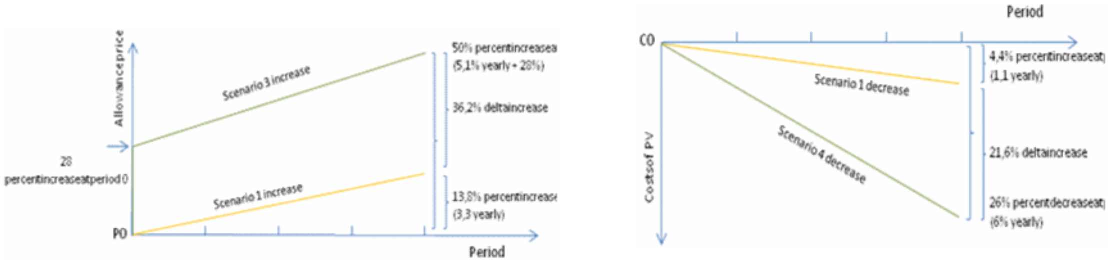

Figure 6. Price allowance and costs of PV modification for scenarios 3 and 4

A 36.2% change on the allowance price between scenarios 1 and 3 in the fourth period results in a 310% change in the value of the option at period zero. A 21.6% change of the PV costs between scenarios 1 and 4 in the fourth period results in a 549% change in the value of the option at period zero. That means that the output of the real option analysis using the assumptions presented in the sections above is more sensitive to changes in the PV costs than in the allowance price.

Scenario 5 shows an increase in the value of the option at time zero 15 times higher than in scenario 1, and it is the only scenario reaching the highest value in the first period. In this scenario it was assumed that part of the revenue from the auction of allowances within the ETS are going to be used to support 30% of the investment costs in renewable energies for electricity generation. The long-term costs reduction for the PV technology remains at 1.1% per year, as in scenario 1. It was estimated that the subsidy for the investment costs will reduce 20% the costs for PV for all the nodes in the lattice. Even higher than in scenario 4, the investment choice to exercise the option increases from 16% in scenario 1 to more than 48% in scenario 5 for the fourth period. In the third period of the analysis the “positive” investment choices (exercise the option and delay the option) increase from 25% to 62% between scenarios 5 and 1.

7 Conclusion and further research questions

The investment decision results obtained at the reference scenario, where the emission allowances prices were estimated based on the current situation in the EU ETS and the average lifetime electric power output costs for photovoltaic were estimated based on current average prices for turnkey installed PV systems in Europe, shows that the emission trading scheme alone will not bring the necessary change in investment patterns to deliver a low-carbon future. A high increase in the allowance price together with a high decrease of the lifetime output electricity costs for photovoltaic is necessary in order to “make attractive” to invest in photovoltaic under the presented assumptions.

The free allocation of allowances for fossil fuels technologies using grandfathering (meaning that the fossil fuels technology do not need to buy the allowances on the market as in scenario 1) almost compensates the additional revenues generated at the photovoltaic technology due to green certificates. Allocating free allowances for fossil-fuels technologies using grandfathering and granting green certificates to low-carbon technologies will also not motivate investments in low-carbon technologies. Thus, for the investment appraisal there is almost no difference with the reference scenario as confirmed in the result of the analysis.

The comparison results of outputs of the model increasing the allowance price at time zero plus the long-term increase of the allowance price and, on the other hand, decreasing the long-term output costs for photovoltaic technology, shows that the value increase of investing in photovoltaic technology instead of in fossil-fuel technology will be more sensitive to changes in the PV costs than in the allowance price.

Using part of the revenue from the auction of emission allowances to support investment costs for photovoltaic technology brought even a higher increase in the value of the investment in photovoltaic technology instead of fossil-fuels technologies, compared to the favorable scenario for higher decrease in the lifetime output electricity costs for PV technology.

Setting a price floor for the emission allowance higher than 70% of the assumed market price, with the intention to provide greater certainty for investors in low-carbon technologies by guaranteeing a minimum price, without modifying another design option of the ETS, showed no influence in the investment patterns using a real options model.

Allocating resources and focusing the policies to reduce lifetime costs of low-carbon technologies seems to be for this analysis more cost-effective than to allocate resources and focus on increasing the price of the allowance within the emission trading scheme.

The result of the analysis confirms the conclusion at Hood (2010) that “the emission trading alone will not solve the climate problem and supplementary and complementary policies will be needed.”

Finally, in designing an ETS, it is critical that the investment patterns of the ETS participants be analyzed and locally evaluated in order to increase the policy efficiency and to bring about a low-carbon future.

