UNIVERZITA KARLOVA V PRAZE
FAKULTA SOCIÁLNÍCH VĚD

INSTITUT EKONOMICKÝCH STUDIÍ

DIPLOMOVÁ PRÁCE

2008 **Jana Chvalkovská**

Univerzita Karlova v Praze
Fakulta sociálních věd

Institut ekonomických studií

DIPLOMOVÁ PRÁCE

Impact Assessment case study: EU ETS and investment decision-making of power generators

Vypracovala: Bc. Jana Chvalkovská
Vedoucí: Ing. Zdeněk Hrubý, CSc.
Akademický rok: 2007/2008

Prohlášení

Prohlašuji, že jsem diplomovou práci vypracovala samostatně a použila pouze uvedené prameny a literature.

V Praze dne 18. července 2008 podpis studenta

Acknowledgements

I would like to thank to everybody, who was supporting me and assisting me with this thesis. Namely my thanks belong to my consultant, Zdeněk Hrubý, to Lit Maxwell from the University of Richmond, to my employer and my colleagues and to my mother for their support and patience.

ABSTRAKT

Tato práce se zabývá hodnocením dopadů regulatorní nejistoty spojené s Evropským systémem obchodovatelných emisních povolení (EU ETS) na investiční rozhodování elektrárenských společností. V současné době probíhá v rámci ČR i EU debata, jejímž předmětem je nutnost výstavby nových elektrárenských kapacit, které by byly schopny i v budoucnu uspokojit rostoucí poptávku po elektřině. Tyto investice jsou však ohrožovány nejasnostmi ohledně budoucího vývoje regulatorního rámce EU ETS, který podmiňuje ceny obchodovatelných emisních povolení. Tato práce s využitím modelu reálné opce analyzuje dopady různých variant budoucího vývoje cen povolenek na investice do výstavby nových elektráren a identifikuje regulatorní nejistotu jako jeden z hlavních důvodů, proč jsou investice do výstavby nových zdrojů ze strany investorů odkládány. Analýza je zasazena do širšího kontextu obecného výkladu o EU ETS a hodnocení dopadů prováděného Evropskou komisí.

ABSTRACT

This thesis is focused on the assessment of impacts of the regulatory uncertainty related to the EU Emission Trading System (EU ETS) on investment decision-making of power generators. The need for investments in new power generation capacities that would be capable to satisfy in the future the growing electricity demand is currently a discussed topic on the Czech as well as on the EU level. These investments are endangered by the uncertainty regarding the future development of the EU ETS regulatory framework, which is a major price driver of the tradable emission allowances. This thesis uses the real option model to analyze the impacts of potential future developments of the emission allowance prices on the investments into new power plants and identifies the regulatory uncertainty as one of the major causes, why investors postpone the investment into the construction of new sources. The analysis is embedded into a broader framework depicturing the EU ETS and the impact assessment procedure conducted by the European Commission.

List of Contents

List of Figures

List of Abbreviations

APWR	Advanced Pressurized Water Reactor
ARA	Amsterdam-Rotterdam-Anwerp
bil.	billion
CBA	Cost Benefit Analysis
CCGT	Combined Gas Cycle Turbine
CCS	Carbon capture and storage

CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CEO	Chief Executive Officer
CER	Certified Emission Reductions
CO2	Carbon dioxide
COM	Communication of the European Commission
DCF	Discounted Cashflows
DG	Directorate General
EC	European Commission
ECCP II.	European Climate Change Program
ECX	European Climate Exchange
EEX	European Energy Exchange
EFTA	European Free Trade Association
EIA	Environmental Impact Asssessment
ERU	Emission Reduction Unit
EU	European Union
EU ETS	Emission Trading System of the European Union
EUA	EU emission allowances
FV	Future Value
GGAS	Greenhouse gas abatement scheme
GHG	Greenhouse gases
GJ	Giga Joule
HFC	Hydro-fluoro carbons
IA	Impact Assessments
IGCC	Integrated gasification combined cycle power plant
IPPC	Integrated Pollution Prevention and Control
IRR	Internal Rate of Return
JI	Joint Implementation
M&O	Mantenance and operations
mil.	million

MW	Mega Watt
MWh	Mega Watt hour
NAP	National Allocation Plan
NPV	Net Present Value
OTC	Over-the-counter
PCB-C	Pressurized Coal Boiler - hard coal
PCB-L	Pressurized Coal Boiler - lignite
PDE	Partial Differential Equation
PV	Present Value
R&D	Research and Development
RIA	Regulatory Impact Assessment
SEC	Statement of the European Commission
SGCT	Steam Gas Cycle Turbine
SWOT	Strengths, Weaknesses, Opportunities, Threats
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

Motto:

"Europe needs to spend EUR 2 trillion on upgrading power networks in the next 25 years…every week a new investment is being cancelled…because of increased regulatory uncertainty." Johannes Teyssen, CEO, E.ON[1]

1 Outline of the thesis

The primary aim of this study is to evaluate some impacts of the uncertainty connected with the EU Emission Trading Scheme (EU ETS) on investment decision-making of a particular group of stakeholders of this regulation – on power generators. This primary aim is, however, embedded into a broader framework.

