Emissions trading and investment decisions

The value of flexibility

dr. Cyriel de Jong, mr. Kasper Walet
Maycroft Consultancy, Amsterdam
www.maycroft.com

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Executive summary

Emission trade as an instrument in the fight against emission of pollutants is booming these days. In order to comply with objectives concerning reduction of global warming mentioned in the Kyoto Protocol, the European Union is currently designing an emission trade system, which is planned to start in 2005.

Consequences of emission trade systems for participants, particularly electricity producers, are far-reaching. Current investment policies determine emission of greenhouse gasses for a longer period. The emissions represent a direct cost for the company while emission rights, equivalent to the amount of polluting gasses produced each year, must be submitted. These costs need to be assessed and are an integral part of any investment strategy concerning reduction capacity.

This is a study about the above mentioned investment issues that will arise with polluting companies under the emission trade system. Insight into the issues is needed, while up until now electricity producers have never been faced with market dictated charging of emissions. Volatility of emission rights prices requires flexible investment options, much more so compared to previous operational policy instruments.

Based on theoretical insights a framework for researching investments is designed. A basic assumption for valuing investment possibilities is the net present value method. An adjustment to this method is necessary in order to incorporate both banking and real options. We will compare the proposed CO_2 trade system to the *US Acid Rain Program*, operational since 1995 – a system designed to restrict emission of carbon dioxide in the US Looking at past experiences with this system (market results, investing behaviour) recommendations to participants are developed. This is followed by a trial case of an actual investment decision, using the presented real option framework and with special attention to practical experiences in the States.

The most adequate valuation procedure for investments in reduction capacity is the net present value method corrected by both banking and real options. Furthermore, the trial case shows that these two corrective factors represent fundamental value. In particular the value of the deferral option is significant; previous experiences with the Acid Rain Program indicate that this option is easily being overlooked.

The most important conclusion of this study is that, when investing in long-term emission reduction, valuation of flexibility using real options is essential. Flexibility is all the more important given the fact that the specific contents of the system have yet to be determined. Implementation of the valuation method for real options will result in stronger-founded investment decisions.

Contents

1 Introduction

The international measures derived from the Kyoto Protocol ‘emission trade’ principle are beginning to take shape. The admitted proposal for a European CO_2 trade system can be viewed as a breakthrough, although certain aspects - especially the development of emission constraints – need further interpretation.

The consequences of mentioned emission system for the energy sector are far-reaching: today’s investment decisions will define the components of productive capacity for the coming decades. The productive capacity in turn will largely determine the discharge of greenhouse gasses. The emission prices of these gasses, together with emission constraints make up the cost of emission. In short: a) the characteristics of emission trading determine future costs of emission and b) these costs are an essential part of long-term investment decisions.

We start with a short introduction of the Kyoto Protocol in section 1.1. Section 1.2 contains the actual objective and research questions. Finally, section 1.3 explains the structure of the study.

1.1 Kyoto Protocol

1.1.1 History

On 9 May 1992 the *United Nations Framework Convention on Climate Change* (UNFCCC) was installed in New York. Main objective was ‘to achieve stabilization of greenhouse gas air concentrations, at a level that will prevent harmful human caused damage to our climate’ (UNFCCC, 2002). The Convention does not specify exactly which level is harmful, yet states that eco-systems should be able to keep their own natural balance, food supply must not be threatened and economic growth must be continued. The UNFCCC offers principles that serve as guidelines for dealing with the climate problem in terms of implementation, responsibility and initiative.

The ownership principle states that industrialized countries possess more means for dealing with the climate issue than the developing countries. Therefore, they are encouraged to share their financial and technical means and resources with developing countries.

The principle of shared yet differentiated responsibility takes notice of the fact that industrialized countries are the biggest contributors to emission worldwide and therefore have a leading role when it comes to emission reduction.

Finally, the precaution principle states that, although there is still a great deal of uncertainty about the causes of climatic changes, there is no reason for postponing measures any longer. After all, waiting for more clarity could lead to climatic changes becoming irreversible.

The UNFCCC was put into effect on 21 March 1994 and at present more than 175 governments (including the EU) are Member of the Convention. Each year there is a *Conference of the Parties* (COP) where implementation of the Convention and effective prevention of climatic changes are discussed. So far, most significant milestone has been the foundation of the Kyoto Protocol, at the 3rd COP in Kyoto, Japan on 11 December 1997.

1.1.2 Main points of the Protocol

The Kyoto Protocol was created as an interpretation of the goals defined in the UNFCCC. The Protocol contains a legally binding commitment for members to reduce emission of greenhouse gasses, compared to their emission levels in ‘basic year’ 1990.
Six different gasses are being reviewed:

i) Carbon dioxide (CO_2)
ii) Methane (CH_4)
iii) Nitrous oxide (N_2O)
iv) Hydrofluorocarbons (HFC_S)
v) Perfluoro carbons (PFC_S)
vi) Sulphur hexafluoride (SF_6)

To determine the discharge levels of these gasses, their equivalent to CO_2 is calculated, depending on their contribution to global warming at a given time. For example, the contribution of 1 ton of methane is equal to 21 tons of carbon dioxide; so the CO_2 equivalent of 1 ton methane is 21 tons (UNFCCC, 2002). See table 1.1 below.

SYMBOL	NAME	CO_2 Equivalent	MAIN SOURCES
CO_2	Carbon Dioxide	1	Fossil fuel combustion, forest clearing, cement production
CH_4	Methane	21	Landfills, production and distribution of natural gas & petroleum, fermentation from the digestive system of livestock, rice cultivation, fossil fuel combustion
N_2O	Nitrous Oxide	310	Fossil fuel combustion, fertilizers, nylon production, manure
HFC's	Hydrofluorocarbons	140 ~ 11,700	Refrigeration gases, aluminium smelting, semiconductor manufacturing
PFC's	Perflourocarbons	6,500 ~ 9,200	Aluminium production, semiconductor industry
SF_6	Sulfur Hexafluoride	23,900	Electrical transmissions and distribution systems, circuit breakers, magnesium production

Table 1.1: Greenhouse gases overview

In order to meet the UNFCCC principles of ownership and differentiated responsibility, the participating countries are categorized as described in the box below.

I. **Annex-I countries**
Industrialised countries, which have historically been the biggest contributors to emission worldwide and therefore have to assume a leading role when it comes to emission reduction. Two subcategories can be distinguished:
    A. **Annex-II countries**
    Members of the *Organisation for Economic Co-operation and Development* (OECD) as of 1992, i.e. Western-European countries (including the EU as a separate party), Canada, the US, Japan, Australia, New-Zealand and Turkey;
    B. ***Economies In Transition (EITs)***
    Countries that evolve into prosperous market economies; especially former Soviet Union members as well as Central and Eastern European countries.
II. **Non-Annex-I countries**
Developing countries: their emission constraints are much less strict than for annex-I countries.

Non-Annex-1 countries are, up until now, not legally obliged to reduce their emissions. Most Annex-1 countries do have such an obligation. They aim to reduce their emission average during the first 'obligatory term' (2008-2012) with a given percentage, compared to their emission level in 1990.

The agreed reduction percentages vary per country and region (Table 1.2). Separate from legally binding commitments starting in 2008, participants will already be tested in 2005 on 'demonstrated progress' concerning emission reduction. However, also due to unclear meaning of the words 'demonstrated progress', no consequences to this testing are involved.

Country	Target 2008-2012 versus 1990
EU-15[1], Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Liechtenstein, Monaco, Rumania, Slovakia, Slovenia, Switzerland	-8%
United States	-7%
Canada, Hungary, Japan, Poland	-6%
Croatia	-5%
New-Zealand, Russian Federation, Ukraine	0%
Norway	+1%
Australia	+8%
Iceland	+10%

Table 1.2: Annex-B countries[2] and their emission goals

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[1] The 15 EU-countries together have made a redistribution of their collective Kyoto-goals. This is done according to the 'burden sharing'-agreement of June 1998. For example, the Dutch reduction objective is less stringent by -6%

[2] Annex-B countries are those mentioned with their emission goals in Kyoto Protocol Annex-B. These are all Annex-1 countries except White Russia, Turkey and Kazakhstan.

The Kyoto Protocol provides three flexible international mechanisms to make observance of emission goals possible in an efficient way:

I) Joint Implementation (JI)
II) Clean Development Mechanism (CDM)
III) Emission Trade

Prior to explaining these mechanisms, it is important to clarify the various administrative units and their interconnection. To each mechanism a different name for administrative units is attached. They all represent the value of 1 ton CO_2 equivalent of emission. JI projects generate *emission reduction units* (ERUs), CDM projects *certified emission reductions* (CERs) and emission trade makes purchase or sale of *assigned amount units* (AAUs) possible.
Combined with already allocated AAUs, the obtained ERUs and CERs plus the purchased or sold AAUs determine the level of emission to which the Annex-1 countries are committed. See the following calculation:

Actual emission target =

+ initially obtained AAUs
+ obtained ERUs
+ obtained CERs
+ AAUs purchased
– AAUs sold

Joint implementation
This mechanism gives Annex-1 countries the opportunity to start projects to reduce emission in other Annex-1 countries. Reductions realized by these projects will provide emission units (ERUs) which can be used to meet the countries' own emission goals. To avoid double counting the same amount of units is subtracted from the host countries' quantity. It is expected that JI projects will mainly take place in Economies in Transition (EITs), because of the relatively lower cost of emission reduction (UNFCCC, 2002)

Clean Development Mechanism
The second mechanism enables Annex-1 countries to implement emission-reducing projects in non-Annex-1 countries. The difference between CDM and JI is the fact that the host country is non-Annex-1 instead of Annex-1. CDM projects provide CERs that (similar to ERUs from JI) can be applied in order to meet the own countries' emission targets.

Emission Trade
The third and final mechanism as part of the Kyoto Protocol is emission trade. Annex-1 countries are given the opportunity to trade in AAUs[3], which enables them to efficiently

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[3] Aside from *assigned amount units* the obtained *emission reduction units* – from JI – and *certified emission reductions* – from CDM – can also be purchased or sold via emission trade. This also still applies to *removal units* (RMUs), which can be obtained through increase of natural CO_2 – storage capacity, usually by re-afforestation

balance their emission target as well as their emission units in portfolio. The economic background of emission trade will be discussed in Chapter 2.

In Figure 1.1 the three Kyoto mechanisms and the resulting flow of emission units is presented in diagram form.

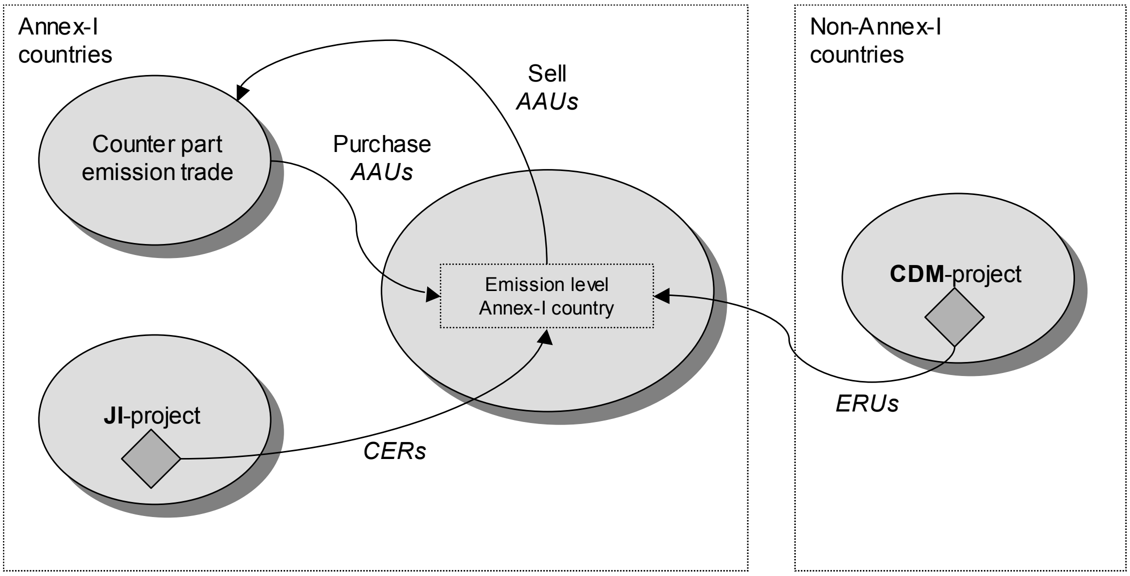

Figure 1.1: Kyoto mechanisms in diagram

1.1.3 Business implications

At present, a European CO_2 emission trade system[4] is being developed, which intends to realize the Kyoto required emission reduction in a cost-effective way. This system – described in detail in Chapter 4 – translates the EU collective emission target into individual targets for the participating nations. Each member state receives a certain amount of emission rights, consistent with the current EU 'burden sharing' agreement.

In a next step, the member states develop their national allocation plan, in which the assigned emission rights are distributed over sectors and companies. The national plans should be ready by April 2004. This way participating companies are faced with a CO_2 emission target - in most cases lower than their current discharge – and therefore are forced to reduce their emission.

As a result of this, companies will experience a managerial problem. Principally, a *make-or-buy*-decision must be made: the company itself can choose to reduce emission (*make*) but can also decide to purchase emission reduction – in the form of emission rights – on the external market (*buy*). This managerial problem will be further discussed in Chapter 2.

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[4] The proposed emission trade system will in this instance only focus on emission of carbon dioxide. Hence the term 'CO_2-emission trade system'. In the future, the remaining five greenhouse gasses will be incorporated in the system

1.2 Research objective

It is the objective of this research to clarify the investment decision for companies falling under the planned CO_2 trading system. This will be achieved (1) on the basis of modern investment theory, and (2) by inferring lessons from an operational SO_2 trading system.

The research model is visualized in Figure 1.2 and can be formulated as follows. Based on (1) a thorough literature review on emission trading and investment theories we obtain insights in the decision process for emitting industries. (b) Next, we analyse the actual strategies in the SO_2 trading system in the United States and relate them to the insights provided in the literature. (c) We judge the relevance of the above analysis for the CO_2 trading system by comparing the two. (d) This yields a clarification and framework for the investment decision under the CO_2 trading scheme.

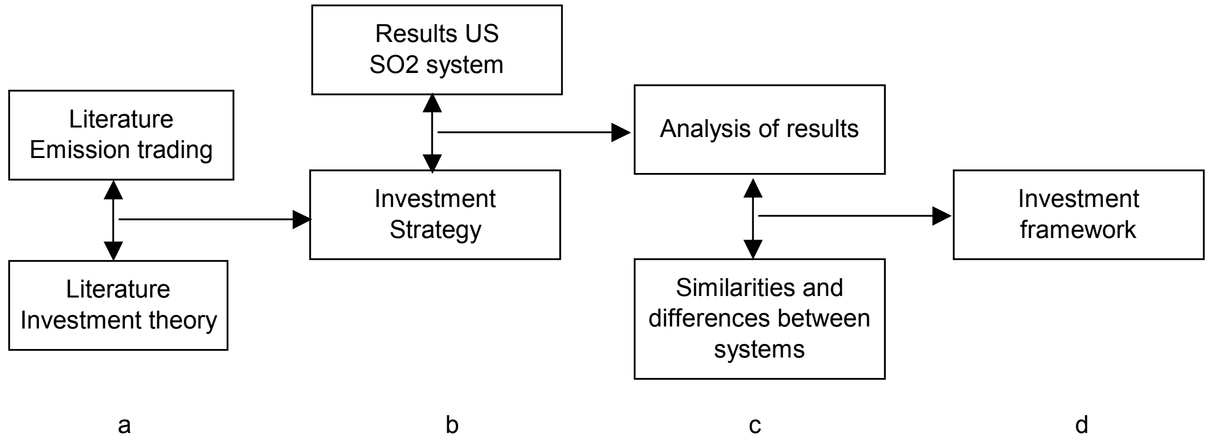

Figure 1.2: **Research framework**

1.3 Structure of the report

We spend approximately one chapter on each phase of the research. This means that in Chapter 2 we start with a review of the literature on emission trading and investment decisions. Then we move on to discuss the results of the US acid rain program in Chapter 3. We describe its SO_2 trading program, analyse investment behaviour and compare it to the theoretical insights from Chapter 2. In Chapter 4 we compare the planned European system for trading carbon dioxide allowances with the SO_2 market in the US. Finally, in Chapter 5 we develop a framework for investment decisions in emission reduction, with special attention to the role of banking and real options (flexibility). The framework is clarified with a case study of a power generator that has the opportunity to invest in emission reduction. Chapter 6 concludes.

2 Emission trading and investment decisions

In this chapter we discuss the theoretical background of emission trading and the resulting investment decisions.

First of all, in section 2.1, emission trade as a policy choice is clarified on the basis of relevant economic theories. Then we shift attention to the actual consequences of emission trade for participating companies in section 2.2. In particular, we focus on compliance strategies and related investment policies. Step by step, it will be demonstrated how investment reduction choices are influenced by various compliance opportunities and the presence of real options. Finally, section 2.3 contains a short conclusion.

2.1 Emission trading as a policy choice

Environmental policies in general, and emission trading in particular, are build upon the theoretical concept of **negative externalities**, defined as ‘negative effects caused by production or consumption of goods or services for others than the actual user and which are not included in price or costs’. So, production or consumption decisions of the user do not account for cost and benefit for third parties. This can be seen as market failure: allocation of production factors is disrupted because the market does not pay attention to these costs and benefits for third parties. Therefore, the market gives an inaccurate view on the actual social costs and benefits that come with some forms of production or consumption.

In order to avoid market failure and to incorporate the negative external effects, several policy instruments are available. Preferably, the incorporation of negative external effects will be the producers’ responsibility as in the ‘polluter pays’ principle.