In order to gain additional knowledge on how the design of the emission trading schemes would affect the investment decisions in the electricity sector, it would be interesting to analyze the different policy scenarios with other renewable technologies like wind, biomass or biogas, and also compare the renewable energy technologies with carbon capture systems added to fossil fuels electricity generators.

To increase the accuracy of the real option model outputs, it would be interesting to compare the results using a 1-year period presented in this master thesis with the results using smaller time periods and increase the investment evaluation to more than 4 periods.

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9 Annex I

Table 5. Value of the option for scenario 1

Period										Node number
0		1		2		3		4		
Delay	0,56	Delay	0,22	Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	1
		Delay	2,55	Delay	1,29	Don't excercise	0,00	Don't excercise	0,00	2
		Don't excercise	0,00	Delay	10,79	Delay	7,60	Don't excercise	0,00	3
		Delay	0,37	Don't excercise	0,00	Delay	40,48	Excercise	44,93	4
				Don't excercise	0,00	Don't excercise	0,00	Excercise	112,78	5
				Delay	1,91	Don't excercise	0,00	Don't excercise	0,00	6
				Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	7
				Don't excercise	0,00	Delay	9,46	Don't excercise	0,00	8
				Delay	0,29	Don't excercise	0,00	Don't excercise	0,00	9
						Don't excercise	0,00	Excercise	45,20	10
						Don't excercise	0,00	Don't excercise	0,00	11
						Delay	1,72	Don't excercise	0,00	12
						Don't excercise	0,00	Don't excercise	0,00	13
						Don't excercise	0,00	Don't excercise	0,00	14
						Don't excercise	0,00	Excercise	10,16	15
						Don't excercise	0,00	Don't excercise	0,00	16
								Don't excercise	0,00	17
								Don't excercise	0,00	18
								Don't excercise	0,00	19
								Don't excercise	0,00	20
								Don't excercise	0,00	21
								Don't excercise	0,00	22
								Don't excercise	0,00	23
								Don't excercise	0,00	24
								Don't excercise	0,00	25

Table 6. Value of the option for scenario 2

Period										Node number
0		1		2		3		4		
Delay	0,65	Delay	0,26	Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	1
		Delay	2,94	Delay	1,55	Don't excercise	0,00	Don't excercise	0,00	2
		Don't excercise	0,00	Delay	12,33	Delay	9,15	Don't excercise	0,00	3
		Delay	0,43	Don't excercise	0,00	Delay	45,58	Excercise	54,05	4
				Don't excercise	0,00	Don't excercise	0,00	Excercise	121,90	5
				Delay	2,19	Don't excercise	0,00	Don't excercise	0,00	6
				Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	7
				Don't excercise	0,00	Delay	10,69	Don't excercise	0,00	8
				Delay	0,36	Don't excercise	0,00	Don't excercise	0,00	9
						Don't excercise	0,00	Excercise	49,93	10
						Don't excercise	0,00	Don't excercise	0,00	11
						Delay	2,13	Don't excercise	0,00	12
						Don't excercise	0,00	Don't excercise	0,00	13
						Don't excercise	0,00	Don't excercise	0,00	14
						Don't excercise	0,00	Excercise	12,62	15
						Don't excercise	0,00	Don't excercise	0,00	16
								Don't excercise	0,00	17
								Don't excercise	0,00	18
								Don't excercise	0,00	19
								Don't excercise	0,00	20
								Don't excercise	0,00	21
								Don't excercise	0,00	22
								Don't excercise	0,00	23
								Don't excercise	0,00	24
								Don't excercise	0,00	25

Table 7. Value of the option for scenario 3

Period										Node number
0		1		2		3		4		
Delay	1,77	Delay	1,52	Delay	1,01	Don't excercise	0,00	Don't excercise	0,00	1
		Delay	7,30	Delay	7,40	Delay	6,29	Don't excercise	0,00	2
		Delay	0,04	Delay	27,16	Delay	33,25	Excercise	38,97	3
		Delay	0,82	Don't excercise	0,00	Excercise	85,67	Excercise	127,73	4
				Delay	0,22	Don't excercise	0,00	Excercise	195,58	5
				Delay	4,03	Don't excercise	0,00	Don't excercise	0,00	6
				Don't excercise	0,00	Delay	1,39	Don't excercise	0,00	7
				Don't excercise	0,00	Delay	18,67	Don't excercise	0,00	8
				Delay	0,54	Don't excercise	0,00	Excercise	8,62	9
						Don't excercise	0,00	Excercise	76,47	10
						Don't excercise	0,00	Don't excercise	0,00	11
						Delay	3,38	Don't excercise	0,00	12
						Don't excercise	0,00	Don't excercise	0,00	13
						Don't excercise	0,00	Don't excercise	0,00	14
						Don't excercise	0,00	Excercise	20,94	15
						Don't excercise	0,00	Don't excercise	0,00	16
								Don't excercise	0,00	17
								Don't excercise	0,00	18
								Don't excercise	0,00	19
								Don't excercise	0,00	20
								Don't excercise	0,00	21
								Don't excercise	0,00	22
								Don't excercise	0,00	23
								Don't excercise	0,00	24
								Don't excercise	0,00	25