On the EU level (and since November 2007 in the level of Czech Republic as well) there has been a broad initiative requiring regulators to assess in advance the potential impacts of their regulatory proposals on all crucial groups of stakeholders. The result of this initiative is the mandatory elaboration of a so called Impact Assessment (on the level of national states called Regulatory Impact Assessments) with every major regulatory act. This thesis does not aspire on being a full Impact Assessment (IA) of the EU ETS regulation, but rather tries to highlight some specific elements related to impacts of this regulation.

Apart from the intended direct effects of any regulatory act, there are usually several indirect effects that can have a strong impact on the stakeholders of such regulation and that were not taken into account by the regulator. This thesis tries to pinpoint one of such effects – the increase of regulatory uncertainty caused by frequent changes of regulation. The secondary aim of this thesis thus will be to demonstrate impacts of regulatory uncertainty caused by rather unsettled approach of the European Commission towards structure of the EU ETS after 2012 and the role of IA in alleviation of the regulatory uncertainty.

---

[1] Quotation adopted from presentation of Westwood (2008)

The structure of the thesis could be described in a following way:

- Firstly, I describe the key information about the past and present of IA (RIA) and of its strengths and weaknesses. Important finding is here the synergy between applied economic research and IA (RIA) process. In this chapter there will be also the description of stakeholders of EU ETS with focus on the power utilities.
- Secondly, I provide some up to date insight into the EU ETS and description of regulatory framework of emission trading.
- Thirdly, I present an introduction into the real option model and describe the specific assumptions of the numerical application of this model. The model I use is a modified version of a numerical real option model from Shockley (2006). I will also provide some basic characteristics of power plants and their role in the carbon constrained world.
- The last part of the thesis is specifically dedicated to a brief presentation of more sophisticated real option models for power generation. I focus on modified versions of Dixit, Pindyck (1994) and Deng, Johnson, Sogomonian (1999).

The major contributions of this thesis shall be:

- application of the real option model on the current situation in the power sector in Europe – showing the relationship between EU ETS and postponed investments into new power plants
- deriving general conclusions related to the impacts of regulatory uncertainty, IA (RIA) and long-term planning
- different systematic description of the effects of IA on the regulatory process (including a short qualitative comparison of IA to one topic in time)
- overview of modified stochastic real option models and discussion of their further deployment in IA procedures
- extensive list of literature to each chapter

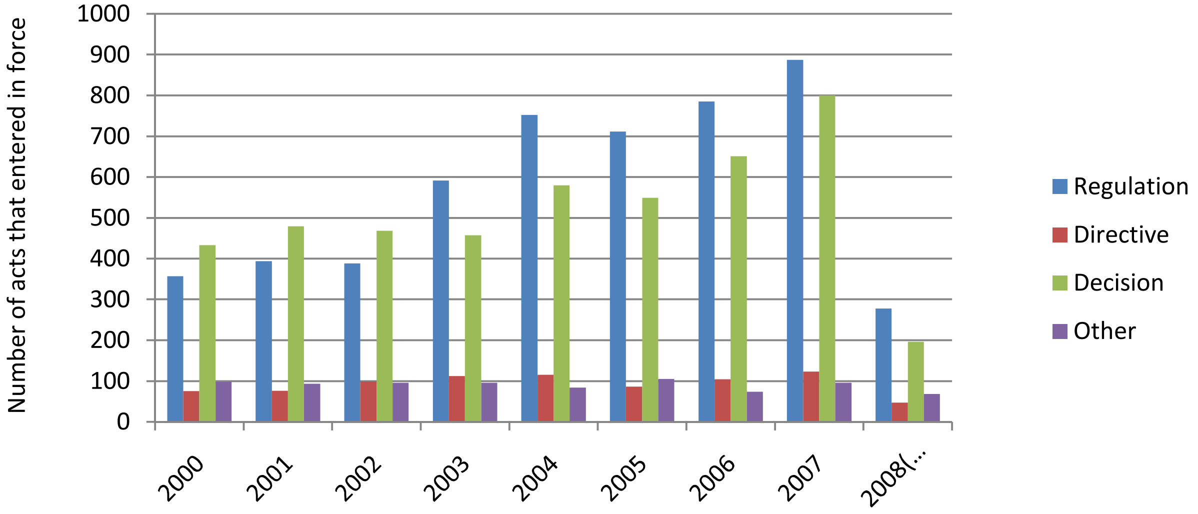
This thesis brings together three widely discussed topics – the relationship between EU ETS and the current situation on the electricity market, the pros and cons of the IA initiative and the application of real option models as a standard and in some aspects more accurate tool of investment evaluation. By this combination of topics supported by a broad range of literature I hope to provide some more complex economic overview of the relationship between regulation, stakeholders of the regulation and investment decision-making.