Policy instruments in this context are: i) direct regulation; ii) market based policies; and iii) communication instruments (information and education).

In theory, the prevention of above mentioned market failure eventually leads to efficient allocation. Tietenberg (1996) mentions that, regarding emission reduction, efficiency is achieved when the marginal cost of emission restriction is equivalent to the marginal damage caused by pollution. He promptly adds that the actual level of efficiency is difficult to establish, mainly because the marginal damage curve cannot be specified in a reliable way. Since efficiency is attainable yet difficult to measure, it is preferred to choose an alternative approach.

An obvious ‘second best’ alternative is to impose an absolute emission allowance based on other considerations such as keeping the emission effects within health and environmental safety limits, and to do so against minimal costs. For this purpose Tietenberg introduces a criterion of *cost efficiency* i.e. achieving a certain specified emission level at minimal costs. Cost minimization will only occur when marginal costs of emission reduction are the same for each of the discharging units.

In short, cost-effectiveness consists of two components: i) realization of the specified emission level and ii) cost minimization. Tietenberg (1996) mentions three different policy options, all of which are in a certain way cost effective:

A. To impose an *emission norm* with an allowance for each emission source. This method, also called the ‘*command-and-control*’ approach is a form of direct regulation. Through individual emission allowances the realization of the fixed total emission level is guaranteed. However, cost minimization does not occur, while marginal costs of various emission sources differ.

B. To impose an *emission tax*, with a tax amount X per emission quantity. This is a market-based policy: decisions concerning emission quantity are left to ‘market forces’ (i.e. emission sources). Charging of emission leads to cost minimized allocation because companies will choose the level of emission at which marginal costs and tax amount X are equal. Yet, tax on emission does not necessarily guarantee the desired emission level. In principle, the level of emission is directly connected to the tax level; in order to realize the desired emission level it is merely required to assess the correct tax amount. Regulating authorities, however, do not have sufficient information on reduction costs of the participating companies, so the chosen tax amount most likely will not lead to the desired emission level. Only by way of *trial-and-error* the assessment of the tax amount can eventually approach the desired emission level.

C. The set up of a system for *trading of emission rights*, in which emission rights are assigned and marketable. The number of rights that is assigned at initial allocation guarantees that the desired emission level will be achieved. Furthermore, the fact that rights can be traded will make cost minimization possible: participants will trade rights among themselves up until the point when marginal reduction costs of all participants are equal.

Table 2.1 presents the degree of cost effectiveness of the three mentioned options. It shows that a system for emission trading unites both cost effective factors, by combining positive aspects of the two other options – an emission norm respectively emission tax. So the system can be regarded as a mixture of direct regulation – due to the establishment of an absolute emission cap – and market based policy – by influencing the market through allocation and trade of emission rights.

		Realisation emission target?	
		YES	NO
Cost minimization?	YES	*Tradable emission rights (combination)*	*Emission tax (market based policy)*
	NO	*Emission cap (direct regulation)*	-

Table 2.1: Cost effectiveness of policy options

The theoretical comparison of the above policy options, listed in Table 2.1, is based on several assumptions. First, it is implicitly assumed that emissions can be measured objectively. However, regulating authorities largely depend on information that is provided by the companies themselves, and these companies could have an interest in manipulating the information if possible. Adequate monitoring procedures, including a penalty structure, should therefore be designed to make some of the policy options viable. Second, it is assumed that with the emission rights trading system a perfectly functioning market is operational. In practice this will not be the case, especially during the initial phase. Third, it is assumed that non-compliance can be detected and penalized effectively. This is especially problematic for an international emission trading system where individual countries are bound by a certain emission cap. Enforcement of country specific emission caps might turn out a utopia.

Furthermore, in selecting the best policy instrument, transaction costs of the different options must be accounted for. Transaction costs of an emission trading system in particular are higher than those of the other two options, because an organized market must be set up.

Consequently, emission trade is not necessarily the better option. When designing an emission trade system close attention must be paid to the preconditions in order to let the system function properly. The foundation of emission trade SO_2 and CO_2 systems will be discussed in Chapters 3 and 4.

Cost effectiveness of an emission trade system presumes the participating companies to be guided by incentives to minimize[5] their compliance costs – i.e. the total cost of meeting the emission target. Choices to be made by participants in this context will be described in the following section.

2.2 Compliance options with emission trading

Entities that are subject to an emission trade regime are free to decide in which way they will achieve their emission target. The various compliance options will be discussed below. Firstly, section 2.2.1 describes the choice between autonomous reduction and external trade. Next, in section 2.2.2 we discuss the opportunity of banking – i.e. collecting emission rights for future use – in relation to compliance decisions. Finally, section 2.2.3 clarifies the concept of real options, which assigns value to flexibility of the various options. It will become clear that investing in autonomous reduction capacity leads to a certain loss of flexibility. Investment decisions must include this loss.

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[5] Special attention must be paid to the fact that, by applying cost-minimization, the value of external marginal benefits – i.e. benefits for environment and society from reduction – is left aside. Apart from the mentioned problematic measurability of reduction-profits, this is a consequence of the concept that companies make decisions on a purely financial basis. Environmental policies, especially emission trade, are largely based on this belief for a reason: external costs and benefits can and must be incorporated, because companies will only change their attitude when they feel it 'in their wallet'.

2.2.2 Autonomous reduction or external trade?

Participants of the emission trade system are faced with the fundamental choice between autonomous reduction and external trade (buying and selling of emission rights). How this decision comes about in case of a participant aiming to minimize costs will be illustrated below.

An emission rights trade system gives the entity the right to discharge a certain maximum of pollutants, within a given time. The fact that rights can be traded leads to realization of emission reduction at a place where costs are lowest. A transaction between two random entities A and B will happen if A has reduction costs P_A that are lower than costs P_B of party B. In this case party A will (further) reduce its emission and then sell the 'released' rights to B at an agreed price P_m. In order for a transaction to take place, this price P_m must be somewhere in between P_A and P_B: $P_A < P_m < P_B$. This way the transaction will guarantee an added value for both parties.

Supply and demand of emission rights creates a market price P*. Parties compare this price to their marginal reduction costs and decide what kind of action should be taken: which amount of emission rights to buy or sell, and which level of emission reduction to be realized internally? Table 2.2 gives an overview of decision making at individual entities' level. Decisions are made on the basis of (expected) market price for emission rights; for the time being, price volatility is left out. In section 2.2.3 the importance of volatility and its role in decision making will be demonstrated.

	Market price emission rights P^* < marginal reduction costs P_u	**Market price emission rights P^* > marginal reduction costs P_u**
Emission level Q_u > Emission target Q_t	**I** BUY emission rights	**II-A** AUTONOMOUS REDUCTION + SELL emission rights (if $Q_t > Q^*$)
		II-B AUTONOMOUS REDUCTION + BUY emission rights (if $Q_t < Q^*$)
Emission level Q_u < Emission target Q_t	**III** SELL emission rights	**IV** AUTONOMOUS REDUCTION + SELL emission rights

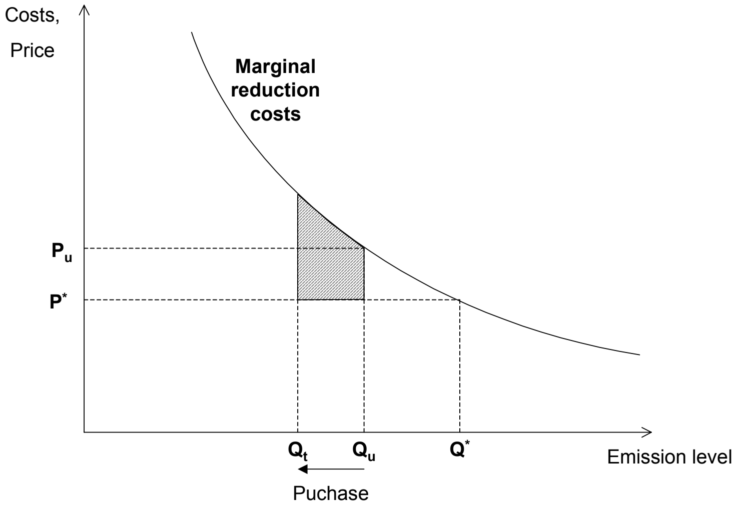
Table 2.2: Decisions depending on individual circumstances

The different circumstances mentioned in Table 2.2 will be reviewed[6] below. First, the symbols will be clarified:

P^*= Market price for emission rights.
P_u= Marginal reduction cost for the party concerned. This cost curve is downward sloping: at higher emission levels marginal reduction costs are lower than at lower emission levels. This is based on the assumption that costs of emission reduction increase when earlier reductions have been carried out.
Q_t= Emission target assigned to concerned party at initial allocation.
Q_u= Current emission level of concerned party.
Q^*= Optimal emission level of concerned party. At this level marginal reduction costs P_u equals market price P^*.

Situation I

In this situation, the current emission level Q_u is higher than target Q_t. Furthermore, marginal reduction costs P_u at emission level Q_u are higher than the market price P^*. To achieve the emission target, buying rights is recommended instead of internal emission reduction. Resulting emission level is Q_u as opposed to the optimum Q^*.



This sub optimal result is based on the cost curve can only be interpreted one way: an increase in emissions does not yield additional returns. More specifically, when $P^* < P_u$ it could be possible that the entity chooses to increase emissions and therefore purchases more rights or sells less. In this case market price P^* must not be compared to marginal reduction costs P_u, but to marginal increase profits $P_{\hat{u}}$, which will typically not be the same. In order to keep a clear view, this option will be left out. Assuming that $P_{\hat{u}} < P_u$ this choice is justified.

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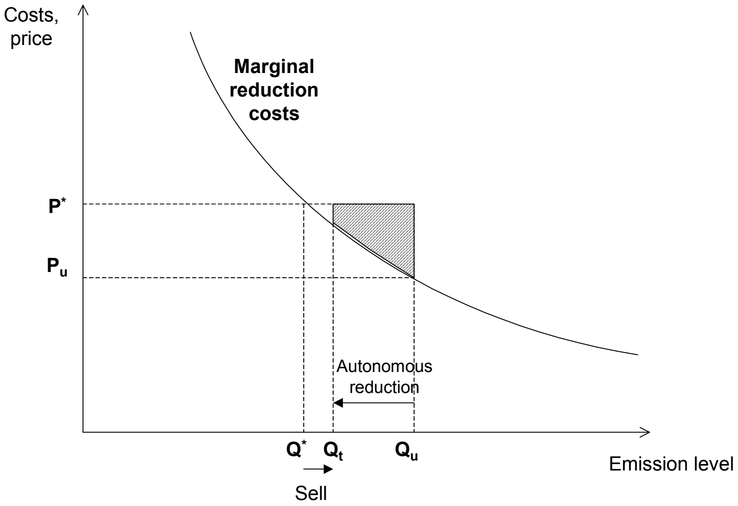
[6] Presented figures are partly based on IEA & OECD (2001:26)

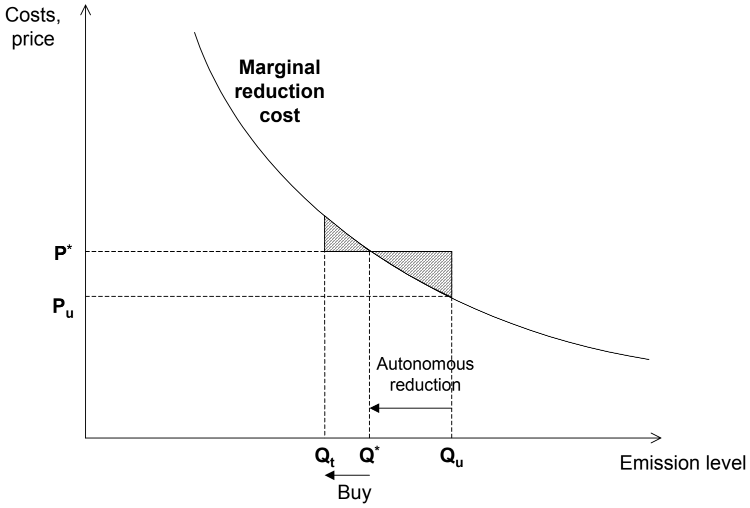
Situation II-A

In this situation, marginal reduction costs P_u at current emission level are lower than the market price P*. Given the fact that current level Q_u is higher than target Q_t, autonomous reduction will take place. Emission will even be reduced below target level, because also at this target Q_t marginal reduction costs are still lower than the market price. Emission will be reduced to Q* and the emission rights that are released because of this are being sold at market price.



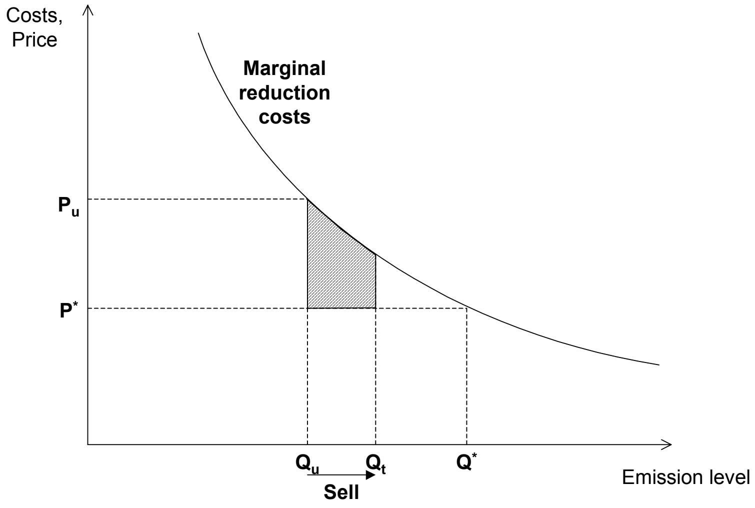
Situation II-B

In this case the starting point is similar to situation II-A: marginal reduction costs at current emission level are lower than market price, and current level is higher than emission target. This also results in autonomous reduction, but here marginal reduction costs already reach market price level before the emission target is achieved. Emission will be lowered to level Q*. The resulting gap between Q* and Q_t will be narrowed through the purchase of emission rights.



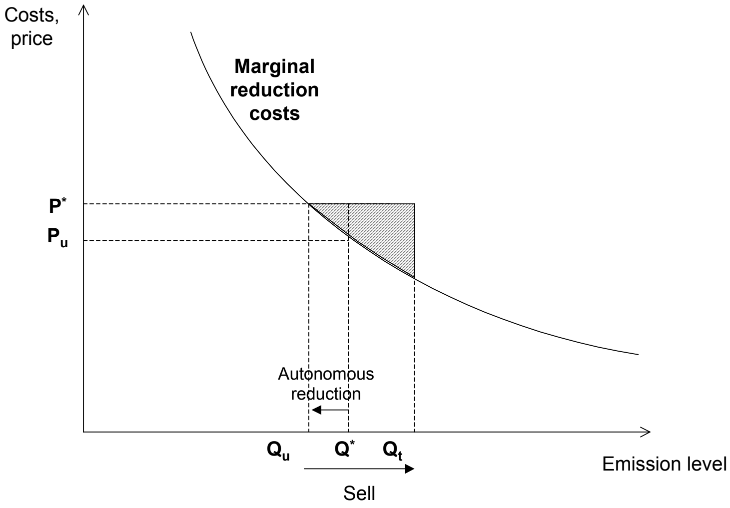
Situation III

Here the marginal reduction costs are higher than the market price. On top of that there is an emission rights surplus since target level is higher than the current emission level. The surplus emission rights can be sold on the market. Just like in situation I, optimal emission level Q* is not reached in this case.



Situation IV

Now, the current emission is lower than the emission target; excess emission rights can be sold at market price. Furthermore, because the market price is higher than marginal reduction costs at current emission level; reducing emission until Q* and selling the resulting rights will add value.



In short, it can be stated that in the above situations emission level Q_u signifies the starting point. At this level marginal reduction costs P_u are applicable. If $Q^* > Q_u$ emission will be maintained at level Q_u and the difference between Q_u and Q_t will either be purchased (situation I) or sold (situation III). If $Q^* < Q_u$ internal emission will be reduced to Q* level. The difference between Q* and Q_t will then be purchased (situation II-B) or sold (situation II-A and IV) on the market.

The examples described above show two different methods for narrowing the gap between actual emission level and emission target: autonomous reduction and external trade. In the examples, both methods are used at the same time, although in real life the timeframe for using both methods varies. After all, trading emission rights can be used as a short-term solution while autonomous reduction requires long-term planning[7].

The cost efficiency resulting from emission trade can be divided into *static efficiency* and *dynamic efficiency* (Gagelmann & Hansjürgens, 2002). Static efficiency is attained when emission rights are redistributed at short notice via trade: static efficiency is about a correction with regard to the *permitted emission level* of the participating entities. Dynamic efficiency can be achieved – or is aimed for – in the long term, when entities correct their *actual emission level,* for example in order to avoid having to buy emission rights or realizing a surplus that can be sold. Static and dynamic efficiency are closely related: both methods complement each other when searching for an optimal (cost minimizing) strategy concerning balance between actual and permitted emission levels.

When making an investment decision on reduction capacity, one needs to consider which part of the already existing static efficiency can be replaced by dynamic efficiency. The fundamental difference between these two plays a part: dynamic efficiency requires a once-only big investment, which will have a lasting effect on emission reduction. Each separate commitment period, a company reaches static efficiency by selling or buying rights. A comparison must be made between initial investment cost in dynamic efficiency and the net

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[7] Here it is assumed that autonomous reduction is durable. An ad-hoc decision to temporary lower production could also bring autonomous reduction; in only few instances will this be a realistic option.

present value of resulting extra benefits on the one hand, and/or avoided cost of static efficiency on the other.