Table 8. Value of the option for scenario 4 (first half)

Period																							Node Number
0		1						2					3					4					
		Carbon			Technology			Carbon		Technology			Carbon		Technology			Carbon		Technology			
Investment desicion	Option Value			Option Value	Investment desicion		Option Value		Option Value	Investment desicion		Option Value		Option Value	Investment desicion		Option Value		Option Value	Investment desicion		Option Value	
Delay	3,12	u1	0,00	4,53	u2	Delay	1,71	u1 u1	2,82	u2 u2	Delay	0,64	u1 u1 u1	1,35	u2 u2 u2	Don't excercise	0,00	u1 u1 u1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	1
																				u2 u2 u2 d2	Don't excercise	0,00	2
																		u1 u1 u1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	3
																				u2 u2 u2 d2	Don't excercise	0,00	4
															u2 u2 d2	Delay	4,94	u1 u1 u1 u1	10,35	u2 u2 d2 u2	Don't excercise	0,00	5
																				u2 u2 d2 d2	Excercise	37,99	6
																		u1 u1 u1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	7
																				u2 u2 d2 d2	Don't excercise	0,00	8
													u1 u1 d1	0,00	u2 u2 u2	Don't excercise	0,00	u1 u1 d1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	9
																				u2 u2 u2 d2	Don't excercise	0,00	10
																		u1 u1 d1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	11
																				u2 u2 u2 d2	Don't excercise	0,00	12
															u2 u2 d2	Don't excercise	0,00	u1 u1 d1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	13
																				u2 u2 d2 d2	Don't excercise	0,00	14
																		u1 u1 d1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	15
																				u2 u2 d2 d2	Don't excercise	0,00	16
										u2 d2	Delay	8,69	u1 u1 u1	14,35	u2 d2 u2	Delay	4,94	u1 u1 u1 u1	10,35	u2 d2 u2 u2	Don't excercise	0,00	17
																				u2 d2 u2 d2	Excercise	37,99	18
																		u1 u1 u1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	19
																				u2 d2 u2 d2	Don't excercise	0,00	20
															u2 d2 d2	Delay	39,87	u1 u1 u1 u1	63,94	u2 d2 d2 u2	Excercise	37,99	21
																				u2 d2 d2 d2	Excercise	136,28	22
																		u1 u1 u1 d1	18,72	u2 d2 d2 u2	Don't excercise	0,00	23
																				u2 d2 d2 d2	Excercise	68,70	24
													u1 u1 d1	3,69	u2 d2 u2	Don't excercise	0,00	u1 u1 d1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	25
																				u2 d2 u2 d2	Don't excercise	0,00	26
																		u1 u1 d1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	27
																				u2 d2 u2 d2	Don't excercise	0,00	28
															u2 d2 d2	Delay	13,52	u1 u1 d1 u1	18,72	u2 d2 d2 u2	Don't excercise	0,00	29
																				u2 d2 d2 d2	Excercise	68,70	30
																		u1 u1 d1 d1	9,17	u2 d2 d2 u2	Don't excercise	0,00	31
																				u2 d2 d2 d2	Excercise	33,67	32
								u1 d1	0,72	u2 u2	Don't excercise	0,00	u1 d1 u1	0,00	u2 u2 u2	Don't excercise	0,00	u1 d1 u1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	33
																				u2 u2 u2 d2	Don't excercise	0,00	34
																		u1 d1 u1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	35
																				u2 u2 u2 d2	Don't excercise	0,00	36
															u2 u2 d2	Don't excercise	0,00	u1 d1 u1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	37