2 Impact Assessment (IA)

2.1 IA Framework

The amount of regulatory acts adopted each year by the European Union has been steadily increasing over the past decade (Figure 1). Due to this fact the EU legislation currently approaches its critical mass and the complicated and often fruitless EU bureaucracy became one of the major concerns of both politicians and citizens in the EU.

Figure 1: Number of regulatory acts adopted annually by the EU from 2000 to May 2008



Source: Mejstřík (2008)

In 2001 the European Commission (EC) started to revive[2] the so called Better Regulation Initiative that aims to increase the quality and effectiveness of the regulatory acts proposed by the EC. The key principles introduced by the Better Regulation Initiative can be summarized as follows:

- decrease of the administrative burden imposed by the EU regulation on citizens and entrepreneurs
- simplification of the EU legislation
- enhancement of the inter-institutional cooperation and coordination among the EU institutions

---

[2] Göteborg European Council in June 2001 and Laeken European Council in December 2001

- involvement of recipients of the EU regulation into the process of legislation
- introduction of a detailed assessment of economic, environmental and social impacts of the proposed legislation.

The last named principle is usually called Impact Assessment (IA)[3] of the European Commission, which is one of the main objects of interest of this thesis. The main idea behind the IA is to evaluate ex ante the potential results of any proposed legislation (on EU level also of selected non-legislative acts) with respect to the competitiveness, environment, economic and social situation of the EU, individual Member States, industrial sectors and other stakeholders of the regulation in question. The crucial mission of IA is to:

- review the causes and consequences of proposed regulatory acts
- prevent adoption of unnecessary or inefficient regulation
- work as a structured argumentation tool in political decision-making
- communicate in an user-friendly way the reasons for adoption of the new regulation to the non-institutional stakeholders of the regulation
- collect data for future monitoring of the efficiency and usefulness of the regulation
- provide alternative options to the proposed regulation (including the self-regulation and co-regulation variants)

Since its factual deployment into the EU legislative process in 2003 until mid-July 2008, there has been not more than 338 IA conducted by various Directorates General (DG) conducted 332 IA as could be seen in Figure 2. Among the most active DG belonged the Energy and Transport DG and Environment DG that co-regulate the EU ETS.

---

[3] The impact assessment procedure has been recently widely adopted by the national Member States as a tool for improvement of national legislation. On the national level IA is called Regulatory Impact Assessment (RIA). In Czech Republic, RIA was firstly introduced by governmental decree number 950/2000 upon recommendation of OECD, the real and functional implementation was, however, firstly realized by the governmental decrees 816/2007 and 877/2007 (that contains methods for proper elaboration of RIA).

Figure 2: IA conducted by DG EC between 2003 and mid-July 2008

DG	2003	2004	2005	2006	2007	2008*
Agriculture and Rural Development	2	1	2	3	3	1
Communication					1	
Competition			2			1
Development	0	3	4,5	4	2	1
Economic and Financial Affairs	1					
Employment, Social Affairs and Equal Opportunities	2	3	2	2	3	
Energy and Transport	3	1	12	9	21	7
Enlargement			2	2		
Enterprise and Industry	1	2	5	2	17	6
Environment	4	4	8	9	9	4
EuropeAid Co-operation Office		4	3	2	3	2
External Relations	1		2,5	1		
Health and Consumers	1		4	5	8	4
Information Society and Media	2	2	3	5	6	1
Internal Market and Services	1	5	4	6	5	4
Justice and Home Affairs	1	2				
Justice, Freedom nd Security		1	12	8	9	5
Maritime Affairs and Fisheries	2	2	1	1	5	1
Regional Policy		1	1	3		
Research			1		4	1
Taxation and Customs Union			4	3	3	
Trade			1	1	3	
Total	**21**	**31**	**73**	**65**	**99**	**38**

Source: http://ec.europa.eu/governance/impact

For completion of this brief description of the IA framework it is necessary to say that the concept of IA originated in the United States in mid-eighties of the last century, during the government of Margaret Thatcher made its way into the British legislative procedure and through United Kingdom also to other old Member States and to the EC. Nearly two decades afterwards, RIA was present in the legislative procedure of the majority of old Member States (A Comparative Analysis of Regulatory Impact Assessment in Ten EU Countries; 2004) and slowly penetrating to the legislation of new Member States and of potential accession countries[4] (Jacobs, Colin, 2005). Outside of the EU and US, RIA was adopted in Mexico, Malaysia and Canada.