Suppose that a company can make an investment *I* today, which yields emission reductions Q_t in years t ahead, and each year the reductions are expected to be worth the market price P_t. If the company has emissions below its allowance, then they can be sold; if the company has emissions above its allowance, they can be used to avoid the costs of buying emission rights. Therefore, each year the investment creates a future value of Q_t multiplied by P_t, which should be discounted at an appropriate risk adjusted interest rate to obtain the present value. Deducting the initial investment yields the net present value of the emission reduction. This is shown in the following calculation:

Net Present Value
= present value of revenues and costs avoided
- initial investment

$$=\sum_t \frac{Q_t \cdot P_t^*}{e^{r \cdot t}} - I \qquad \text{(I)}$$

Ideally, each investment with a positive net present value should be carried out. If there are multiple competing projects to invest in, then the one with the highest net present value should be selected, or a combination of projects must be selected that produces the highest (positive) net present value. Standard investment theory is based upon this principle, rather than principles such as ‘minimum payback period’ or ‘maximum revenue’, because the net present value represents the potential increase in total firm value.

A company can use the net present value criterion to achieve dynamic efficiency though (dis)investments in reduction capacity. A change in reduction capacity can be part of an investment in production capacity, but this is not necessarily the case. If it is, the initial investment does not only affect emission reduction; the present value of extra benefits and avoided costs of static efficiency should be integrated in the net present value calculation:

This integral view on investment decisions however does not dismiss the comparison to be made between initial investment and resulting benefits and cost savings. In order to keep things clear, investments in reduction capacity will be regarded as autonomous, separate investment projects.

2.2.2 Banking

An important factor in an emission trade system is the possibility of banking: to save up emission rights for future use. A participant who has surplus rights can – instead of selling them – keep these rights in an emission bank and use them later to comply with the target that applies at that time.

Figure 2.2 shows the course in time of the total emission target and the actual emission under a trade system, assuming participants are fully informed and make optimal decisions. The system includes two phases and in the second phase (after time T) the emission target is more stringent than in phase 1 (before time T). In this situation banking activities can be divided into three separate terms:

i. $0 \leq t < T$ The first phase of the system is in force. Emission target $Y_{t(I)}$ is as yet relatively easy to achieve and this gives participants the opportunity to put the excess rights ($Y_{t(I)}$ - e_t) in the emission bank;

ii. $T \leq t < \tau$ Start of the second phase, with more stringent emission targets. The emission bank set up earlier is now used to make up for the emission surplus that has arisen.

iii. $t \geq \tau$ At a certain moment τ in the second phase, the emission bank is used up. From this moment onwards emission target $Y_{t(II)}$ and emission e_t are equal.

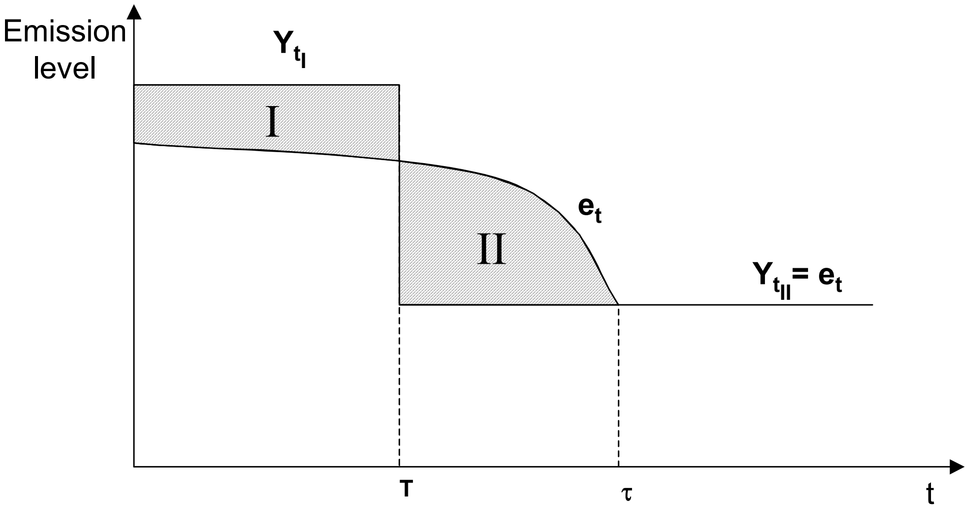

Figure 2.1: Development of emission through banking

Figure 2.1 clearly shows the improved flexibility caused by banking. At transition point from first to second phase (T) the emission target is immediately sharpened, which would oblige to a similar reduction of emission without a banking option. Banking on the other hand gives the opportunity of gradually reducing emission during a longer period until the second phase target. This also provides ecological benefits, because part of the reduction takes place earlier in time. After all, by banking, the emission in phase 1 is being reduced to below the emission target level (field 1); corresponding emission rights will be used in the second phase in order to make a gradual decrease of emission level possible (field II). The surfaces of I and II are equal; part of the emission reduction is transferred from phase 1 to phase 2.

Banking can be an attractive option, for example when a lowering of the target or increase of emission rights prices is expected. Banking brings about more flexibility in the way entities cover their emission goals. More or less, it is another form of trade. Next to *spatial trading* (external trade with other participants), now there is the opportunity of *intertemporal trading* (´transfer´ of emission rights to the own company in the future)[8].

Theoretical cost savings of various trade concepts are comparable. Spatial trading leads to a situation in which marginal reduction costs of all participants are similar: they are equal to the market price of emission rights. Trade activity will continue until this optimal situation is reached (Tietenberg, 1996). Intertemporal trading causes a similar saving of costs; in an optimal situation the market price in different periods – discounted against the risk free interest – will stay the same through banking (Schennach, 1998). Figure 2.2 shows this dynamic market efficiency in diagrammatic form[9].

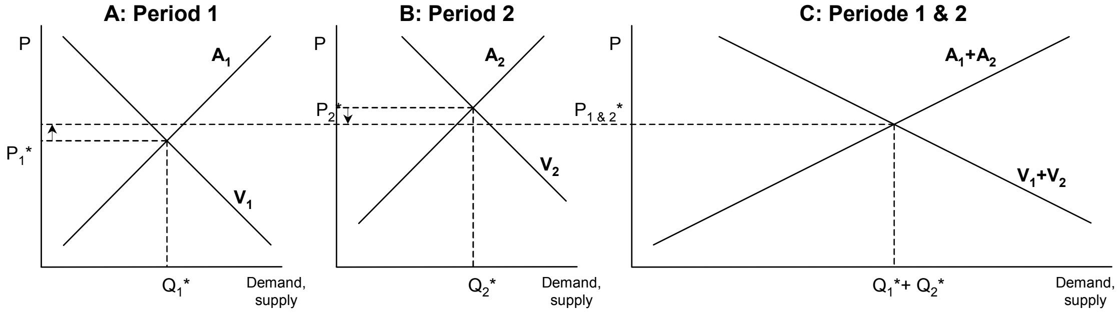

Figure 2.2: Emission rights market under banking

Figure 2.2 shows a situation in two successive periods; in period 1 the price of emission rights P_1 is lower than price P_2 in period 2. As long as the price in period 1 is still lower than in period 2, there is an incentive for participants in period 1 to save up emission rights in an emission bank. In this period the demand for rights V_1 increases and the supply A_1 declines, resulting in a higher price.

In period 2 on the other hand, the demand for rights V_2 decreases and the supply A_2 increases, causing a lower price. Both periods can be seen as ´communicating vessels´ in which the collective demand $V_1 + V_2$ and collective supply $A_1 + A_2$ in both periods eventually give a balanced price $P_{1\,\&\,2}$. This shows that the price of emission rights in different periods – discounted at risk free interest rate – are equal in the resulting balanced situation. However, this result is based on the assumption that prices in period 1 are below the prices in period 2. If the reverse is true, then prices in the two periods will only converge if borrowing of emission rights is allowed: the higher costs in period 1 will then be avoided and replaced by the market price in period 2.

More generally, in a world of perfect markets where participants can make perfect forecasts on the future availability of and need for emission rights then there is a direct relation between prices in different periods. First, when both banking and borrowing of emission rights are allowed, then the prices in different periods will be equal, except for their time

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[8] Theoretically transfer from future emission rights to the present is possible. This opposite to banking, called borrowing, could present serious objections, particularly from an ecological point of view. In practice this method is not used and will therefore not be discussed here.

[9] It is implicitly assumed that *spatial trading* in the various periods has already fully taken place. So, marginal reduction costs of all participants and market price for emission rights are equal.

value. This results from the possibility to bank when future prices are (expected to be) higher, and the possibility to borrow[10] when future prices are (expected to be) lower. When only banking is allowed (as is typically the case), then the result is somewhat less strong: the price in period t will not rise with more than the interest rate[11].

This result of inter temporal price relations is formally demonstrated in Schennach (1998). He demonstrates that the investment problem is an integral part of an optimisation-problem through several periods in time (see the frame[12] on the next page).

The assumption of perfect foresight about future market situations, on which the Schennach (1998) result is based, can be relaxed when we replace actual prices with expected (forward) prices. in the case of forward trading. The relation between forward prices (for emission rights in different forward periods) and spot prices is equal to the general forward price relation for storable commodities (…). This relation states that the forward price for delivery of the commodity in period t (F_t) equals the current spot price (S), valued forward to period t:

Forward price relation for storable commodity:

forward price for delivery in period t = spot price valued forward to period t

$$F_t = S \cdot e^{rt} \qquad \text{(II)}$$

This result can be translated directly to assess the current market forecasts of some companies and institutions (Figure 2.1). Some market forecasts due not accurately incorporate the banking option. For example, an expected increase from € 10 in 2007 to € 12 in 2008 is probably based on the assumption of stricter emission targets from 2008 onwards. However, the jump in price is not sustainable, because companies will respond to this expected price increase by banking before 2008, which in turn will make prices converge. Forward arbitrageurs will drive this convergence process, as they do in all markets for storable commodities.

The possibility of banking makes an adjustment to the net present value calculation in section 2.2.1 necessary, because mutations in the emission bank will alter yearly proceeds and costs:

Net Present Value including banking

= present value of revenues and costs avoided

- initial investment

$$= \sum_t \frac{(\mathrm{Q}_t - \Delta S_t) \cdot P_t^*}{e^{r \cdot t}} - I \qquad \text{(III)}$$

The net present value with banking of course is higher than without banking. After all, banking creates extra flexibility to achieve the fixed emission target; a company can make use of this according to their own insights. Actually the above calculation presents an optimisation problem: mutations in the emission bank through the years should be chosen in a way that maximizes the total net present value.

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[10] The explicit assumption 'borrowing' may be relaxed when emission banks are sufficiently filled to meet future demand for emission rights.

[11] The interest rate should be risk-adjusted to incorporate the price uncertainty about future emission rights.

[12] This problem applies to al participating units together. Under the implicit assumption of complete information, optimal decisions of the individual units can be derived from this.

Inter temporal price relation

On a general economic level, efficiency in a single period of time is attained when the emission m_t is at a level that ensures that (1) marginal costs for additional emission reduction c'_t (m_t) equal the market price for emission rights P_t., and (2) when both are as low as possible. Efficiency in a multi-period framework is attained when marginal reduction costs in each period equal the market price for emission rights in that period and when the sum of all costs (discounted back to today at interest rate r) is minimized.

$$\min_{\{m_0, m_1, \ldots\}} \left\{ \sum_{t=0}^{\infty} c_t(m_t) \cdot e^{-rt} \right\}$$

With the possibility of banking, the actual emissions m must be at a level that ensures that the above mentioned objective (overall cost minimization) is achieved. The emission levels cannot be chosen freely, however, but are subject to two logical banking constraints:

1) The emission bank account in period t+1 (S_{t+1}) equals the account in period t plus the allocated rights (Y_t) minus the emission m_t
2) The bank account may not become negative (since borrowing is not allowed)

$$S_{t+1} = S_t + Y_t - m_t$$
$$S_{t+1} \geq 0$$

where

m_t	actual emission in period t;
$c'_t(m)$	marginal costs for emission reduction in period t;
Y_t	total number of allocated rights in period t;
S_t	emission bank account in period t;
r	interest rate;

It can be shown (Schennach, 1998) that efficiency is attained when:

$$c'_{t+1}(m_{t+1}) = (c'_t(m_t) - \lambda_t) \cdot e^r$$

where

λ_t	Lagrange multiplier related to the constraint $S_{t+1} \geq 0$

The above result states that the marginal costs of emission reduction in period t+1 equal:

1) the marginal costs in period t (time value adjusted) when borrowing is not optimal ($S_{t+1} > 0$),
2) somewhat less than the marginal costs in period t (time value adjusted) when borrowing would have been optimal ($S_{t+1} = 0$ and thus $\lambda_t > 0$)

If the non-borrowing constraint is binding (2), then no emission rights will be transferred to the next period. This is a situation where market prices for emission rights increase with less than the interest rate or even decrease.

2.2.3 Real options

Investment decisions always take place in a dynamic environment, where there is uncertainty about future market circumstances. The standard net present value method is a much used way to judge various investment projects. However, this method is based on some implicit assumptions that projects in practice not always comply with. Especially the assumption that either an investment can be reversed free of charge, or – if the investment is final – the decision has a 'now-or-never' character: if the decision not to invest has been made, the possibility of investing ends altogether, even in the coming periods (Dixit & Pindyck,1994).

In order to involve these shortcomings in the net present value method, an additional valuation of *real options* can be used. The surplus value of this approach lies in the fact that the degree of flexibility of projects is being valued. The presence of these options influences the value of an investment project and therefore the decisions that are to be made.

A few options deserve special attention: firstly the *deferral option*, also called *option to wait*. A company that has an opportunity to invest in fact has an American call option[13]. The company has the right – not the obligation – to 'buy' assets at any chosen time. If the company actually invests, in a way the option is claimed; the possibility is dismissed to postpone investment until more or better information is available. The resulting loss of option value – *opportunity cost* – needs to be incorporated in the decision, as part of the project costs.

A second option is the *abandonment option.* If a company has invested in a project, changing circumstances in time could cause the project to – contrary to expectations – make a loss. The possibility to disinvest at acceptable cost – in fact to dispose of an (American) put option – increases flexibility and represents a certain value. With projects that actually have this kind of flexibility, this value needs to be part of the initial investment decision, by adding the value of the abandonment option to the net present value of the project.

Apart from the above-mentioned options, some other examples of real options can be given. They all provide flexibility in their own way and therefore represent value, particularly the *option to expand* (American call option) and the *option to switch* (combined put and call option).

Probably the two most important optionalities are those to defer and to abandon. Incorporating these two options the net present value can be adjusted as follows:

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[13] An American option can be claimed either on or before the expiry date, as opposed to European options which can only be claimed on expiry date. These terms by the way do not indicate geographic division of use of options.

Net Present Value including banking and real options

= present value of revenues and costs avoided
+ abandonment option (AO)
- deferral option (DO)
- initial investment

$$= \sum_t \frac{(Q_t - \Delta S_t)\cdot P_t^*}{e^{r\cdot t}} + AO - DO - I \qquad \text{(IV)}$$

The project generates value – and thus should be executed – if the overall NPV is positive. The effect is that projects are accepted that have a negative 'standard' NPV, but which may be abandoned easily. Similarly, projects with positive 'standard' NPV are not yet executed, because there is a significant option to defer (Pike & Neale, 1999).

Real options have a significant role in the choice of strategy when it concerns achieving emission targets: an investment in autonomous reduction capacity involves both creating and losing options. The following case may clarify this:

Case - Investment selection with real options

A power generator participates in an emissions trading scheme with an emissions target below its current level. For the time being the company fulfils its obligations through the purchase of emission rights. The company considers replacing the emission rights purchase plan by an investment in autonomous emission reduction. It analyses two potential projects, A and B.

Project A is characterized by a low initial investment, high operational costs and a reasonable emission reduction. Furthermore, project A is highly flexible: disinvestments are relatively cheap because the machinery can easily be sold to other companies when emission rights trade at low prices.

Project B demands a higher initial investment, but requires lower operational costs. Furthermore, it achieves an emission reduction twice the size of project A. However, the project B is not so flexible. The machinery is very user specific, such that the investment should be treated as a sunk and irreversible cost: disinvestments will hardly ever be optimal, even at very low price levels.

Decision problem: the impact of real options

The company is faced with four opportunities: (i) investing in A, (ii) investing in B, (iii) investing in both A and B, or (iv) not investing. If it is decided not to invest today (iv), then the investment opportunity is not lost: investment may be postponed up to T periods ahead (T is the investment horizon). The investment horizon depends on the extent to which new technologies become available.

Both projects can be judged on the basis of expected market developments using the standard NPV method. The possibility to postpone the investment creates a deferral option that should be treated as an opportunity cost. In addition, project A contains an abandonment option that increases its net present value.

In Chapter 5 we will formally analyse how real options can be valued. Here we just assign some hypothetical values to the different options, in a situation where the option values are decisive:

	Standard NPV	**Deferral option**	**Abandonm. option**	**Actual NPV**
Project A	-2	+2	+5	+1
Project B	+2	+4	--	-2

According to the standard NPV, investing in project B would be optimal. Investment in project A on the other hand is not wise even if it were the only available project. The real option values radically change this situation. Due to its high and irreversible initial costs it is better not to start project B yet, but to wait for market developments that make the investment more certain. Because of the relatively low initial investment, the option to defer (an opportunity cost!) is not so valuable for project A. Moreover, this investment can sufficiently be recouped if markets move against it. So, project A should be undertaken directly.