																				u2 u2 d2 d2	Don't excercise	0,00	38
																		u1 d1 u1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	39
																				u2 u2 d2 d2	Don't excercise	0,00	40
													u1 d1 d1	0,00	u2 u2 u2	Don't excercise	0,00	u1 d1 d1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	41
																				u2 u2 u2 d2	Don't excercise	0,00	42
																		u1 d1 d1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	43
																				u2 u2 u2 d2	Don't excercise	0,00	44
															u2 u2 d2	Don't excercise	0,00	u1 d1 d1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	45
																				u2 u2 d2 d2	Don't excercise	0,00	46
																		u1 d1 d1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	47
																				u2 u2 d2 d2	Don't excercise	0,00	48
										u2 d2	Delay	2,64	u1 d1 u1	3,69	u2 d2 u2	Don't excercise	0,00	u1 d1 u1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	49
																				u2 d2 u2 d2	Don't excercise	0,00	50
																		u1 d1 u1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	51
																				u2 d2 u2 d2	Don't excercise	0,00	52
															u2 d2 d2	Delay	13,52	u1 d1 u1 u1	18,72	u2 d2 d2 u2	Don't excercise	0,00	53
																				u2 d2 d2 d2	Excercise	68,70	54
																		u1 d1 u1 d1	9,17	u2 d2 d2 u2	Don't excercise	0,00	55
																				u2 d2 d2 d2	Excercise	33,67	56
													u1 d1 d1	1,77	u2 d2 u2	Don't excercise	0,00	u1 d1 d1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	57
																				u2 d2 u2 d2	Don't excercise	0,00	58
																		u1 d1 d1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	59
																				u2 d2 u2 d2	Don't excercise	0,00	60
															u2 d2 d2	Delay	6,49	u1 d1 d1 u1	9,17	u2 d2 d2 u2	Don't excercise	0,00	61
																				u2 d2 d2 d2	Excercise	33,67	62
																		u1 d1 d1 d1	4,22	u2 d2 d2 u2	Don't excercise	0,00	63
																				u2 d2 d2 d2	Excercise	15,50	64
					d2	Delay	12,21	u1 u1	17,63	d2 u2	Delay	8,69	u1 u1 u1	14,35	d2 u2 u2	Delay	4,94	u1 u1 u1 u1	10,35	d2 u2 u2 u2	Don't excercise	0,00	65
																				d2 u2 u2 d2	Excercise	37,99	66
																		u1 u1 u1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	67
																				d2 u2 u2 d2	Don't excercise	0,00	68
															d2 u2 d2	Delay	39,87	u1 u1 u1 u1	63,94	d2 u2 d2 u2	Excercise	37,99	69
																				d2 u2 d2 d2	Excercise	136,28	70
																		u1 u1 u1 d1	18,72	d2 u2 d2 u2	Don't excercise	0,00	71
																				d2 u2 d2 d2	Excercise	68,70	72
													u1 u1 d1	3,69	d2 u2 u2	Don't excercise	0,00	u1 u1 d1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	73
																				d2 u2 u2 d2	Don't excercise	0,00	74
																		u1 u1 d1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	75
																				d2 u2 u2 d2	Don't excercise	0,00	76
															d2 u2 d2	Delay	13,52	u1 u1 d1 u1	18,72	d2 u2 d2 u2	Don't excercise	0,00	77
																				d2 u2 d2 d2	Excercise	68,70	78
																		u1 u1 d1 d1	9,17	d2 u2 d2 u2	Don't excercise	0,00	79
																				d2 u2 d2 d2	Excercise	33,67	80
										d2 d2	Delay	42,20	u1 u1 u1	59,51	d2 d2 u2	Delay	39,87	u1 u1 u1 u1	63,94	d2 d2 u2 u2	Excercise	37,99	81