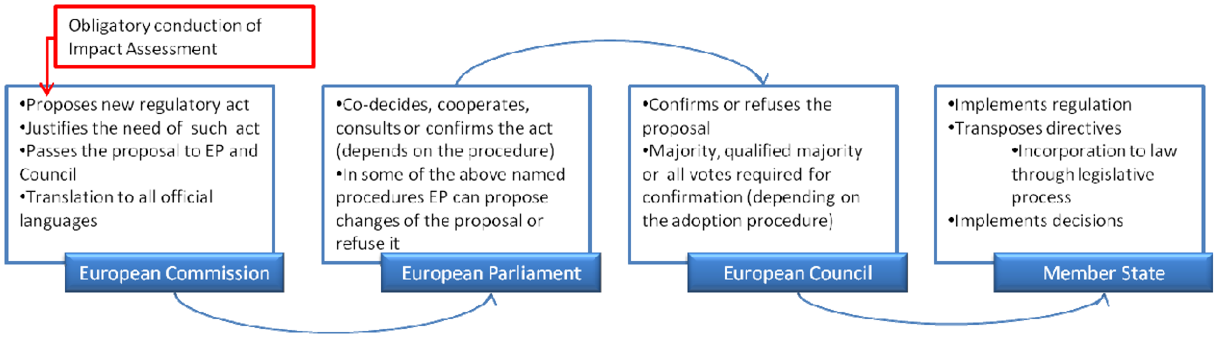
---

[4] Such as are Croatia, Bosnia Herzegovina etc.

2.2 Costs and benefits of IA

The process of adoption of European legislation is extremely costly and yet – as was discussed above – the amount of regulations coming from the EC steadily increases. This situation is obviously not sustainable in the long run. The administration has to become somewhat slimmer and more efficient in order to stimulate the competitiveness of EU on the global market[5]. The IA in the framework of the wider Better Regulation Initiative is deemed to be a tool for achievement of this target. Figure 3 describes the most important steps of the adoption of EU legislation from the EU-level till the transposition or application on the national level.

Figure 3: Simplified scheme of adoption of European legislation



Source: Author based on Tichý et al. (2006)

The legislative process in the EU begins at the EC that proposes a new regulation or a change of an existing regulatory act. The proposed act has to be approved later on through a specific procedure[6] by the European Parliament (in up to three readings) and submitted to the European Council for final confirmation or denial. Most of the documents in this process have to be issued in all the 23 official languages of the EU. Once the act is officially approved by the Council and announced, the individual Member States have to implement it in the prescribed form[7] on the national level.

---

[5] The reduction of bureaucracy and of administrative burden was one of the cornerstones of the renewed Lisbon Agenda designed for enhancement of EU competitiveness.

[6] Co-decision, cooperation, confirmation and consultation – more on the procedures in Svoboda (2004) and Tichý et al. (2006)

[7] Transposition of directives, direct implementation of decisions and regulations

This whole process is rather costly as it requires considerable amount of man-hours[8] on both EU and national level. The implementation of IA introduces to this process another costly and time-consuming procedure, yet despite this fact IA aspires to actually decrease the costs of legislation. The decrease of costs shall be achieved by prevention of adoption of redundant, unnecessary regulatory acts and by increasing the quality of the newly adopted acts. The simple idea behind the whole impact assessment system is that a carefully prepared and assessed regulation will be of better quality and would not require frequent amendments.

In an ideal world, the positive impacts of IA on the quality of newly adopted regulatory acts (including the elimination of redundant, unnecessary acts) would overweight the costs of elaboration of IA. Inherent assumption is though that the IA fulfill perfectly their role and that they are created exactly according to the rules and principles set for IA by the EC[9]. Report (The Evaluation Partnership Limited, 2007) conducted on behalf of the EC provided qualitative and quantitative evaluation of IA performed between years 2003 and 2006. Key points of critique contained in this Report were:

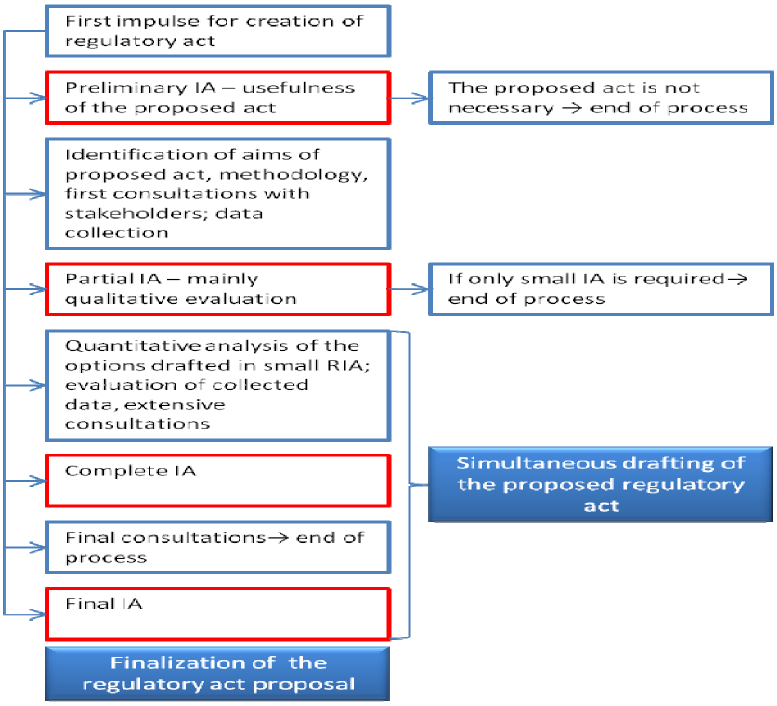
- the principles of IA are often misunderstand by officials conducting it – instead of endeavoring to find objectively a solution to an identified problem, they tend to use IA to defend their pre-selected solutions
- the timing of IA conduction often contradicts the binding principles of IA; IA are frequently elaborated after the finalization of the regulatory act and hence they result to be entirely pro forma and waste of money (see Figure 4)
- IA conducted by EC vastly differ in quality
- the approach towards IA is often not appropriate for the type of proposal it assesses.