2.3 Conclusion

When making production and consumption decisions, usually the negative external effects of emission are not taken into consideration; this is a form of market failure. Prevention of this market failure will eventually result in a more efficient allocation, although the degree of efficiency is difficult to measure. An alternative is aiming for cost effectiveness: to be able to achieve the determined emission level against minimal costs. Theoretically, a system of emission rights trading is an excellent way to attain this cost effectiveness.

Under an emission trade regime, participants must decide how they are going to achieve their fixed emission target. Actually, companies need to take a *'make-or-buy'* decision: aim for autonomous reduction (*make*) or trade emission rights (*buy*). Investment decisions can be based on the net present value calculation of the various projects available. By successively adding the influence of banking and the value of real options, a more accurate net present value calculation is obtained, which serves as a guideline when making investment decisions.

In the next chapter, this augmented net present value concept (including banking and real options) will be used as a framework for judging investment in reduction capacity under the Acid Rain Program, the SO_2 trade system in the United States. Later on the real option methodology will be explained further. We will apply the methodology to a case study in which we calculate the net present value of a CO_2– reducing investment project. This will demonstrate the important role of real options within the decision making process.

3 Compliance strategies in the Acid Rain Program

As discussed in Chapter 2, captive companies have several options to achieve their emission goals. Especially the fundamental difference between static and dynamic efficiency came up. In order to explore producers' behaviour it is useful to take a look at past experiences with the SO_2 trade system in the U.S, and also to analyse whether the systems are comparable. Firstly, a short resume of the SO_2 trade system will be given; then we discuss the observed investment behaviour under this system. Finally, we investigate the meaning of these experiences with regard to expected investment behaviour under the future CO_2 system.

3.1 Characteristics of the SO_2 trade system

The emission trade system in the US is also known as the US Acid Rain Program, since its main goal is to reduce acid rain. Main cause of acid rain in the States is sulphur dioxide, SO_2 , To deal with the SO_2 emission problem Title IV of the 1990 Clean Air Act Amendments was formulated; based on criteria mentioned in Title IV policy makers developed the definitive Acid Rain Program.

Gagelmann & Hansjürgens (2002) have distinguished five aspects, which together determine the functioning of an emission trade system: (i) the range of the system, (ii) determination of the total emission level, (iii) primary allocation method of emission rights, (iv) market forces and (v) monitoring. Below we explain each aspect and its function within the SO_2 trade system. In Chapter 4 the characteristics of an emission trade system will be reviewed with regard to the proposed CO_2 system.

3.1.1 Scope of the system

First of all, the scope of the trade system must be established. Two choices are possible: a 'downstream' system or an 'upstream' system. 'Downstream' means that the obligation to obtain emission rights lies with the emitting entities themselves[14]. An 'upstream' system on the other hand commits producers and importers of fuels to obtain emission rights, depending on the greenhouse gas emission that these fuels will eventually cause.

The most remarkable advantage of an 'upstream' system is that, through cost benefits, a larger share of emission can be part of an emission trade system. With a 'downstream' system the costs of monitoring of the transport sector and private households are often too high. Consequently, an 'upstream' system increases both ecological effectiveness and economic efficiency of the trade system.

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[14] In this context it is important to realize that emitters are not by definition the same entities as the *end users* of energy. This is an important distinction when it concerns electricity production: the end user is the consumer of electricity, yet the power generator produces the CO_2 -emission. If the producer is responsible for obtaining emission rights, this can be seen as a 'downstream'-system (even though the producer obviously is not the end user).

Advantages of a ‘downstream’ system could be that it holds a direct incentive to reduce emission; end users are responsible for their own emission and will actively search for reduction options. The incentive of an ‘upstream’ system, through including emission costs in fuel prices, is indirect and therefore less powerful. Besides, part of the increased efficiency will probably disintegrate, because price setting of producers and importers determines if emission costs are eventually passed on to the right end user (i.e. ‘polluter’). In other words, the ‘upstream’ system does not necessarily comply with the ‘polluter pays’ principle.

Apart from this choice between ‘upstream’ or ‘downstream’ it is also important to establish which (branches of) industrial sectors should be included in the trade system. Both feasibility of implementation – initially, smaller companies will possibly be spared – and competitive considerations as well as ecological effectiveness need to be considered. Lastly, policy makers must decide which particular greenhouse gasses will be included in the system.

The SO_2 trade system has a ‘downstream’ approach: the emitting entity is obliged to obtain sufficient emission rights. Participation to this program is limited to electricity producers, who together are responsible for 70% of SO_2–emission in the States in 1985. The program is divided in two phases. To Phase I (1995-1999) 263 large, most pollutant units were obliged to participate. These so-called Table A-units – they are mentioned in Table A of the statute – are responsible for 57% of SO_2 emission by electricity producers in 1985 (Ellerman et al., 2000). In phase II (from 2000) most remaining installations of producers were included in the program[15]. Producers had an *opt-in* choice for Phase I: they could decide to let certain units participate in Phase I even though they are not mentioned in Table A. In the first three years of Phase I (1995-1997), a total of 199 units made this opt-in choice, 138 of them participating each of these three years.

3.1.2 Stipulation of total emission level

With regard to the total emission level, the first choice that needs to be made is between a system with absolute allowance (cap and trade) and a system with a relative allowance, stipulating maximum emission levels *per production unit*.

The Acid Rain Program uses an absolute allowance system (cap-and-trade), that is being reviewed each year. Target is to reduce SO_2–emission by 50% in 2010 compared to basis year 1985, and to consolidate that level the following years.

Figure 3.1 shows that the actual emission in 2001 (10.6 million tons) is already 34% lower than emission in 1985 (17.3 million tons). The amount of allocated rights in 2001 (9.6 million tons) is even 40% lower compared to the level in 1985. The fact that emission in 2000 and 2001 are higher than the amount of allocated rights does not imply that participants fall short of their collective target; saved up rights (through banking) compensate for the emission surplus.

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[15] The total amount of electricity-producing units in the US in 1995 is 2918, consisting of 263 Table A-units and 2655 other units. Of these other units 2604 were included in Phase II; the remaining 651 units did not participate, for various reasons.

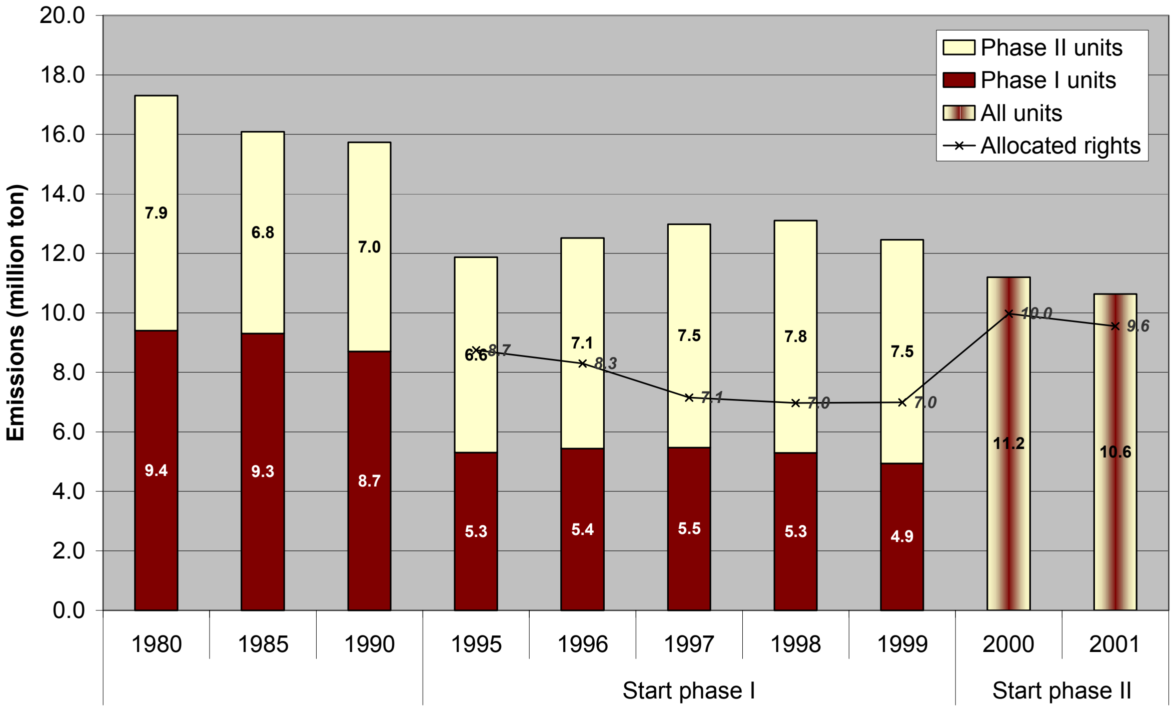

Figure 3.1: SO_2–emission, 1980-2002 (EPA, 2003)

3.1.3 Primary allocation method of emission rights

There are two variations of the primary allocation method[16]. The first one is to distribute emission rights via auction. From an economic efficiency point of view this is the best option, as emission rights will find their way to those entities that have the highest autonomous reduction costs; these entities will be prepared to bid the highest price for rights in order to avoid autonomous reduction. The alternative is free allocation, based on for instance current emission or production ('grandfathering').

Allocation of rights under Title IV mainly happens through 'grandfathering', free allocation based on historical production[17]. Participants to Phase I receive rights equivalent to 2.5 lbs/mmBtu[18] multiplied by average fuel use over the years 1985-1987. In Phase II large, 'polluting' installations receive rights equivalent to 1.2 lbs/mmBtu multiplied by average fuel use over 1985-1987. 'Cleaner' installations in this phase have a target below 1.2 lbs/mmBtu, depending on size of installation, emission details over 1985 and use of fuel (Wirth, 1998).

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[16] *Primary allocation* is the way emission rights are divided over participating entities at the beginning of a trade period. *Secondary allocation* is allocation as a result of emission trade between parties. Secondary allocation defines the actual economic efficiency of the trade system whereas primary allocation mainly determines the costs for individual entities. This is part of the reason that the primary allocation method is regarded as controversial.

[17] This method implicitly takes into account '*early action*' of participants, as opposed to allocation of rights based on historical emissions.

[18] "lbs/mmBtu" means pounds SO_2 per million British thermal units.

In addition to free allocation, each year an auction of a limited amount of rights takes place. This auction is installed particularly to give new installations the opportunity to obtain rights[19]. In Phase I 150,000 and in phase II 250,000 rights per year were auctioned. This corresponds with a percentage between 1.7% and 2.6% of the total amount of allocated rights per year from 1995-2001 (see Figure 3.1). The auction method is the so-called *zero revenue auction*: proceeds return to the participating producers in proportion with the amount of deducted rights[20].

3.1.4 Market forces

Demand and supply forces are the foundation of an emission trade system. The efficient distribution of rights depends on the way actual trade takes place between entities with different internal cost structures. A functional market is first and foremost a liquid market. Requirements are i) continuous sufficient supply and demand; ii) enough market parties; and iii) minimal market restrictions (Gagelmann & Hansjürgens, 2002).

In spite of the relatively small number of participants the SO_2–system has developed into a liquid market. The presence of a few hundreds of units means that there are enough market parties, which create sufficient supply and demand. Also the market restrictions are minimal. Ellerman et al. (2000) give some examples of restriction absence: (i) international trade is possible; (ii) trade activities are not controlled by a supervisor beforehand or after; (iii) purchase and ownership of rights is possible to third parties – not limited to producers that need to reach their emission target; (iv) emission trade techniques and frequency will not be restricted; and (v) rights can be saved up for future use via banking.

Ellerman et al. (2000) also observe that the SO_2 market is efficient, because it increasingly possesses the following characteristics: (i) transparent price information for buyers and sellers; (ii) low transaction costs; (iii) quick possibility of arbitrage; and (iv) participants make optimal use of reduction possibilities via emission trade. Rose (2000) is more conservative about this last point; he states that cost reductions are achieved via trade, but there is certainly no question of optimal use of possibilities as yet.

3.1.5 Monitoring

The final aspect of a functional emission trade system is effective monitoring, consisting of surveillance and sanctioning. Without monitoring emission trade cannot function properly; environmental effectiveness of the system would be jeopardized and participants would lose confidence.

Surveillance on emission levels is done by the obligatory installation of *Continuous Emission Monitoring* (CEM) equipment. In addition, there is a database, the *Allowance Tracking System*, which registers the exact amount of rights per participant. Transactions between parties are processed, so that at any given time information on the ability of parties to cover

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[19] Installations starting after 1985 do not obtain rights through 'grandfathering'.

[20] Rights that will be auctioned become available by deducting part of the initially allocated rights. Proceeds will go to producers whose rights have been deducted.

their emission can be provided. When at the end of a year a party cannot show sufficient rights to cover their total emission, penalties of more than \$2000 per ton SO_2 are fined[21]. When the penalty amount is compared to the (average) rights price, it becomes clear that this is an effective way to get parties to keep within their targets. In 2001 the penalty amount (\$277) is already 13 to 18 times higher than the market price of emission rights, varying from \$152 to \$211[22].

3.2 Market results[23]

In this section we discuss the experiences with the SO_2–trade system from 1995 until and including 2002. Market results will be investigated, followed by an analysis of participants' strategies.

3.2.1 Over compliance

In Phase 1 (1995-1999) and the first three years of Phase II (2000-2002) of the trade program practically all participants have reached their emission goals. Non-observance of emission targets is sporadic: in the 2000-2002 period the equivalent of respectively 54, 11 and 33 emission rights was fined (EPA, 2001, 2002, 2003). This is an encouraging result, but in principle this only means that the total emission equals the amount of provided emission rights and that the internal and/or external re-allocation of rights functions properly. It is more interesting to look at how, and to what extent, extra emission reduction (*over compliance)* is taking place.

Over compliance had a strong impact during the first years of the program. While in the five years of Phase I the total amount of allocated rights was 38.1 million (equal to the same amount in tons SO_2), the total emission was merely 26.5 million tons SO_2. The remaining 11.6 million rights can be used to cover emission in the following years via banking. In the first three years of Phase II over compliance disappeared: the actual emission was higher than the amount of allocated rights. Consequently, a total of 3.0 million rights have been withdrawn from the emission bank.

3.2.2 Low price of emission rights

The price of emission rights during the first years of Phase I was considerably lower than expected. In 1992 the first emission rights transactions were reported, against prices of \$300 and \$265 per ton – as was expected at the time. Then the prices, both auction prices, market prices and prices of direct transactions – have shown a downward trend: around \$100 per ton in 1996 and 1997. From 1998 it has been more or less stable at \$150-\$200 per ton (see Figure 3.2), still lower than initially expected.

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[21] This penalty of \$2000 per ton was in force in 1990; it is corrected yearly for inflation. In 2001 the fine was \$2774 per ton (EPA, 2002)

[22] These amounts are respectively the minimum and maximum of observed average monthly price of emission rights in 2001

[23] Data derived from Ellerman et al. (2000) and Schmalensee et al. (1998).

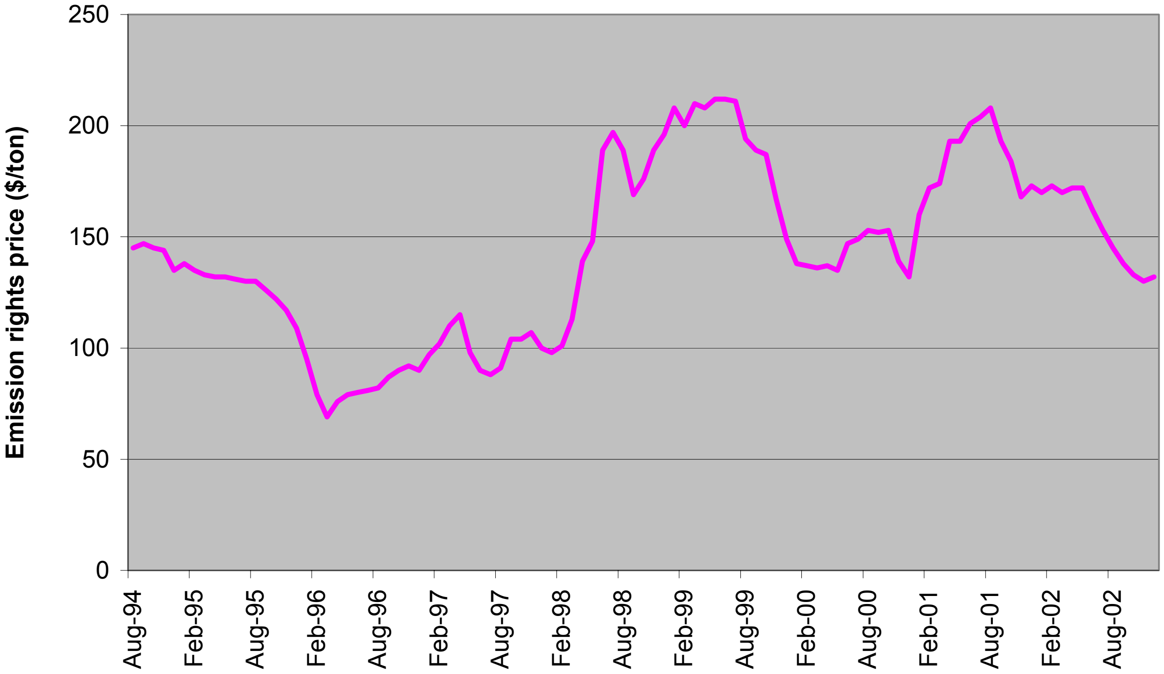

Figure 3.2: Average monthly prices SO_2 – rights. Source: Cantor Fitzgerald

There are various explanations for these relatively low prices of emission rights. Each of them will be discussed below:

i. Market defects
ii. Inadequate models
iii. Deviating incentives
iv. Market principles
v. Irreversible investments

i. Market defects

Ellerman et al. (2000: 299) mention three shortcomings of the market, suggested by third parties, which may have contributed to the low prices of emission rights: a) faulty designing of the auction method; b) insecurity regarding exchange value based on rights transactions; and c) trade barriers and transaction costs. However, none of these seem to be convincing statements. Schmalensee et al. (1998) too notice that opponents of emission trade consider the low price of rights as a symptom of the malfunctioning emission trade market, yet these critics are unable to give a sound basis for their statements. Bohi and Burtraw (1997) mention the auction method as a possible cause; it may incite both buyers and sellers to give out reserve prices that are too low. However, the influence of this factor has never been demonstrated in a convincing way.

ii. Inadequate models

Prices of emission rights are forecasted through models that represent reality, yet at the same time show a simplified version of this reality. Bohi and Burtraw (1997) argue that certain aspects of the trade program are not incorporated in the models on which prices are based, and therefore these models are inadequate. Three aspects of the program are not included in the forecasting models:

a) allocation of bonus rights when investing in scrubbers[24];
b) phasing of the trade program – most potential sellers of rights will join in Phase I, whereas potential buyers will only join in Phase II;
c) substitution and compensation units which lead to a further decrease of compliance costs.