																				d2 d2 u2 d2	Excercise	136,28	82
																		u1 u1 u1 d1	18,72	d2 d2 u2 u2	Don't excercise	0,00	83
																				d2 d2 u2 d2	Excercise	68,70	84
															d2 d2 d2	Excercise	115,17	u1 u1 u1 u1	151,14	d2 d2 d2 u2	Excercise	136,28	85
																				d2 d2 d2 d2	Excercise	201,80	86
																		u1 u1 u1 d1	85,05	d2 d2 d2 u2	Excercise	68,70	87
																				d2 d2 d2 d2	Excercise	134,23	88
													u1 u1 d1	27,60	d2 d2 u2	Delay	13,52	u1 u1 d1 u1	18,72	d2 d2 u2 u2	Don't excercise	0,00	89
																				d2 d2 u2 d2	Excercise	68,70	90
																		u1 u1 d1 d1	9,17	d2 d2 u2 u2	Don't excercise	0,00	91
																				d2 d2 u2 d2	Excercise	33,67	92
															d2 d2 d2	Excercise	66,26	u1 u1 d1 u1	85,05	d2 d2 d2 u2	Excercise	68,70	93
																				d2 d2 d2 d2	Excercise	134,23	94
																		u1 u1 d1 d1	50,78	d2 d2 d2 u2	Excercise	33,67	95
																				d2 d2 d2 d2	Excercise	99,19	96
								u1 d1	7,60	d2 u2	Delay	2,64	u1 d1 u1	3,69	d2 u2 u2	Don't excercise	0,00	u1 d1 u1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	97
																				d2 u2 u2 d2	Don't excercise	0,00	98
																		u1 d1 u1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	99
																				d2 u2 u2 d2	Don't excercise	0,00	100
															d2 u2 d2	Delay	13,52	u1 d1 u1 u1	18,72	d2 u2 d2 u2	Don't excercise	0,00	101
																				d2 u2 d2 d2	Excercise	68,70	102
																		u1 d1 u1 d1	9,17	d2 u2 d2 u2	Don't excercise	0,00	103
																				d2 u2 d2 d2	Excercise	33,67	104
													u1 d1 d1	1,77	d2 u2 u2	Don't excercise	0,00	u1 d1 d1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	105
																				d2 u2 u2 d2	Don't excercise	0,00	106
																		u1 d1 d1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	107
																				d2 u2 u2 d2	Don't excercise	0,00	108
															d2 u2 d2	Delay	6,49	u1 d1 d1 u1	9,17	d2 u2 d2 u2	Don't excercise	0,00	109
																				d2 u2 d2 d2	Excercise	33,67	110
																		u1 d1 d1 d1	4,22	d2 u2 d2 u2	Don't excercise	0,00	111
																				d2 u2 d2 d2	Excercise	15,50	112
										d2 d2	Delay	21,04	u1 d1 u1	27,60	d2 d2 u2	Delay	13,52	u1 d1 u1 u1	18,72	d2 d2 u2 u2	Don't excercise	0,00	113
																				d2 d2 u2 d2	Excercise	68,70	114
																		u1 d1 u1 d1	9,17	d2 d2 u2 u2	Don't excercise	0,00	115
																				d2 d2 u2 d2	Excercise	33,67	116
															d2 d2 d2	Excercise	66,26	u1 d1 u1 u1	85,05	d2 d2 d2 u2	Excercise	68,70	117
																				d2 d2 d2 d2	Excercise	134,23	118
																		u1 d1 u1 d1	50,78	d2 d2 d2 u2	Excercise	33,67	119
																				d2 d2 d2 d2	Excercise	99,19	120
													u1 d1 d1	15,72	d2 d2 u2	Delay	6,49	u1 d1 d1 u1	9,17	d2 d2 u2 u2	Don't excercise	0,00	121
																				d2 d2 u2 d2	Excercise	33,67	122
																		u1 d1 d1 d1	4,22	d2 d2 u2 u2	Don't excercise	0,00	123
																				d2 d2 u2 d2	Excercise	15,50	124
															d2 d2 d2	Excercise	40,90	u1 d1 d1 u1	50,78	d2 d2 d2 u2	Excercise	33,67	125
																				d2 d2 d2 d2	Excercise	99,19	126
																		u1 d1 d1 d1	33,02	d2 d2 d2 u2	Excercise	15,50	127
																				d2 d2 d2 d2	Excercise	81,03	128