---

[8] Man-hour – price of one hour of work of one official (including income tax, mandatory insurance, overhead costs etc.)

[9] EU methodology SEC(2005)791

Figure 4: Scheme of relationship between IA timing and drafting of regulatory acts



Source: Author – modification of Renda (2006)

As major benefits of IA were in the Report described:

- improvement of communication between regulators from EC and non-institutional stakeholders
- increased interest in data gathering – especially regarding the efficiency of the legislation
- some improvements in the EC officials' understanding of the purpose and use of IA

The conclusions about the costs and benefits of IA as listed in the Report do not, however, provide a full catalogue of all the pros and cons related to IA (RIA) in general. Regulation is part of the institutional framework that sets rules for functioning of both existing and future markets. Therefore it can significantly influence the behavior of market participants – both in a positive and negative way. Stable and coherent regulation of markets decreases the regulatory uncertainty of acting agents and enables them to fix their long-term plans and targets. Long-term plans are crucial part of a proper investment decision- making, which is on the other hand an essence of successful business.

If we accept this straightforward relation between regulation and business - stable, coherent, and transparent regulatory framework as a necessary condition for sound and growing business - the positive procedural impacts of IA (RIA) become quite noticeable.

Firstly, the implementation of IA (RIA) into the legislation is expensive and prolongs the legislative process. Most of these extra costs are imposed on the regulator who is then less likely to propose unnecessary or obsolete regulations. IA (RIA) shall hence work as a barrier that filters out some proposals of unnecessary regulation (avoid pointless changes of existing regulatory framework). This effect of IA (RIA) I denote as a Stabilization Effect.

Secondly, IA (RIA) attempts to disclose the motives underlying the proposed regulation and confront them with arguments of stakeholders of the regulation. This effort shall result in two positive effects – Transparency Effect and Timely Discussion Effect[10]. The obligation to enclose IA (RIA) to any legislative proposal makes the regulators to disclose at least partially their reasons underlying the proposal. This shall increase the transparency of the whole process and enable stakeholders of the regulation to properly adjust their expectations. The Effect of Timely Discussion relates to the essential component of IA (RIA) – consultations. Throughout the whole process of IA (RIA) formation, stakeholders not only receive information regarding the reasons behind the assessed regulation, but shall also trigger out an exchange of different points of view between the regulator and the recipients of the regulation. During this discussion, all involved parties might be able to smooth some hotspots in the proposal before the regulation is actually adopted. A fact-founded discussion during the legislative process shall lessen the resistance against proposed changes and thus also the need for frequent changes of the regulation in the future. The

---

[10] Again my personal notation.

consultations also help to wide-spread the fact that there might be a change in regulation – so that the stakeholders will not be surprised by an unexpected change of rules.

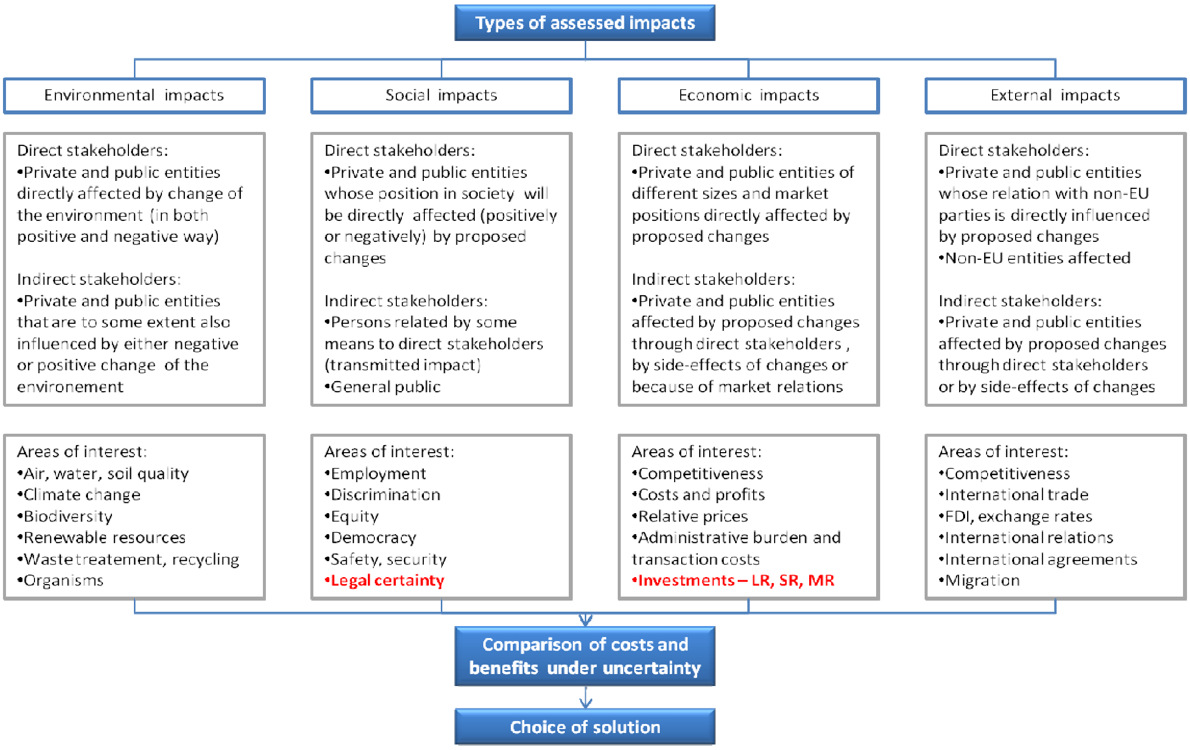
Thirdly, IA (RIA) introduces into the legislative process a piece of a long-desired data-based economic discussion. Both on the EU level and national level, the political discussion concerning new legislation often lacks any underlying analysis. IA (RIA) endeavors to fill this gap, by providing at least assessment of the most important expected impacts of the proposed regulation. Any attempt to gather a robust data-set describing the regulated area is valuable because it facilitates not only adoption of appropriate regulatory measures, but also a prudent monitoring of the effectiveness of any adopted regulation. The Data Effect is one of the most important benefits that shall result from the implementation of the IA (RIA) procedure.