By leaving out these aspects, emission rights prices based on models are being structurally over-estimated.

iii. Deviating incentives

Flexibility mechanisms of an emission trade system intend to give participants the opportunity to minimize their cost of compliance. Implicit assumption is that the decisions participants make are indeed caused by an incentive to minimize costs. In practice this is not always the case; for example at public utilities cost minimization is certainly not the main objective.

According to Bohi and Burtraw (1996) deviating incentives have contributed to low emission prices. The authorities have systematically created incentives to invest in scrubbers, causing investments that are in fact non-economical to be carried out. These investments further diminish the need for other compliance options (such as the purchase of rights), which leads to a lower price. Ellerman et al. (2000) agree that political pressure and grant schemes have brought about a number of investments in scrubbers, but doubt the influence of this on emission rights prices – pointing out some intended investments being cancelled for economic reasons, in spite of political pressure.

iv. Market principles

This concerns the changing market circumstances that have affected - in this case lowered - marginal costs of compliance. In this context Bohi and Burtraw (1997) have distinguished four possible explanations:

a) competition and innovation have lowered the costs of both scrubbing and switching;
b) availability of inexpensive low-sulphur coals;
c) equilibrium effects: the costs of the trade program are included in the electricity prices → higher prices lead to less electricity demand → which in turn causes indirect emission reduction.

The pressure on prices through innovation, as mentioned in a) is also acknowledged by other authors. Both Schmalensee et al. (1998) and Ellerman et al. (2000) recognize the influence of innovation, but they believe the difference between expected and actual prices is too big to be caused just by cost reduction through innovations.

v. Irreversible investments

Ellerman et al. (2000) say that mentioned arguments do not fully explain the low emission prices during the period 1995-1997. Furthermore they observe that a convincing argumentation should not only explain the low prices but also the difference between (low) prices on one hand and (high) long-term marginal compliance costs on the other. Theory

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[24] Scrubbers are installations which can de-sulphurize emission gasses. They require substantial investments and guarantee long-term SO_2-reductions. Scrubbing is one of the two most important methods for autonomous emission reduction. The second method is *fuel switching* – switching to fuels that contain less sulphur, such as low-sulphur coal or natural gas. This method provides more flexibility than scrubbing.

predicts that marginal costs and emission prices are equal, but in reality this does not happen; emission rights prices in 1995-1998 vary from $70 to $ 130, while long-term marginal compliance costs are around $350 in 1995.

Both observations originate from two phenomena that influence each other (Schmalensee et al., 1998; Ellerman et al., 2000):

a) long-term investments in scrubbers and long-term coal purchasing contracts lead to inflexibility within the compliance strategy;
b) the unexpected availability of cheap low-sulphur coal diminishes the required emission reduction.

These two will be clarified below.

Compliance decisions need to be made at an early stage. Especially the decision to purchase scrubbers already required commitments back in 1992 and 1993, when price information was incomplete and uncertain. An inquiry among participants in 1996 showed that the choice for scrubbing was largely made based on the expectation that emission prices would be somewhere around $300 and $400 per ton. Besides, many participants who chose fuel switching have signed long-term contracts back in 1992-1994 to buy low-sulphur coal at premium prices. They had in mind the expected market circumstances in Phase I, especially the predicted high(er) prices of both emission rights and low-sulphur coal.

The expected higher prices of rights have led to reduction capacity over investing, which resulted in lower than expected prices. After all, over investing enabled producers to cover their emission targets autonomously. As a result, the external demand for emission rights decreased; for example only 13 of the 49 participating producers have called for emission rights the first three years of the program. The paradoxical situation of high price expectations eventually resulting in lower actual prices, is a typical example of a ***self-denying prophecy***. Market players anticipate market developments influencing these developments at the same time. In this case, their collective behaviour leads to predictions remaining unfulfilled.

Apart from the expected high emission prices, another factor has contributed to over investing in valuable reduction capacity: the initially expected high price of low-sulphur coal combined with the sudden availability of inexpensive low-sulphur coal. Looking back, it can be concluded that long-term contracts for the purchase of coal have been entered at prices that were too high.

A correcting response to these unpredicted market developments is expected. The inquiry mentioned earlier shows that certain proposed investments in scrubbers have indeed been cancelled. A third of the respondents mentioned the low emission prices as a reason, two thirds pointed out the low price of low-sulphur coal in comparison with the costs of scrubbing (Schmalensee et al,. 1998).

3.3 Compliance strategies

In the previous section market results during the first years of the program have been discussed. This section deals with compliance strategies of the individual participants and also the coherence between strategies and market results.

The three most important options to meet emission targets are:

i) autonomous reduction;
ii) trading;
iii) banking.

Compliance strategies can contain one or more of these options. In the first place, the choice of strategy depends on price signals in the market. Swift (2001) notices that in practice, participants do indeed quickly respond to these signals by adjusting their strategy. In Phase I of the trade program he distinguishes three stages in which price signals are followed by participants' behaviour changes.

The first stage - even before the program becomes operational in 1995 - shows over investing in reduction capacity. In the next stage, structurally lower emission prices become evident - resulting in proposed scrubbers investments being cancelled. Instead, more use is made of the fuel switching method in the third stage.

To support the basic strategy of autonomous reduction, from 1995 intra-utility trading and banking were introduced to re-allocate available emission rights both in space and time. During the third and last stage, near the end of Phase I, the majority of participants were active on the external emission trade market. Nevertheless, most of the companies still believe in internal solutions, working with both autonomous reduction and banking.

Ellerman (2000) agrees with this, but emphasizes the actual *shift* of compliance strategies in time, instead of the gradual appearance of various *additional* compliance options. According to Ellerman, before 1995 internal solutions dominate. After 1995, when over investing becomes apparent, he notices a shift towards strategies that are based on the market circumstances at that particular time. Flexibility in order to adjust strategies to market changes is a fact.

In the following sections the three options (autonomous reduction, trading and banking) will be discussed in detail.

3.3.1 Autonomous reduction

The two major ways of reducing SO_2–emission are scrubbing and fuel switching[25]. Scrubbing requires a substantial initial investment, followed by relatively low operational costs. Scrubbing leads to long-term emission reduction; once the scrubber is acquired SO_2 emission will be reduced against relatively low costs during a longer period.

The other method, fuel switching, requires lower initial investment than scrubbing but extra costs result from the purchase of (more expensive) low-sulphur fuel. Fuel switching gives the

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[25] These are the two most important methods. A few other methods do exist, but their role is marginal.

producer more flexibility; when emission rights prices drop, the producer could choose to switch back to more sulphur rich fuels. Nevertheless, long term buying contracts could limit this flexibility.

The actual emission reduction during the years 1995-1997 was achieved mainly through fuel switching. Still, a substantial part of reductions (37%) during these years was realized via scrubbing (see Table 3.1)

	1995		1996		1997		Total	
Scrubbing	1.3	32%	1.5	39%	1.6	40%	4.4	37%
Fuel switching	2.8	68%	2.3	61%	2.4	60%	7.5	63%
Total	4.1	100%	3.8	100%	4.0	100%	11.9	100%

Table 3.1: Emission reduction methods (million tons). Source: Swift (2001)

Moreover, emission reduction via scrubbing shows an upward trend. This is logical, given the long-term character of this type of investment. It is expected that, in view of the *sunk cost* component of the investment, the absolute contribution of scrubbing will not diminish in the coming years. This does not apply to fuel switching; emission reduction through fuel switching dropped by 0.5 million tons in 1996 (2.3 tons) compared to 1995 (2.8 tons).

Scrubbing
Scrubbing is responsible for 35% of emission reduction in the first 5 years of Phase I. From the early Nineties a total of 27 scrubbers have been installed, with a capacity of 16.167 MW (Swift, 2001). This is significantly lower than expected; the other reduction method, fuel switching, soon turned out to be the less expensive alternative. Many companies decided to install a scrubber at just one of their units, then use the rights that become available to fulfil emission targets at the remaining units. This policy was followed by 16 of the 51 participating companies in Phase I.

Switching
A total of 59% of emission reduction in Phase I was achieved through fuel switching. 34 of the 51 participants have based their strategy on this method. Here too, companies reduce emission at a limited amount of units and then use the released emission rights to fulfil targets of the remaining units.

3.3.2 Trading

At the start of the trading program external emission rights trade was still in its infancy. Few participants were willing to opt for purchasing rights in an evolving, uncertain market. Uncertainty about availability of rights in itself was already a reason to opt for a safer alternative: autonomous reduction. Almost every participant to Phase I made this choice. As Ellerman (2000:193) puts it: ‘an executive needed little imagination to realize that the consequences of not having enough allowances to cover emission in phase I were more serious than the consequences of having spent a little more (and reduced emissions more) from not having relied on the allowance market’. Clearly, the phrase shows that the loss of flexibility through internal investments was not accounted for.

Inter-utility trading – external trade of emission rights in order to cover targets – makes up for less than 3% of total required emission rights in phase I (1995-1999): 708,372 of the total 26.5 million rights.

Only three participating companies in Phase I exceeded their emission target: Illinois Power (emission surplus 503,208 tons), Tampa Electric (60,138) and Duquesne Power (14.237 tons). Twelve companies used inter-utility trading to be able to exceed their target, but just during one or two years of the 5-year period of Phase I. Illinois Power is the only company whose strategy is purely based on the purchase of rights. Tampa Electric and Duquesne Power both combine purchase of rights with fuel switching (Swift, 2001).

The low level of external trade does not imply that units do not make use of trade opportunities. On the contrary, there is a brisk trade among units, but mainly through intra-utility trading. Participants with a number of units internally re-allocate their emission rights, so that each individual unit covers its target. This results in a concentration of reduction at certain particular units. For instance, if a scrubber is acquired at a large unit, enough reduction will be realized to cover the targets of other units. Nearly 60% of companies work with intra-utility trading in Phase I (Swift, 2001). During the period 1995-1997 this internal re-allocation of rights covered around 75% of the demand for rights by over emitting units (Ellerman et al., 2000:16).

As shown in Table 3.2, external trade activities increase as Phase I progresses (Ellerman et al, 2000). This table is about transactions between non-related parties, which do not necessarily participate to Phase I; also Phase II-participants and third parties are allowed to trade emission rights.

Period	*Number of traded rights in external market*
Tot en met maart 1993	130,000
April 1993-March 1994	226,384
April 1994-March 1995	1,466,996
April 1995-March 1996	4,917,560
April 1996-March 1997	5,105,924
April 1997-March 1998	8,452,358
Total	**20,299,222**

Table 3.2: Traded rights in phase I

3.3.3 Banking

An overview of banking activities of participants in the first few years of the program is given in Figure 3.3. The emission bank gradually expands in the course of Phase I. At the end of 1999 a total of 11.6 million rights are collected through banking. Over the first two years of Phase II an amount of 2.3 million rights are withdrawn from the bank. This is in accordance with the theoretical concept of banking, as discussed in 2.2.2: in Phase I, when targets are still relatively flexible, the emission bank expands. Then, at the beginning of

Phase II emission rights are withdrawn from the bank. This procedure ensures a gradual reduction of emission until the - now more stringent - target is covered.

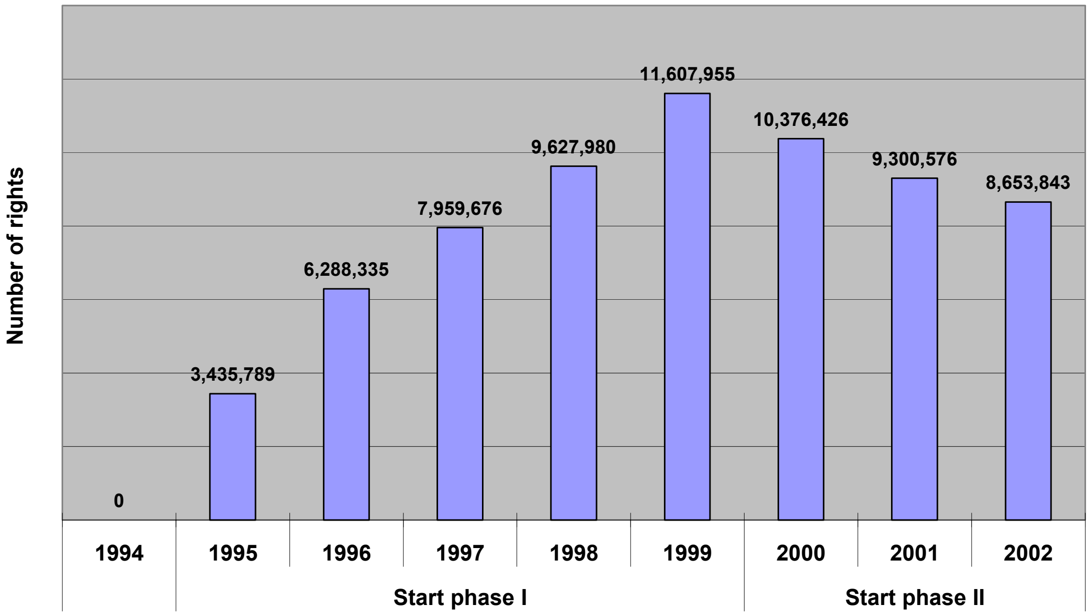

Figure 3.3: Emission bank size at end of the year

Practical experience proves that when defining compliance strategies, the option of banking is used in addition to autonomous reduction. Schennach (1998) recognizes this as well. Phaneuf and Requate (2002) on the other hand, consider banking and investing in reduction capacity as substitutes and therefore say that banking causes investments to drop. This is partly true: banking does make it possible to postpone investments that may be necessary in the coming periods. Yet, Phaneuf and Requate do not recognize that banking and investments carried out in previous periods[26] can go together. Even more, banking can be an extra reason to invest in reduction capacity in time, because it provides more flexibility concerning allocation of surplus rights that are released after reduction. Burtraw and Mansur (1999) conclude that the banking option indeed has played a part in reduction capacity over investing.

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[26] Phaneuf and Requate (2002) make their point based on the assumption that banking and investing take place in one and the same period. Yet, when an emission constraint lies below current emission level, the rights in bank in period t correspond with surplus rights – investments as such – in period t-1 or earlier. Phaneuf and Requate do not pay enough attention to this dynamic component.

3.4 Conclusion

When analysing market results of the first few years of the Acid Rain Program, two observations can be made: (i) Phase I of the program shows substantial over compliance, accompanied by banking of surplus rights; and (ii) the price of emission rights is considerably lower than expected, while marginal reduction costs and the (lower) emission rights prices vary. This is caused by over investments in reduction capacity, which in turn is caused by an over estimation of both emission rights prices and prices of low-sulphur coal. Participants' compliance strategies are predominantly based on internal solutions, linking autonomous reduction investments to banking.

To which extent do the observations mentioned above differ from the theoretical insights as researched in Chapter 2?

Practical experiences with the trade system indicate that the choice between autonomous reduction and external trade is indeed made on the basis of expected emission prices. As observed investment behaviour shows, investments are done when prices are expected to be high; intended investments are reversed when prices turn out to be lower. In addition to this, banking is an integral part of any investment decision. The observed banking pattern is in accordance with the model of Schennach (1998). Moreover, banking has contributed to reduction investments. The banking opportunity adds to the net present value of an investment, so that more often they turn out to be cost effective.

Over-investment in reduction capacity could indicate that participants do not pay enough attention to the value of flexibility when deciding upon strategies. Particularly, the value of the *deferral option* – the option to postpone an investment – is being overlooked. Given the fact that a deferral option lowers the net present value of a project, overlooking this option means the net present value is being overestimated. Result is that over-investment in reduction capacity occurs.

Naturally, the valuation of the deferral option will only affect an investment policy if it represents sufficient value. Chao and Wilson (1993) have calculated the value of the deferral option at $85 per emission right. It shows that this option can play a significant role in the decision-making process regarding investment policies.

Furthermore, the deferral option is only useful with investment projects that have a relatively low net present value: projects that are just *'at-the-money'*. Then the added value of deferral compared to direct investment is highest[27]. Assuming that projects are more often just *'at-the-money'* than well *'in-the-money'* the deferral option is an important factor in a large number of projects.

Insley (2002) concludes that investment behaviour of electricity producers under the Acid Rain Program possibly does comply with proposed policies using 'real option' techniques.