Table 9. Value of the option for scenario 4 (second half)

d1	0,00	1,92	u2	Delay	0,51	d1 u1	0,72	u2 u2	Don't excercise	0,00	d1 u1 u1	0,00	u2 u2 u2	Don't excercise	0,00	d1 u1 u1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	129
																		u2 u2 u2 d2	Don't excercise	0,00	130
																d1 u1 u1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	131
																		u2 u2 u2 d2	Don't excercise	0,00	132
													u2 u2 d2	Don't excercise	0,00	d1 u1 u1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	133
																		u2 u2 d2 d2	Don't excercise	0,00	134
																d1 u1 u1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	135
																		u2 u2 d2 d2	Don't excercise	0,00	136
											d1 u1 d1	0,00	u2 u2 u2	Don't excercise	0,00	d1 u1 d1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	137
																		u2 u2 u2 d2	Don't excercise	0,00	138
																d1 u1 d1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	139
																		u2 u2 u2 d2	Don't excercise	0,00	140
													u2 u2 d2	Don't excercise	0,00	d1 u1 d1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	141
																		u2 u2 d2 d2	Don't excercise	0,00	142
																d1 u1 d1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	143
																		u2 u2 d2 d2	Don't excercise	0,00	144
								u2 d2	Delay	2,64	d1 u1 u1	3,69	u2 d2 u2	Don't excercise	0,00	d1 u1 u1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	145
																		u2 d2 u2 d2	Don't excercise	0,00	146
																d1 u1 u1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	147
																		u2 d2 u2 d2	Don't excercise	0,00	148
													u2 d2 d2	Delay	13,52	d1 u1 u1 u1	18,72	u2 d2 d2 u2	Don't excercise	0,00	149
																		u2 d2 d2 d2	Excercise	68,70	150
																d1 u1 u1 d1	9,17	u2 d2 d2 u2	Don't excercise	0,00	151
																		u2 d2 d2 d2	Excercise	33,67	152
											d1 u1 d1	1,77	u2 d2 u2	Don't excercise	0,00	d1 u1 d1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	153
																		u2 d2 u2 d2	Don't excercise	0,00	154
																d1 u1 d1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	155
																		u2 d2 u2 d2	Don't excercise	0,00	156
													u2 d2 d2	Delay	6,49	d1 u1 d1 u1	9,17	u2 d2 d2 u2	Don't excercise	0,00	157
																		u2 d2 d2 d2	Excercise	33,67	158
																d1 u1 d1 d1	4,22	u2 d2 d2 u2	Don't excercise	0,00	159
																		u2 d2 d2 d2	Excercise	15,50	160
						d1 d1	0,34	u2 u2	Don't excercise	0,00	d1 d1 u1	0,00	u2 u2 u2	Don't excercise	0,00	d1 d1 u1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	161
																		u2 u2 u2 d2	Don't excercise	0,00	162
																d1 d1 u1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	163
																		u2 u2 u2 d2	Don't excercise	0,00	164
													u2 u2 d2	Don't excercise	0,00	d1 d1 u1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	165
																		u2 u2 d2 d2	Don't excercise	0,00	166
																d1 d1 u1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	167
																		u2 u2 d2 d2	Don't excercise	0,00	168
											d1 d1 d1	0,00	u2 u2 u2	Don't excercise	0,00	d1 d1 d1 u1	0,00	u2 u2 u2 u2	Don't excercise	0,00	169
																		u2 u2 u2 d2	Don't excercise	0,00	170
																d1 d1 d1 d1	0,00	u2 u2 u2 u2	Don't excercise	0,00	171
																		u2 u2 u2 d2	Don't excercise	0,00	172
													u2 u2 d2	Don't excercise	0,00	d1 d1 d1 u1	0,00	u2 u2 d2 u2	Don't excercise	0,00	173
																		u2 u2 d2 d2	Don't excercise	0,00	174
																d1 d1 d1 d1	0,00	u2 u2 d2 u2	Don't excercise	0,00	175
																		u2 u2 d2 d2	Don't excercise	0,00	176
								u2 d2	Delay	1,23	d1 d1 u1	1,77	u2 d2 u2	Don't excercise	0,00	d1 d1 u1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	177
																		u2 d2 u2 d2	Don't excercise	0,00	178
																d1 d1 u1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	179
																		u2 d2 u2 d2	Don't excercise	0,00	180
													u2 d2 d2	Delay	6,49	d1 d1 u1 u1	9,17	u2 d2 d2 u2	Don't excercise	0,00	181
																		u2 d2 d2 d2	Excercise	33,67	182
																d1 d1 u1 d1	4,22	u2 d2 d2 u2	Don't excercise	0,00	183
																		u2 d2 d2 d2	Excercise	15,50	184
											d1 d1 d1	0,78	u2 d2 u2	Don't excercise	0,00	d1 d1 d1 u1	0,00	u2 d2 u2 u2	Don't excercise	0,00	185
																		u2 d2 u2 d2	Don't excercise	0,00	186
																d1 d1 d1 d1	0,00	u2 d2 u2 u2	Don't excercise	0,00	187
																		u2 d2 u2 d2	Don't excercise	0,00	188
													u2 d2 d2	Delay	2,85	d1 d1 d1 u1	4,22	u2 d2 d2 u2	Don't excercise	0,00	189