A sole data-gathering is, however, not enough. In order to evaluate accurately the impacts of the proposed regulation the regulator needs to use various methods of modeling and estimation. The most common are:

- simple cost and benefit analysis (CBA)
- multi-criteria analysis
- micro-simulation
- general equilibrium models
- project-based valuation (such as is the internal rate of return, discounted cash flows etc.)
- SWOT analysis
- a variety of other macro-, micro- and econometric models

The application of one or all these methods depends on data availability, ability of the regulator to apply the selected method(s) and on type of the assessed impact. Given the assumption that the IA (RIA) will be conducted correctly and their results taken seriously[11], it adds to the above mentioned positive effects another element – a Synergic Effect between IA (RIA) and applied economic research. A scheme of the Synergic Effect is depictured in Figure 6, the whole set of IA effects that I have identified is in Figure 7.

Figure 5: Basic types of assessed impacts in IA (RIA) – red impacts were added by author



Types of assessed impacts

Environmental impacts	Social impacts	Economic impacts	External impacts
Direct stakeholders: •Private and public entities directly affected by change of the environment (in both positive and negative way) Indirect stakeholders: •Private and public entities that are to some extent also influenced by either negative or positive change of the environement	Direct stakeholders: •Private and public entities whose position in society will be directly affected (positively or negatively) by proposed changes Indirect stakeholders: •Persons related by some means to direct stakeholders (transmitted impact) •General public	Direct stakeholders: •Private and public entities of different sizes and market positions directly affected by proposed changes Indirect stakeholders: •Private and public entities affected by proposed changes through direct stakeholders , by side-effects of changes or because of market relations	Direct stakeholders: •Private and public entities whose relation with non-EU parties is directly influenced by proposed changes •Non-EU entities affected Indirect stakeholders: •Private and public entities affected by proposed changes through direct stakeholders or by side-effects of changes
Areas of interest: •Air, water, soil quality •Climate change •Biodiversity •Renewable resources •Waste treatement, recycling •Organisms	Areas of interest: •Employment •Discrimination •Equity •Democracy •Safety, security •Legal certainty	Areas of interest: •Competitiveness •Costs and profits •Relative prices •Administrative burden and transaction costs •Investments – LR, SR, MR	Areas of interest: •Competitiveness •International trade •FDI, exchange rates •International relations •International agreements •Migration