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[27] The added value of deferral must be separated from its actual value. The added value equals the value of the option minus standard net present value of the project. When a project is well *'in-the-money'* the added value of deferral is small (as opposed to the value of the deferral option!). After all, the risks at these projects are small, even when volatility of emission rights prices is high. Projects that are just *'at-the-money'* carry higher risks and the influence of the deferral option increases. See a graphic illustration of the added value of deferral in Figure 5.9

He demonstrates that differing policies in case of investment in a scrubber, in an otherwise identical market, could be caused by differing expectations concerning volatility of emission prices. Also the willingness to take risks plays a part. Ben-David et al. (2000) have tested this willingness in an experimental setting. His statement is that market parties avoid risks in an uncertain market environment (caused by volatility of market price). Yet the experiment shows that participants are in fact prepared to take risks, by postponing investments and opting for a *'wait-and-see'* –strategy.

Nevertheless, it is clear that companies under the SO_2 regime, particularly at the starting phase, have made decisions that were not optimal from a financial point of view. In the early Nineties many companies followed the self-sufficiency policy, not necessarily for financial reasons, yet because of unfamiliarity with the new system (Burtraw, 2000:22). Later companies have gone through a learning process and bit-by-bit started to make more solid financial decisions. By looking at past experiences with the SO_2 system, participants of the proposed CO_2 system can learn to go through this process quicker and sooner. An important lesson in this case is that the deferral option deserves special attention.

Concerning the net present value calculation, experiences with the SO_2 system indicate that most often calculation III in section 2.2.2 is used; the choice between autonomous reduction and external trade plus banking opportunities make up the final investment policy. However, the use of calculation IV from section 2.2.3 – including the value of flexibility through real options – gives a better understanding of the true net present value of projects. In case of the Acid Rain Program, this could have resulted in more solid investment decisions and, to a certain extent, over investing could have been avoided.

4 The European CO_2 trading system

Within the European Union the first multi-national trade system for greenhouse gas emission is currently in the making. On 9 December 2002, the 15 EU countries' ministers accepted a proposal, later followed by the approval of the European Parliament. The system will become operational in 2005, starting with an initial phase that lasts till the end of 2007.

4.1 Characteristics of the trading system

Gagelmann & Hansjürgens (2002) have distinguished five aspects, which together determine the functioning of an emission trade system: (i) the range of the system, (ii) determination of the total emission level, (iii) primary allocation method of emission rights, (iv) market forces and (v) monitoring. We used these five aspects to discuss the characteristics of the trade system within the EU.

4.1.1 Range of the system

The European Union has opted for a 'downstream' approach, similar to the SO_2 system. This means that not the fuels will be liable under the system, but the end users of these fuels that emit CO_2. The system involves the following activities (European Commission, 2001):

- ✓ Power generating
- ✓ Oil refining
- ✓ Coke ovens
- ✓ Metal industry
- ✓ Production of cement and lime
- ✓ Production of building materials and ceramics
- ✓ Glass fibre production
- ✓ Production of paper, cardboard and pulp

Initially the system will only apply to CO_2 emission; at a later stage, possibly from 2008, the remaining greenhouse gasses mentioned in the Kyoto Protocol will be involved as well. The EU expects that around 46% of the CO_2 emissions in the EU will be produced by the 4,000 to 5,000 installations that fall under the emission trading regime. Since CO2 emissions represent the bulk of all greenhouse gas emissions, this corresponds to around 38% of the total estimated emission of the six Kyoto greenhouse gasses in 2010.

4.1.2 Stipulation of total emission level

The EU proposal uses a cap-and-trade system with absolute emission allowances. These allowances are not yet established. In the first phase, this will not be done by the European Commission, but by participating countries themselves. The countries must submit a national allocation plan to the European Commission, who will then either accept or reject the plan. The plan must meet the criteria mentioned in appendix III of the proposal. With regard to stipulation of the absolute emission allowance the following criteria apply:

- The total number of emission rights to be allocated must be consistent with the commitment of the member state as described in the Kyoto Protocol; sectors and companies must proportionally cover the Kyoto target (the rest of the target must be covered by emission sources that do not participate to the trade system).
- The total number of emission rights to be allocated should be in line with actual and expected emission trends.

4.1.3 Primary allocation method

Based on political considerations – some parties strongly oppose an auction – the proposal recommends a free allocation system for the first period (2005-2007). In the second period (2008-2012) member states are given the opportunity to auction rights, up to 10% of their allocated total.

The free allocation program can be implemented in various ways. Participants can choose the method they prefer and must write this down in their allocation plan. Individual EU member states must take a number of considerations into account in the design of their national allocation plan (as mentioned in appendix III of the proposal). First, attention must be paid to previous reduction efforts (‘early action’) and technical reduction possibilities of specific sectors and/or companies. Another criterion says that a unit cannot obtain more rights than necessary to cover its emission. This could dispute the aforementioned ‘early action’ principle, which says that companies that have already lowered their emission should not be ‘punished’ for this by receiving less rights than their more pollutant counterparts. Furthermore, the fact that units cannot obtain more rights than necessary could frustrate emission rights trade due to a fundamental shortage of supply. After all, in a well functioning market the supply of rights is created by: (i) certain entities receiving more rights than needed to cover their emission and (ii) entities building up an emission rights surplus if they successfully apply cost efficient autonomous reduction. Mentioned criterion would make the supply of rights via point (i) disappear, implying that the supply of rights at the start of a trade period would be practically zero. Thirdly, there is a statement that points out that a national allocation plan ‘*must be consistent with other legislative and policy instruments within the European Union. Rights cannot be allocated to cover emission that is being reduced or terminated through communal legislation concerning renewable energy from electricity production’* (European Commission, 2001:36). Although (obligatory and/or subsidized) investments in renewable energy can be perceived as ‘early action’, electricity producers do not receive emission rights for this kind of effort. Generating electricity from renewable sources already gives benefits such as governmental allowances and granted green certificates. The European Commission does not want to create another benefit in the shape of allocation of rights for avoided emission. Finally, the last statement says that allocation plans should not encourage unfair competition.

4.1.4 Market forces

The requirements for a liquid market mentioned in section 3.1.4 are incorporated in the European Commission's proposal. The participation of 4,000 to 5,000 installations from various sectors seems to guarantee the presence of a sufficient number of market parties. The question is whether this sufficient supply and demand is secured on a continuous basis: it often happens that one company owns several installations. Re-allocation of rights will first take place via internal trade[28], so the European Commission expects that internal trade will dominate the first period (2005-2007). What limits initial liquidity furthermore, is that only a certain number of allocated rights will be traded, namely those rights that the selling party does not need to use in order to cover its own emission target[29]. Nevertheless, satisfactory supply and demand – and therefore liquidity – are expected to be present in the future trade system, even though it may take a few years. Experiences with the SO_2 system and the RECLAIM program in Southern California indicate this. Even with a much smaller number of participants, a liquid market did arise in both cases.

With regard to market restrictions, banking will be allowed in the first (2005-2007) and following five-year periods (2008-2012, etc). Only during the transition from first to second phase (2007-2008) individual member states can impose restraints. Moreover, it is essential to create a system of plain and transparent rules, which promotes free trade of emission rights with as few obstacles as possible. In particular, it is important to look at the EU emission trade in relation to current relevant communal and national legislation. Although section 25 of the proposed directive contains a statement that encourages free trade, no absolute clarity is given about this. For instance, it is uncertain whether an existing measure regarding energy efficiency will still be valid. If so, installations are faced with permanent efficiency requirements, which will restrict emission trade possibilities.

4.1.5 Monitoring

In the proposed EU trade, an independent authority is going to monitor the system. Each member state may decide whether this will be a public or private institution. Participating companies must report their yearly emission to this authority, after which verification follows. If a report turns out to be unsatisfactory, the participant can be temporarily excluded until the report has been revised. Apart from the monitoring of individual participants, a balanced administration of purchase and sale of rights is necessary – the EU system suggests a central register in which all trade activities and present emission rights are recorded per member.

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[28] The benefit of internal trade compared to external trade is the fact that transaction costs are lower. Also the issue of *inter-company pricing* comes up. By manipulating the internal transaction price of emission rights, companies with branches in different countries could assign their profits in the country with the lowest tax rates. To prevent this, the CO_2-trade system needs to make use of legislation that already exists about internal prices being tested by economic value. This means that internal transaction prices must follow external market prices.

[29] Speculative trade is likely to come up during the course of the system. This type of trade adds to liquidity of the market.

Sanctioning takes place if a member, at the end of a trade period, does not possess enough rights to cover emission. During the first period (2005-2007) the fee is €40 per ton CO_2 equivalent; from 2008 onwards the fee will be €100 per ton CO_2 equivalent. Apart from this, an emission rights shortage will also have its effect in the following period; the amount will be deducted from the number of rights to be allocated in that period. Therefore, even if emission rights trade at very high prices, it is wise to avoid the penalties.

4.2 Implications for the CO_2 system

We compare the forthcoming CO_2 system to the SO_2 system in the US (as discussed in the previous chapter) to infer lessons about how the CO_2 market will function. Although the systems differ on some points, as shown when comparing respectively section 3.1 and 4.2, they are comparable with regard to investments decisions on business level.

There are two crucial similarities between the two systems: the banking possibility and the use of an absolute emission allowance. Other characteristics of the trade systems (range, collective emission level, primary allocation method, monitoring) indeed affect an investment decision, yet in the model used in Chapter 5 these factors are connected with expectations regarding level and volatility of emission prices through the years. As such, these characteristics are in fact input variables of the investment model.

Within the context of the theoretical framework discussed in Chapter 2 and the example case in Chapter 5, a translation from SO_2 system to CO_2 system is very well possible. Most important lesson to be learned from findings mentioned in Chapter 3.4 is that the 'investment restricting' nature of the deferral option must be acknowledged and valued. This way the *sunk costs* that participants to the SO_2 system had to deal with, can be avoided. Put differently: flexibility concerning compliance decisions must be valued, as will be demonstrated in the next chapter through an example case. The example will show that the deferral option may indeed have a considerable effect on the net present value calculation of an investment project.

5 Example investment case

To illustrate the framework of investment decisions demonstrated earlier, and especially the influence of banking and real options, an example case will be worked out below. In this example we calculate the net present value of a relatively simple investment project. Although imaginary values are applied, the results do provide clear insights into the effect of banking and real options, as well as the extent to which various other variables influence the net present value of an investment project.

5.1 Case description

The case describes the situation of a European power generator, which is liable under the emission trading system from 2005 onwards. From the start of 2004 it faces an investment opportunity that will reduce its emissions with 48,000 ton annually. The investment costs are equal to €6 million in 2004, but the investment may be postponed till 2009 the latest[30]. If the project is deferred, the initial investment amount will increase with the risk free interest rate equal to 4% per annum. The economic life span of the project is 20 years, which means that the emissions reductions are achieved in all the 20 years following the investment. After the decision to invest has been taken, it will take a year to implement it. So, if the investment decision is taken in 2004 the first emission reductions will be realized in 2005.

The abatement costs to realize the emissions reductions are determined by the project variables. On the other hand, the revenues are mainly based on the expected price development of emissions allowances in the coming years. These revenues can be direct revenues from the sales of the emission rights if the power producer already meets its emission target. Alternatively, the revenues can be avoided costs from buying emission rights in the market to meet its target. Finally, the revenues can be a combination of both actual sales revenues and avoided costs.

For this case we set the expected price for the right to emit one ton of CO_2 in 2005 on €12.50. In 2008, at the start of the first Kyoto Compliance Period we expect a price of €16.00 per ton CO_2. In 2013, at the start of the second Kyoto Compliance Period the expected price is €13.00 per ton CO_2. For the other years the price equals the price of the previous year, increased with the risk free interest rate of 4% (using continuous discounting). So the expected price in 2006 will be: €12.50 $\cdot$ $e^{0,04}$ = €13.01. See Figure 5.1.

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[30] One could assume that the investment opportunity remains after 2009 as well. However, at that time better alternatives (cheaper / more effective) will normally be available, making the current investment opportunity no longer a viable option.

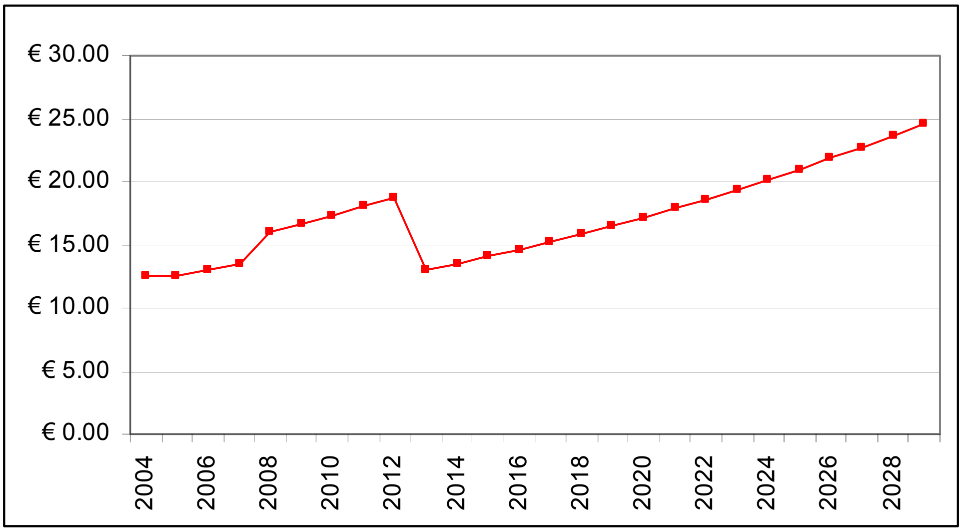

Figure 5.1: Expected price of emission rights

Note that the price increase from €13.54 to €16.00 is at odds with an efficiently working market as outlined in section 2.2.2. Unless we assume very high risk premia, extreme jumps in forward prices are not sustainable, because companies will respond to this expected price increase by banking before 2008, which in turn will make prices converge. This forward arbitrage drives the convergence process, and results in no or limited benefit of banking to individual companies. However, we maintain this jump in the case to illustrate the impact of banking.

For purely financial reasons, banking will have little benefits. However, there may be reasons for individual companies to bank. First, banking will mostly be applied to avoid trading costs. Second, companies that have a preference to comply to emission targets in-house, for example to support an environmentally friendly image, may apply banking. The latter effect should not be underestimated if we consider the results of the US Acid Rain Program, in which only a few companies heavily relied on (external) emissions trading.

Through the emission reduction a cost saving or sales revenue is realized each year. Its net present value is calculated by taking into account the WACC, de *weighted average cost of capital*. In this case we use a WACC of 10%, which includes a premium above the risk free rate, because the investment cost is risky and the company's financing costs are above the risk-free rate.

Finally, we need to come up with a realistic estimate of the volatility of the emission price to quantify the real option value. In this case we use a volatility of 15% unless stated otherwise. The level of 15% might be somewhat on the low side compared to the 24% volatility in the market for SO_2 allowances[31]. On the other hand, in a comparable investment case, Dixit and Pindyck (1994) apply a somewhat lower volatility of 12% and we do not want to overestimate the value of the deferral option.

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[31] Calculation of the 24% volatility is based on the monthly price data in the period August 1994 till December 2002, published by Cantor Fitzgerald.

5.2 Calculation

The net present value (NPV) calculations were all carried out in a spreadsheet program. The calculation of the NPV without deferral option is rather straightforward, so we limit the amount of explanation for this situation. Calculations that incorporate the deferral option are much more complicated, although they could still be carried out in a spreadsheet program. The relative complexity arises from the many steps that we need to go through, and the different actions that the investor may take in response to different price scenarios. This will be explained below.

5.2.1 Situation without deferral option

If the deferral option is neglected, we can rely on the formulas I and III of Chapter 2 in the situations excluding and including banking respectively. In the case of not using the banking opportunity the calculation of the NPV reads as follows:

$$NPV = \sum_{t} \frac{Q_t \cdot P_t^*}{e^{r \cdot t}} - I$$

$$NPV = \left(\sum_{i=1}^{20} \frac{48{,}000 \cdot P_t^*}{e^{0{,}10 \cdot i}} \right) - 6{,}000{,}000$$

$$NPV = 48{,}000 \cdot \left(\frac{12.50}{e^{0{,}10 \cdot 1}} + \frac{\cdot 13.01}{e^{0{,}10 \cdot 2}} + \frac{\cdot 13.54}{e^{0{,}10 \cdot 3}} + \frac{\cdot 16.00}{e^{0{,}10 \cdot 4}} + \ldots + \frac{\cdot 24.65}{e^{0{,}10 \cdot 25}} \right) - 6{,}000{,}000$$

$$NPV = 62{,}014$$

In this case the NVP of the project is simply the difference between the revenues from the emission reduction during the life span of the project minus the investment costs, while taking into account the financing costs (WACC).

Next, we incorporate the possibility to bank. Then we need to determine first of all in what periods it would be optimal to bank our emission rights and when to sell them in the future. It is optimal to bank when the expected increase in the emissions price exceeds our financing costs (WACC = 10%). This is clearly the case when we bank in 2007 and sell in 2008 (expected increase is 17%), but also when we bank in 2006 and sell in 2008 (expected increase in emissions price is 10.34% per year). We incorporate the mutation in the emission bank in the calculation of the NPV as follows (formula III in Chapter 2).