																		u2 d2 d2 d2	Excercise	15,50	190
																d1 d1 d1 d1	1,66	u2 d2 d2 u2	Don't excercise	0,00	191
																		u2 d2 d2 d2	Excercise	6,09	192
			d2	Delay	5,74	d1 u1	7,60	d2 u2	Delay	2,64	d1 u1 u1	3,69	d2 u2 u2	Don't excercise	0,00	d1 u1 u1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	193
																		d2 u2 u2 d2	Don't excercise	0,00	194
																d1 u1 u1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	195
																		d2 u2 u2 d2	Don't excercise	0,00	196
													d2 u2 d2	Delay	13,52	d1 u1 u1 u1	18,72	d2 u2 d2 u2	Don't excercise	0,00	197
																		d2 u2 d2 d2	Excercise	68,70	198
																d1 u1 u1 d1	9,17	d2 u2 d2 u2	Don't excercise	0,00	199
																		d2 u2 d2 d2	Excercise	33,67	200
											d1 u1 d1	1,77	d2 u2 u2	Don't excercise	0,00	d1 u1 d1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	201
																		d2 u2 u2 d2	Don't excercise	0,00	202
																d1 u1 d1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	203
																		d2 u2 u2 d2	Don't excercise	0,00	204
													d2 u2 d2	Delay	6,49	d1 u1 d1 u1	9,17	d2 u2 d2 u2	Don't excercise	0,00	205
																		d2 u2 d2 d2	Excercise	33,67	206
																d1 u1 d1 d1	4,22	d2 u2 d2 u2	Don't excercise	0,00	207
																		d2 u2 d2 d2	Excercise	15,50	208
								d2 d2	Delay	21,04	d1 u1 u1	27,60	d2 d2 u2	Delay	13,52	d1 u1 u1 u1	18,72	d2 d2 u2 u2	Don't excercise	0,00	209
																		d2 d2 u2 d2	Excercise	68,70	210
																d1 u1 u1 d1	9,17	d2 d2 u2 u2	Don't excercise	0,00	211
																		d2 d2 u2 d2	Excercise	33,67	212
													d2 d2 d2	Excercise	66,26	d1 u1 u1 u1	85,05	d2 d2 d2 u2	Excercise	68,70	213
																		d2 d2 d2 d2	Excercise	134,23	214
																d1 u1 u1 d1	50,78	d2 d2 d2 u2	Excercise	33,67	215
																		d2 d2 d2 d2	Excercise	99,19	216
											d1 u1 d1	15,72	d2 d2 u2	Delay	6,49	d1 u1 d1 u1	9,17	d2 d2 u2 u2	Don't excercise	0,00	217
																		d2 d2 u2 d2	Excercise	33,67	218
																d1 u1 d1 d1	4,22	d2 d2 u2 u2	Don't excercise	0,00	219
																		d2 d2 u2 d2	Excercise	15,50	220
													d2 d2 d2	Excercise	40,90	d1 u1 d1 u1	50,78	d2 d2 d2 u2	Excercise	33,67	221
																		d2 d2 d2 d2	Excercise	99,19	222
																d1 u1 d1 d1	33,02	d2 d2 d2 u2	Excercise	15,50	223
																		d2 d2 d2 d2	Excercise	81,03	224
						d1 d1	4,22	d2 u2	Delay	1,23	d1 d1 u1	1,77	d2 u2 u2	Don't excercise	0,00	d1 d1 u1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	225
																		d2 u2 u2 d2	Don't excercise	0,00	226
																d1 d1 u1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	227
																		d2 u2 u2 d2	Don't excercise	0,00	228
													d2 u2 d2	Delay	6,49	d1 d1 u1 u1	9,17	d2 u2 d2 u2	Don't excercise	0,00	229
																		d2 u2 d2 d2	Excercise	33,67	230
																d1 d1 u1 d1	4,22	d2 u2 d2 u2	Don't excercise	0,00	231
																		d2 u2 d2 d2	Excercise	15,50	232
											d1 d1 d1	0,78	d2 u2 u2	Don't excercise	0,00	d1 d1 d1 u1	0,00	d2 u2 u2 u2	Don't excercise	0,00	233
																		d2 u2 u2 d2	Don't excercise	0,00	234
																d1 d1 d1 d1	0,00	d2 u2 u2 u2	Don't excercise	0,00	235
																		d2 u2 u2 d2	Don't excercise	0,00	236
													d2 u2 d2	Delay	2,85	d1 d1 d1 u1	4,22	d2 u2 d2 u2	Don't excercise	0,00	237
																		d2 u2 d2 d2	Excercise	15,50	238
																d1 d1 d1 d1	1,66	d2 u2 d2 u2	Don't excercise	0,00	239
																		d2 u2 d2 d2	Excercise	6,09	240
								d2 d2	Delay	12,29	d1 d1 u1	15,72	d2 d2 u2	Delay	6,49	d1 d1 u1 u1	9,17	d2 d2 u2 u2	Don't excercise	0,00	241
																		d2 d2 u2 d2	Excercise	33,67	242
																d1 d1 u1 d1	4,22	d2 d2 u2 u2	Don't excercise	0,00	243
																		d2 d2 u2 d2	Excercise	15,50	244
													d2 d2 d2	Excercise	40,90	d1 d1 u1 u1	50,78	d2 d2 d2 u2	Excercise	33,67	245
																		d2 d2 d2 d2	Excercise	99,19	246
																d1 d1 u1 d1	33,02	d2 d2 d2 u2	Excercise	15,50	247
																		d2 d2 d2 d2	Excercise	81,03	248
											d1 d1 d1	9,57	d2 d2 u2	Delay	2,85	d1 d1 d1 u1	4,22	d2 d2 u2 u2	Don't excercise	0,00	249
																		d2 d2 u2 d2	Excercise	15,50	250
																d1 d1 d1 d1	1,66	d2 d2 u2 u2	Don't excercise	0,00	251
																		d2 d2 u2 d2	Excercise	6,09	252
													d2 d2 d2	Excercise	27,75	d1 d1 d1 u1	33,02	d2 d2 d2 u2	Excercise	15,50	253
																		d2 d2 d2 d2	Excercise	81,03	254
																d1 d1 d1 d1	23,81	d2 d2 d2 u2	Excercise	6,09	255
																		d2 d2 d2 d2	Excercise	71,61	256