Comparison of costs and benefits under uncertainty

Choice of solution

Source: Author based on modification of SEC(2005)791

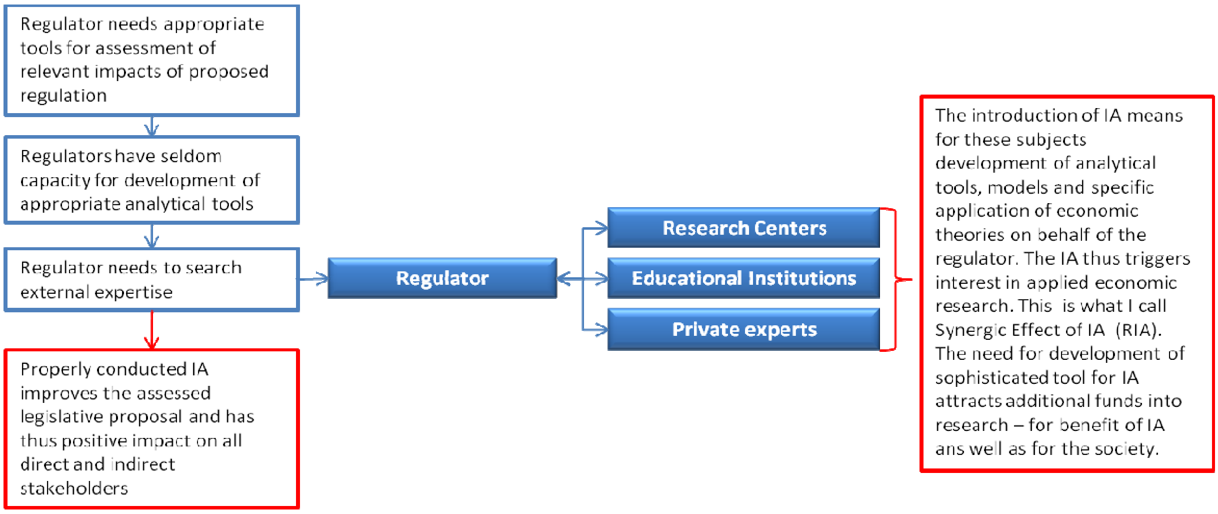
Based on The Evaluation Partnership (2007) Report, most IA assessed in the Report evaluated appropriately the direct economic impacts on identified stakeholders; less successful was the evaluation of environmental and social impacts. Better monetized were the costs of regulation – estimation of benefits related to proposed changed of regulation were usually described only in qualitative terms. This situation is caused by the fact that regulation is often implemented in order to protect some good or service that cannot be efficiently provided by regular markets (public good). The monetization of actions conducted in public interest (such as is e.g. purchase of public good, preservation of certain relations or structures that are important for the society etc.) is rather difficult because the estimated value of public interest is often

---

[11] Recent steps of the Impact Assessment Board (IAB) support this assumption – the Board returned several IA back to Directorate General because the provided assessment of impacts was considered insufficient.

determined by subjective perceptions and preferences. The IA methodology (SEC(2005)791) on pp. 34 to 38[12] suggests to each main category impacts several sub-topics that can be taken into evaluation. Even from the analysis provided in the Report can be seen some signs of tighter cooperation between the regulators and researchers[13], but the Report analyzed the selected IA from the point of view of qualitative and quantitative comparison across different fields of regulation.

Figure 6: Synergic Effect of IA implementation



Regulator needs appropriate tools for assessment of relevant impacts of proposed regulation

Regulators have seldom capacity for development of appropriate analytical tools

Regulator needs to search external expertise

Properly conducted IA improves the assessed legislative proposal and has thus positive impact on all direct and indirect stakeholders

The introduction of IA means for these subjects development of analytical tools, models and specific application of economic theories on behalf of the regulator. The IA thus triggers interest in applied economic research. This is what I call Synergic Effect of IA (RIA). The need for development of sophisticated tool for IA attracts additional funds into research – for benefit of IA ans well as for the society.

Source: Author

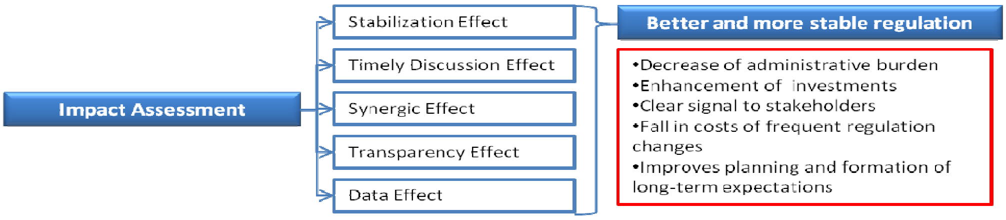
Such analysis, however, does not show the development in time of the analytical methods used. Therefore I would like to provide in the following short case study a brief insight into the development of analytical tools used in IA dedicated to one topic in time and demonstrate thus the Synergic Effect (Figure 6), which a consider to be one of the contributions of this study. The case study is focused on IA related to the EU ETS and thus also offers some introduction to the regulatory framework of this scheme.

---

[12] Czech translation

[13] This cooperation is an IA (RIA) feature that should be welcomed given the fact that before IA (RIA) the only document usually accompanying a regulatory proposal was an explanatory report ("důvodová zpráva") often written by lawyers for lawyers without any strong connection to recent developments in the regulated area.