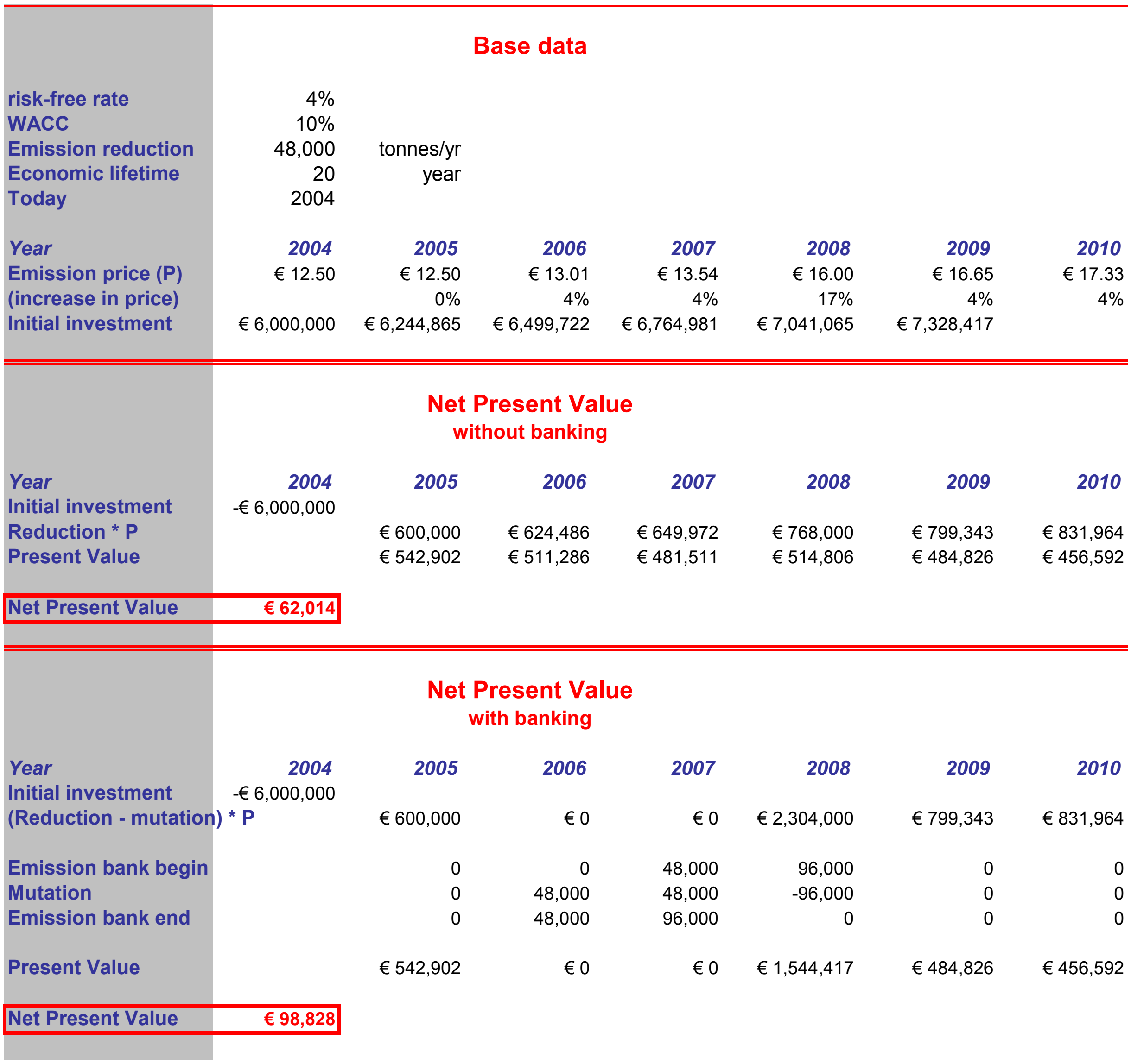
$$NPV = \sum_t \frac{(Q_t - \Delta S_t)\cdot P_t^*}{e^{r\cdot t}} - I$$

$$NPV = \left(\sum_{i=1}^{20} \frac{(48{,}000 - \Delta S_t)\cdot P_t^*}{e^{0{,}10\cdot i}}\right) - 6{,}000{,}000$$

$$NPV = \left(\frac{48{,}000\cdot 12.50}{e^{0{,}10\cdot 1}} + \frac{144{,}000\cdot 16.00}{e^{0{,}10\cdot 4}} + \frac{48{,}000\cdot 16.65}{e^{0{,}10\cdot 5}} + \ldots + \frac{48{,}000\cdot 24.65}{e^{0{,}10\cdot 25}}\right) - 6{,}000{,}000$$

$$NPV = 98{,}828$$

Banking offers a company some flexibility to optimize the revenues of emission reductions, by selling allowances (or avoid having to buy allowances) in years with a relatively high price. Due to arbitrageurs in the market, the value of the banking is however limited. In this case, banking increases the value of the project by less than €37,000. A snapshot of the Excel calculations, up to 2010, is given in the Figure below.



Base data

risk-free rate	4%	
WACC	10%	
Emission reduction	48,000	tonnes/yr
Economic lifetime	20	year
Today	2004	

Year	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***
Emission price (P)	€ 12.50	€ 12.50	€ 13.01	€ 13.54	€ 16.00	€ 16.65	€ 17.33
(increase in price)		0%	4%	4%	17%	4%	4%
Initial investment	€ 6,000,000	€ 6,244,865	€ 6,499,722	€ 6,764,981	€ 7,041,065	€ 7,328,417	

Net Present Value
without banking

Year	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***
Initial investment	-€ 6,000,000						
Reduction * P		€ 600,000	€ 624,486	€ 649,972	€ 768,000	€ 799,343	€ 831,964
Present Value		€ 542,902	€ 511,286	€ 481,511	€ 514,806	€ 484,826	€ 456,592
Net Present Value	**€ 62,014**						

Net Present Value
with banking

Year	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***
Initial investment	-€ 6,000,000						
(Reduction - mutation) * P		€ 600,000	€ 0	€ 0	€ 2,304,000	€ 799,343	€ 831,964
Emission bank begin		0	0	48,000	96,000	0	0
Mutation		0	48,000	48,000	-96,000	0	0
Emission bank end		0	48,000	96,000	0	0	0
Present Value		€ 542,902	€ 0	€ 0	€ 1,544,417	€ 484,826	€ 456,592
Net Present Value	**€ 98,828**						

Figure 5.2: Overview of calculations of net present value

5.2.2 Situation with deferral option

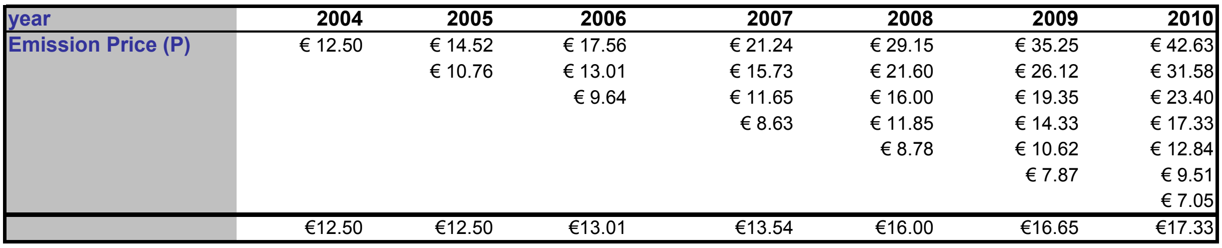
If we include the deferral option in our decisions process, we have to find a way to value this option. For the underlying case study the binomial option price model can be used. Such a binomial model analyzes how the development in time of a certain variable, in this case the emission allowances price, influences the NPV. On the basis of the NVP values in the different nodes of the decision tree we can derive an optimal decision path. This path determines the timing and circumstances under which the investment will take place. In most cases a risk neutral valuation is used in such calculations. In our case this is impossible due to the fact there are insufficient hedging opportunities caused by a still illiquid futures market in emission rights. Frequent delta hedging with futures is therefore impossible.

An example (for the situation without banking) of the first two periods of the decision tree will probably give some insight. The necessary basic data in Excel are listed in Figure 5.2. Below we will show you the different steps that will ultimately lead to the calculation of the NPV of the investment project.

i) The NPV of an investment is based on the price development of the emission allowances over time. First of all we have to establish the (expected) allowance price for the consecutive periods. The allowance price in respectively an '*up' state* (modeled price increase) and a *'down' state* (modeled price decline) of the binomial model can be established as follows (Hull, 2001):

$$\begin{cases} P_{u+1,t+1} = P_{u,t} \cdot e^{\mu_t + \sigma} \\ P_{u,t+1} = P_{u,t} \cdot e^{\mu_t - \sigma} \end{cases} \quad (0 \le u \le t)$$

$P_{u,t}$ is the price of an emission allowance in year t, when up to then an 'up'–tick has occurred *u* times. The average (in percentage) change of the allowance price at time t is equal to μ_t and the volatility is equal to σ. The Figure below shows how the price process can be modeled in Excel (up to 2010).



year	2004	2005	2006	2007	2008	2009	2010
Emission Price (P)	€ 12.50	€ 14.52	€ 17.56	€ 21.24	€ 29.15	€ 35.25	€ 42.63
		€ 10.76	€ 13.01	€ 15.73	€ 21.60	€ 26.12	€ 31.58
			€ 9.64	€ 11.65	€ 16.00	€ 19.35	€ 23.40
				€ 8.63	€ 11.85	€ 14.33	€ 17.33
					€ 8.78	€ 10.62	€ 12.84
						€ 7.87	€ 9.51
							€ 7.05
	€12.50	€12.50	€13.01	€13.54	€16.00	€16.65	€17.33

Figure 5.3: Binomial tree price process of emissions prices

The table should be interpreted as follows. For convenience we assume a price in 2004 equal to the expected price in 2005. In 2005, the price can either be €14.52 or €10.76. If the price is €14.52 in 2005, then it can either move up to €17.56 or move down to €13.01 in 2006; if the price is €10.76 in 2005, then it can either move up to €13.01 or move down to €9.64 in 2006. Continuing this, for example from a price of €26.12 in 2009, in 2010 the price is either €31.58 or €23.40. Of course, this binomial structure is a simplification of reality, but it is convenient to model the price uncertainty. It can be extended to a finer grid, assuming for example monthly price movements. Since the tree then grows much larger (12 possible prices in 2005, up to 72 possible prices in 2010) for demonstration purposes we keep the analysis a bit simpler here.

The last row of Figure 5.3 contains the expected price in the different years. This expected price is obtained as a weighted average of the possible prices in that year. These weights are not completely equal, but are derived in two stages. First, we establish the probability of an up-tick (q) and the probability of a down-tick in price ($1-q$). It can be shown (Hull, 2001) that the probability q should equal 46.3%, using the following formula:

$$q = \frac{e^{\sigma} - 1}{\mathrm{e}^{2\sigma} - 1}$$

For example, with the up-price being €14.52 and the down-price being €10.76, this ensures that the weighted average price in 2005 equals €12.50.

Next, we take into account that different orders of up and down ticks lead to the same price in a certain year. For example, the (middle) price of €13.01 in 2006 is possible if prices were €14.52 in 2005, then dropped to €13.01, but also when prices were €10.76, then moved up to €13.01. So, there are often multiple price trajectories (in this case 2) that lead to the same price. Combining the probabilities of up- and down-ticks with the number of possible trajectories to arrive at a certain price, we obtain the probabilities of future prices, as shown in the Figure below.

year	2004	2005	2006	2007	2008	2009	2010
Probability of Price	100.0%	46.3%	21.4%	9.9%	4.6%	2.1%	1.0%
		53.7%	49.7%	34.5%	21.3%	12.3%	6.8%
			28.9%	40.1%	37.1%	28.6%	19.8%
				15.5%	28.7%	33.2%	30.7%
					8.3%	19.3%	26.8%
						4.5%	12.4%
							2.4%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 5.4: Probabilities of future prices in the binomial tree of Figure 5.3

Combining the info from Figures 5.3 and 5.4, we can see that there is a probability of 1.0% that the price goes as high as €42.63 in 2010.

ii) The yearly revenues of the investment equal the product of the emissions price and the annual emissions reduction. We calculate these revenues for each possible future price.

year	2004	2005	2006	2007	2008	2009	2010
Revenues per year		€ 697,101	€ 842,969	€ 1,019,359	€ 1,399,387	€ 1,692,208	€ 2,046,302
		€ 516,425	€ 624,486	€ 755,160	€ 1,036,692	€ 1,253,619	€ 1,515,938
			€ 462,631	€ 559,436	€ 768,000	€ 928,704	€ 1,123,035
				€ 414,441	€ 568,948	€ 688,001	€ 831,964
					€ 421,487	€ 509,683	€ 616,334
						€ 377,583	€ 456,592
							€ 338,252
	€0.00	€600,000.00	€624,486.46	€649,972.24	€768,000.00	€799,342.67	€831,964.47

Figure 5.6: Yearly revenues for the years 2005-2010 for the emission prices in Figure 5.3

iii) The revenues calculated in ii) are for the first year after the investment, i.e. the first year that the project is operational. For example, when we decide to invest in 2004, the first revenues will be realized in 2005. In general, when investing in year *t* the first revenues will be realized in year *t+1*, up to year *t+20*. We obtain the present value of total expected revenues by summing the – to year *t* discounted – revenues from year *t+1* to year *t+20*.

The expected revenues in a certain year depend on the emission price in that year. For example, if we had invested in 2006 and the emission price in 2007 were €21.24 then expected discounted revenues over the years 2007-2026 equalled €11,109,011, whereas at a price of €8.63 in 2007 they equalled only €4,516,587. This is logical, because the higher next year's price, not only the larger the first revenue, but also the higher we expect prices in the coming 20 years and thus the overall revenues. The discounted future revenues are shown in Figure 5.6.

year	2004	2005	2006	2007	2008	2009	2010
Present Value		€ 7,783,780	€ 9,303,002	€ 11,109,011	€ 13,252,980	€ 15,580,202	€ 18,267,729
		€ 5,766,366	€ 6,891,833	€ 8,229,757	€ 9,818,049	€ 11,542,097	€ 13,533,067
(expected cost saving			€ 5,105,596	€ 6,096,754	€ 7,273,390	€ 8,550,596	€ 10,025,542
from year t onwards				€ 4,516,587	€ 5,388,260	€ 6,334,437	€ 7,427,105
when invested in year t-1)					€ 3,991,721	€ 4,692,667	€ 5,502,134
						€ 3,476,413	€ 4,076,081
							€ 3,019,635

Figure 5.6: Expected future revenues of investment for emission prices in Figure 5.3

iv) The NPV of the investment in year *t* equals the future expected revenues minus the investment amount. For example, when we invest in 2004, future – to 2005 discounted – revenues are either €7,783,780 or €5,766,366 (see Figure 5.6) with respective probabilities of 46.3% and 53.7%. When we discount these numbers back to 2004 and deduct the investment of €6,000,000 in 2004, then we obtain a net present value of €62,014 (Figure 5.7). Please note that this is the same number as we obtained earlier, since it is the net present value if we invest directly in 2004, so ignoring any flexibility. The net present values for the other years are derived likewise (Figure 5.7).

year	2004	2005	2006	2007	2008	2009
Net Present Value when investing	€ 62,014	€ 1,000,321	€ 2,151,984	€ 3,556,450	€ 5,092,808	€ 6,898,505
		-€ 877,499	-€ 90,381	€ 881,323	€ 1,947,929	€ 3,211,146
			-€ 1,751,565	-€ 1,100,459	-€ 381,854	€ 479,484
(present value t+1 -/-				-€ 2,568,600	-€ 2,107,800	-€ 1,544,182
initial investment)					-€ 3,386,413	-€ 3,043,350
						-€ 4,153,961

Figure 5.7: Net present value when invested in 2004-2009, with prices in Figure 5.3

v) The next step is to compare the value of direct investment with the value of deferring the investment and determining an optimal action (invest, defer, or cancel project). We can calculate the NPV of the deferral option in previous years by means of so-called *backward valuation*. We need to work backwards rather than forwards, because the value of deferral depends on our actions in the future years. So, first we establish what we do in the future and then we know what is best to do today: we are working backwards in the tree structure of the binomial model. We derive the value of the deferral option assuming that from now on the optimal choices are made, i.e. to invest, defer or cancel. This means that we will always choose the option that maximizes the NPV.

Please note first that we assumed that 2009 is the last date that we may invest, so the value of deferral is €0 in 2009. Similar to an American style financial option, our option to invest expires in that year. The optimal choice in 2009 is to invest if the NPV of the investment project is positive (this will be determined by the price of emission allowances at that moment in time). In case of a negative NPV the project will definitely not become operational.

One year before expiration of our investment option, the first actual backward valuation will take place. We calculate the NPV of the deferral option in 2008 assuming that we take an optimal decision in 2009. The NPV of the deferral option in 2008 is equal to the discounted values of the optimal decisions (deferral or investment) in 2009 multiplied with the respective probabilities *q* and *1-q*. For example, if the emission price equals €21.60 in 2008, then directly investing yields a value of €1,947,929 (Figure 5.7). If we defer investment one more period, then the NPV is either €3,211,146 or €479,484 (Figure 5.7), depending on whether emission prices move to €26.12 or €19.35 (Figure 5.3). Weighting and discounting these continuation values yields a deferral value of €1,577,194. This is less than the value of direct investment of €1,947,929, so with a price of €21.60 it is optimal to invest directly in 2008, assuming we did not yet invest before.

vi) Next we repeat step v) for all prices and all previous years. This finally leads to the NPV of the deferral option in 2004. In the figures below you see the calculations of the deferral option, the NPV assuming optimal actions, and the optimal actions.

year	2004	2005	2006	2007	2008	2009
Net Present Value deferral option	€ 557,476	€ 1,106,386	€ 1,932,486	€ 3,078,851	€ 4,448,912	€ 0
		€ 194,119	€ 422,942	€ 912,899	€ 1,577,194	€ 0
			€ 35,158	€ 83,998	€ 200,688	€ 0
				€ 0	€ 0	€ 0
					€ 0	€ 0
						€ 0

year	0	1	2	3	4	5
Net Present Value with optimal choice	€ 557,476	€ 1,106,386	€ 2,151,984	€ 3,556,450	€ 5,092,808	€ 6,898,505
		€ 194,119	€ 422,942	€ 912,899	€ 1,947,929	€ 3,211,146
			€ 35,158	€ 83,998	€ 200,688	€ 479,484
				€ 0	€ 0	€ 0
					€ 0	€ 0
						€ 0

year	0	1	2	3	4	5
Invest?	WAIT	WAIT	EXERCISE	EXERCISE	EXERCISE	EXERCISE
		WAIT	WAIT	WAIT	EXERCISE	EXERCISE
			WAIT	WAIT	WAIT	EXERCISE
				CANCEL	CANCEL	CANCEL
					CANCEL	CANCEL
						CANCEL

Figure 5.8: Derivation of optimal actions and project values in 2004-2009, with prices in Figure 5.3

In this example the decision in 2004 should be to wait as the NPV of deferral (€557,476) is larger than the NPV of investing (€62,014). In general, in Figure 5.8 the black numbers indicate that it is optimal to invest. We see that the ‘hurdle price’ above which it is optimal to invest is in fact shifted upwards compared to the price at which the net present value of direct investment becomes positive. Put differently: we want to have more certainty before deciding to invest, because future prices might

If banking is also taken into account, the case becomes more complex. However, as we outlined earlier, the financial value of banking for individual companies will be limited, because arbitrageurs will quickly destroy any banking profits in a properly functioning market. Therefore, banking can safely be ignored in investment decisions.