Table 10. Value of the option for scenario 5

Period										Node number
0		1		2		3		4		
Delay	8,68	Delay	5,44	Delay	2,66	Delay	2,95	Don't excercise	0,00	**1**
		Delay	25,23	Delay	20,47	Delay	10,51	Excercise	17,44	**2**
		Delay	1,77	Excercise	65,55	Excercise	75,04	Excercise	31,50	**3**
		Delay	12,59	Don't excercise	0,00	Excercise	124,71	Excercise	148,58	**4**
				Delay	6,68	Don't excercise	0,00	Excercise	192,00	**5**
				Delay	33,54	Don't excercise	0,00	Don't excercise	0,00	**6**
				Don't excercise	0,00	Excercise	26,12	Don't excercise	0,00	**7**
				Delay	3,57	Excercise	75,79	Don't excercise	0,00	**8**
				Delay	21,44	Don't excercise	0,00	Excercise	81,00	**9**
						Don't excercise	0,00	Excercise	124,43	**10**
						Delay	12,73	Don't excercise	0,00	**11**
						Excercise	50,43	Don't excercise	0,00	**12**
						Don't excercise	0,00	Don't excercise	0,00	**13**
						Don't excercise	0,00	Excercise	45,97	**14**
						Delay	7,98	Excercise	89,39	**15**
						Excercise	37,28	Don't excercise	0,00	**16**
								Don't excercise	0,00	**17**
								Don't excercise	0,00	**18**
								Excercise	27,80	**19**
								Excercise	71,23	**20**
								Don't excercise	0,00	**21**
								Don't excercise	0,00	**22**
								Don't excercise	0,00	**23**
								Excercise	18,39	**24**
								Excercise	61,81	**25**

Table 11. Value of the option for scenario 6

Period										Node number
0		1		2		3		4		
Delay	0,56	Delay	0,22	Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	**1**
		Delay	2,55	Delay	1,29	Don't excercise	0,00	Don't excercise	0,00	**2**
		Don't excercise	0,00	Delay	10,79	Delay	7,60	Don't excercise	0,00	**3**
		Delay	0,37	Don't excercise	0,00	Delay	40,48	Excercise	44,93	**4**
				Don't excercise	0,00	Don't excercise	0,00	Excercise	112,78	**5**
				Delay	1,91	Don't excercise	0,00	Don't excercise	0,00	**6**
				Don't excercise	0,00	Don't excercise	0,00	Don't excercise	0,00	**7**
				Don't excercise	0,00	Delay	9,46	Don't excercise	0,00	**8**
				Delay	0,29	Don't excercise	0,00	Don't excercise	0,00	**9**
						Don't excercise	0,00	Excercise	45,20	**10**
						Don't excercise	0,00	Don't excercise	0,00	**11**
						Delay	1,72	Don't excercise	0,00	**12**
						Don't excercise	0,00	Don't excercise	0,00	**13**
						Don't excercise	0,00	Don't excercise	0,00	**14**
						Don't excercise	0,00	Excercise	10,16	**15**
						Don't excercise	0,00	Don't excercise	0,00	**16**
								Don't excercise	0,00	**17**
								Don't excercise	0,00	**18**
								Don't excercise	0,00	**19**
								Don't excercise	0,00	**20**
								Don't excercise	0,00	**21**
								Don't excercise	0,00	**22**
								Don't excercise	0,00	**23**
								Don't excercise	0,00	**24**
								Don't excercise	0,00	**25**