The table below summarizes the value of the investment opportunity under the alternative assumptions of banking and deferral. The difference between €557,476 and €62,014 is the pure deferral option value of €495,462.

		Deferral option	
		No	*Yes*
Banking	*No*	**€ 62,014**	**€ 557,476** WAIT
	Yes	**€ 98,828**	

Table 5.1: Project values under the assumptions of banking and deferral

The example clearly shows the consequences in case the deferral option is not or not sufficiently recognized. The NPV including banking (but without taking the deferral option in consideration) is €98.828. So, on first sight the decision should be to invest in the project. However, deferral of the project has a higher NPV and therefore the optimal decision is to wait.

5.2.3 Sensitivity analysis

The example is based on a number of assumptions that not necessarily need to be correct. It is insightful to analyze how the project value and the optimal decisions change in response to changes in our assumptions.

We start to analyze at what emission prices in 2005 it becomes optimal to invest right now and call these price levels “hurdle rates”. These hurdle rates are derived under the logical assumption that expected percentage price changes in the years after 2005 remain constant (so there is a parallel shift in the price curve). In the case we assumed an expected emission price of €12.50 in 2005. This level was just enough to make the net present value (ignoring the option to defer) positive. More precisely, the hurdle rate at which the project just gets a positive NPV is €12.37 if we exclude banking and €12.30 if we include banking (see Table 5.2).

			Deferral option	
			No	*Yes*
Banking	*No*	Price	**€ 12.37**	**€ 15.29**
		NPV	**€ 0**	**€ 1,415,056**
	Yes	Price	**€ 12.30**	
		NPV	**€ 0**	

Table 5.2: Investment hurdles and corresponding NPV under the assumptions of banking and deferral

The project has a positive net present value at a price of €12,50, but it is optimal to postpone. We calculated that waiting is optimal up to an expected price of €15.29. At that point, the direct revenues from the investment outweigh the benefits of waiting for even better market circumstances. The net present value at this price equals €1,415,056 (Table 5.2).

The relation between the two net present values (excluding and including the option to wait) is depicted in Figure 5.9 below. The red line depicts the classical call option value. When the expected emission price is above the hurdle rate of €15.29, the option is deep in-the-money, which means in this case that we should invest directly. On the other hand, when the emission price is rather low, we are not obliged to invest and rather wait for better prices. The value of the project never falls below zero, although at a price below €8 the project as a whole can safely be cancelled altogether: below an expected price of €8 in 2005, the probability is negligible that prices will rise sufficiently in the future to make the project economical. In other words, below €8 the project is so far out-of-the-money, that it has no value.

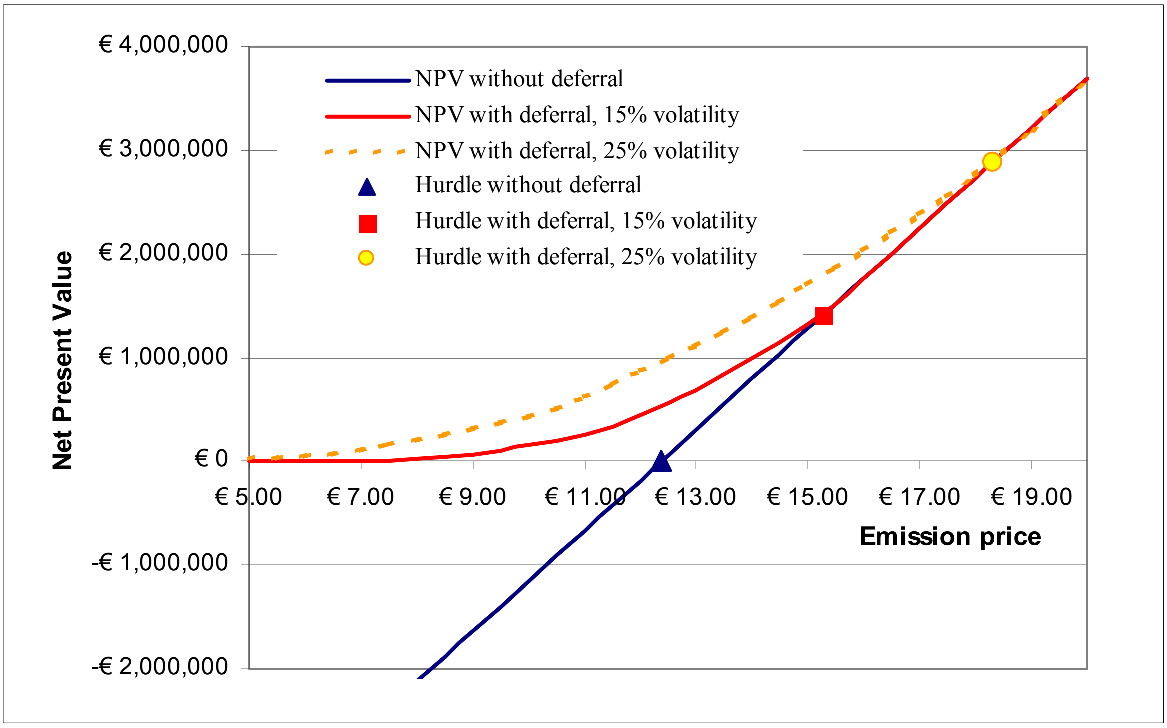


Figure 5.9: Project values and hurdle rates of investment case

Again similar to options in financial markets, the option to wait increases in value when there is more uncertainty about future prices. On the one hand, adverse price movements can then be avoided if we wait to invest. On the other hand, we can fully benefit from positive price movements if we invest later. Fore example, if the volatility in emission prices is higher than 15%, then the value of the project increases and we observe an outward shift of the value curve in Figure 5.9. The picture shows that a higher volatility not only increases the project value, but also makes it optimal to wait even longer before investment takes place. With a volatility rise from 15% to 25%, the value of the project nearly doubles from €557,476 to €992,082. At the same time, the hurdle rate above which investment is economical reaches a level of €18.31 (was €15.29).

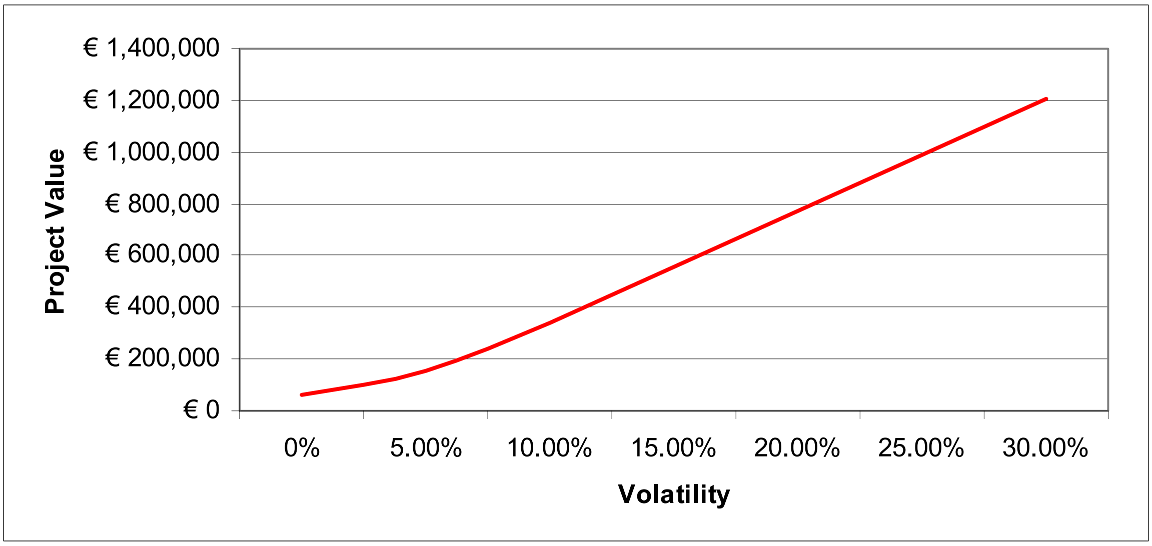


Figure 5.10: Project values for different levels of price volatility

We can extend the analysis to determine in general how the volatility influences the investment decision. In Figure 5.10 the project value for different volatility levels are shown. It appears that there is a close to linear relation between the two variables. We obtain a similar linear relation between volatility levels and investment hurdles. Unfortunately, this strong dependence of optimal decisions on our assumption of volatility complicates the decision-making. Volatility is a notoriously hard statistic to estimate, especially in a market that still needs to start. At the same time, it has a strong impact on what is optimal.

Finally, it is insightful to analyze how changes in the investment costs impact the project. The investment costs have their analogue in the exercise price of financial options. So, the lower the investment costs (i.e. the exercise price), the further the project is in-the-money, the more valuable the project and so the sooner should be decided to actually carry it out. Higher investment costs negatively impact the value of the project, both with and without taking the deferral option into account. However, the gap between the two widens as well, so the pure option value (defined as the value with deferral option minus the value without deferral option) is an upward sloping function of investment costs (Figure 5.11). In other words, the larger the initial investment, the more important it is that we can postpone direct investment.

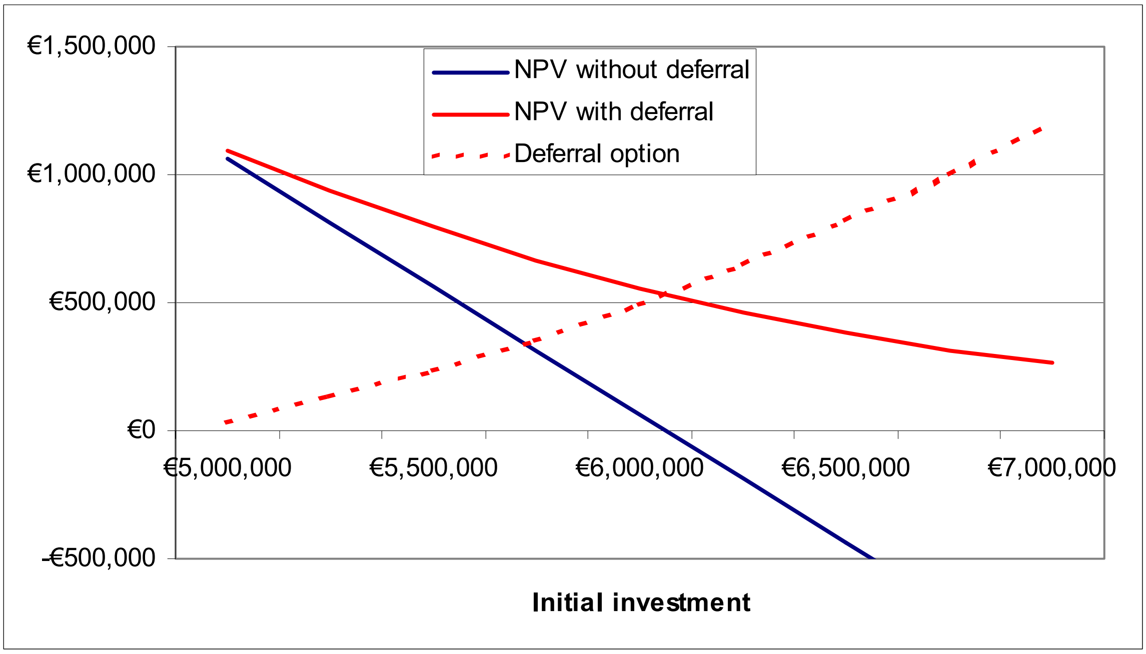


Figure 5.11: Project values and value of the deferral option for different investment costs

5.3 Technological progress

Up till now we have not explicitly taken technological progress into account. We simply assumed that from 2010 onwards, new techniques become available, making the current investment opportunity outdated. We assumed that this new technology would not have an impact on current decisions, which might not be realistic. In general, technological progress will be an extra reason to forego current investments and wait till later. Technological progress could lead to a lower initial investment, lower marginal costs or a larger emission reduction.

- If technological progress leads to a lower initial investment, then we need to assess whether we can predict this lower investment well or not. If we can, we simply let investment costs decrease over the years (instead of the inflation correction we made earlier). If we can't predict the lowering of investment costs well and if it has a significant impact on our decisions, then we should ideally treat future investment costs as a stochastic (uncertain) variable. Uncertain future investment cost decreases would add to the value of the option-to-wait, because by postponing the investment we learn about how technological progress evolves. This allows us to make more sound decisions in the future. Mathematically, the 'cost reduction uncertainty' could be included in the tree framework as an additional dimension. This leads to a so-called 'binomial forest' instead of a binomial tree, which need to be solved with more advanced computer software than Excel. Alternatively, a more flexible simulation approach could be chosen, such as described by Longstaff and Schwartz (2001). To get an idea of how such a model would work in the case of asset valuation, we refer to De Jong and Walet (2003), who describe the valuation of gas storage.
- In our case we assumed that variable costs are negligible. However, if variable costs are non-negligible, technological progress may lead to new techniques with lower

variable costs, which can be included directly in the calculations. For example, it might be that variable costs are €3 per ton when we decide to invest in 2004 or 2005, but €2 per ton when we invest in 2006 or later. On the other hand, if the decrease in variable costs is highly uncertain and has a non-negligible effect on the investment value, then the investment problem becomes more complex. Just as with uncertain decreasing investment costs, the option-to-wait will increase in value: postponing the investment gives us the time to learn how technological progress evolves. Similar techniques as described above ('trinomial forests', 'least-squares Monte Carlo') may then be used to improve decisions.

- Finally, new technologies can make larger emission reductions possible. In that case, the effect will be similar as when variable costs decrease.

5.4 Conclusion

The example case shows the influence of price uncertainty on the investment decision process. We learned that banking and the option to defer an investment have opposite influences on the decision to invest yes or no. Banking will more easily lead to making the investment, though the effect is very limited, since banking profits will quickly evade due to arbitrageurs in the market. On the other hand, the deferral option makes a project more valuable, but leads to a more hesitant attitude towards direct investments. The deferral option is especially valuable when a project is close to at-the-money, so when direct investment is on the edge of being economical or not.

The case also highlights the sensitivity of optimal decisions on model variables, especially the expected price level and the price volatility of emission rights. Widely varying expectations from market participants about future prices underline the difficult task of investment decision makers. In general however, this 'model uncertainty' is an extra reason for an attitude of wait-and-see.

6 Conclusions and recommendations

An emission trade regime forces participants to sharply observe their CO_2 management. The value of an investment in reduction capacity depends on the amount of emission reduction that is achieved. If emission of greenhouse gasses is realized internally, it is easier to comply with future emission restrictions. In this case less emission rights need to be purchased or more rights can be sold.

The valuation of an investment in emission reduction is a significant issue. The most obvious method to value emission reduction is the net present value (NPV) calculation. On the basis of reduction and the (forecasted) emission rights prices per year during the life span of an investment, the net present value can be determined. A complicating factor in this matter is that a trade system can offer a *banking* opportunity, i.e. saving up obtained rights for future use. Banking increases the possibilities for participants to cover their emission targets and therefore has a positive effect on the NPV of a reduction investment.

The standard NPV approach is a much-used and widely accepted method to value projects. It does however present a few shortcomings, which come down to the fact that not enough attention is paid to flexibility involving investment decisions. A correction to the NPV method, by means of the valuation of real options, solves this problem.

The obtained insights in this report show that when evaluating investment projects the standard NPV method should be extended with banking and real options. Yet, experiences with the SO_2 system in the US, operational since 1995, indicate that not sufficient consideration is given to the presence of real options. This has resulted in reduction capacity over investing, causing participants to experience high *sunk costs*. These costs could have been avoided if particularly the *deferral option* had been acknowledged.

A comparison of the proposed CO_2 system within the EU to the SO_2 system operating in the US is very well possible in this context. Both systems offer banking opportunities and apply an absolute emission maximum. Some aspects of the two systems vary, yet these aspects are reflected by expectations concerning (volatility of) emission rights prices; as such they serve as input variables within the theoretical framework. Consequently, the most significant implication for the forthcoming CO_2 system is that the value of flexibility is of great importance when deciding upon investment strategies. The example case in Chapter 5 demonstrates even more so that the impact of the deferral option is considerable.

The case shows that the standard NPV method fails, because the value of flexibility is not acknowledged. Flexibility is all the more important given the fact that various aspects of the forthcoming trade system have yet to be specified. Real options play an important role in the decision-making process when it concerns reduction investments. In general, directly investing in investment projects become less appealing when the option to wait is taken into account.

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