Figure 7: Relationship between IA and improvement of regulation



Source: Author

IA&EU ETS case study

EC has conducted 12 IA assessing various parts of the EU ETS regulation (accomplished from 2003 until mid-2008):

- ENV 2003/07/23 Legislation on the Kyoto flexible instruments Joint Implementation (JI) and Clean Development Mechanism (CDM); (SEC(2003)785; COM(2003)403)
- ENV 2005/02/09 Communication on Winning the Battle against Global Climate Change (SEC(2005)180; COM(2005)35)
- ENV 2005/09/27 Reducing the climate change impact of aviation (SEC(2005)1184; COM(2005)459)
- ENV 2006/10/06 Mobilizing public and private finance towards global access to climate-friendly, affordable and secure energy services: The Global Energy Efficiency and Renewable Energy Fund (SEC(2006)1224; COM(2006)583)
- ENV 2006/12/20 Including aviation activities in the scheme for greenhouse gas emission allowance trading within the Community (SEC(2006)1685; COM(2006)818)
- ENV 2007/01/10 Communication on limiting Global Climate Change to 2 degrees Celsius (SEC(2007)7; SEC(2007)8; COM(2007)2)
- ENV 2007/02/07 Communication on the results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles (SEC(2007)60; SEC(2007)61; COM(2007)19)
- ENV 2007/12/19 Regulation setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2

emissions from light-duty vehicles (SEC(2007)1723;SEC(2007)1724; COM(2007)856; SEC(2007)1725)

- ENV 2008/01/23 Directive amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community Impact Assessment (SEC(2008)85/3; COM(2008)16; SEC(2008)84)
- ENV 2008/01/23 Directive on the geological storage of carbon dioxide and amending Council Directives 85/337/EEC, 96/61/EC, 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC and Regulation (EC) No 1013/2006 (SEC(2008)54; SEC(2008)55; COM(2008)18; SEC(2008)56)
- ENV/TREN 2008/01/23 Communication '20 20 by 2020 Europe's climate change opportunity' (SEC(2008)85/3; COM(2008)30; SEC(2008)84)
- ENV/TREN 2008/01/23 Decision on effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020 (SEC(2008)85/3; COM(2008)17; SEC(2008)84)

All the above mentioned IA documents try to some degree deal with the economic, social and environmental impacts of EU ETS on different groups of stakeholders. In order to evaluate properly the economic, social, environmental and other impacts in IA, the regulator (EC) needs to apply – as was discussed above – some analytical tools. The existing models are often insufficient for description of the areas, where the proposed regulation should be implemented. Thus the works on IA could result in greater interest in applied economic, mathematic, statistics etc. and in more profound cooperation between regulators and R&D institutions. This increased interest in application of theories could be demonstrated on our example of IA to the EU ETS. Following Figure 8 provides an overview of models used for the assessment of costs and benefits of the proposed climate mitigation policy or regulation and of the climate change itself.

Figure 8: Overview of models applied in IA to the EU ETS

IA year	2003/2004	2005/2006	2007/2008
Models applied	POLES	POLES, GEM-E3, DIMA, PESETA, PAGE2002, AERO, TREMOVE, MESSAGE	POLES, GEM-E3, PRIMES/GAINS, DIMA, TREMOVE, Copert IV., PACE, FAIR

Source: Author

It could be seen that with increasing number of IA increases also the scope of models applied in order to assess the impacts and that could have a further positive impact on future EC proposals as well as on the EC decision-making. In case of the EU ETS the models used for IA were also applied on evaluation of the proposals of National Allocation Plans for Phase II. of the EU ETS (see following chapter) and played thus a crucial role in formation of the current 5-year period of the carbon emission trading in Europe.

The following short overview of the models listed in Figure 8 shall provide a basic idea what kind of models the EC currently uses for assessment of impacts of proposed regulation and show both the progress and insufficiencies of the procedure:

- AERO – Aviation Emissions and Evaluation of Reduction Options model developed in order to assess impacts of inclusion of aviation into the EU ETS; Vlek; Vogels (2000)[14]
- DIMA – Dynamic Integrated Model of Forestry and Alternative Land Use.
- FAIR – Framework to Assess International Regimes for differentiation of commitments; model for calculation of abatement costs of emission reduction targets for EU 27 (den Elzen, Lucas, Gijsen; 2007)
- GAINS – assesses impacts of non-CO_2 greenhouse gases reduction.
- GEM-E3 – computable general equilibrium model representing all economic sectors and their interactions; assessment of macro economic impacts at Member State level resulting from GHG emission reduction.

---

[14] SEC(2005)85

- PACE – global general equilibrium model focused on electricity generation technologies and energy intensive industries.
- PAGE2002 – integrated assessment model of climate change, includes technology change and its relationship with abatement costs.
- PESETA – within the framework of this study were used three structural models – DSSAT crops for impacts on agriculture, DIVA for Coastal Systems and LISFLOOD model for River Basin Floods; POLES – global partial equilibrium model used for assessment of a future international agreement on the EU energy system; the model does not include macro economic impacts.
- PRIMES model – partial equilibrium model dealing with all sectors and fuel types; used to assess changes in the energy system such as are investment costs, changes in fuel mix, consumption etc.
- TREMOVE – studies the effects of emission reduction policies on the transport sector – both freight and passenger; based on its predecessor Copert IV. model

Some of the above mentioned models are capable to incorporate the uncertainty about the future development of market prices etc. (at least in the form of various scenarios), none of them, however deals with the problems related to frequent changes of regulatory framework. In thesis I try to demonstrate the impacts of such regulatory uncertainty and propose an appropriate model to assess them.

2.3 Structure of IA (RIA)

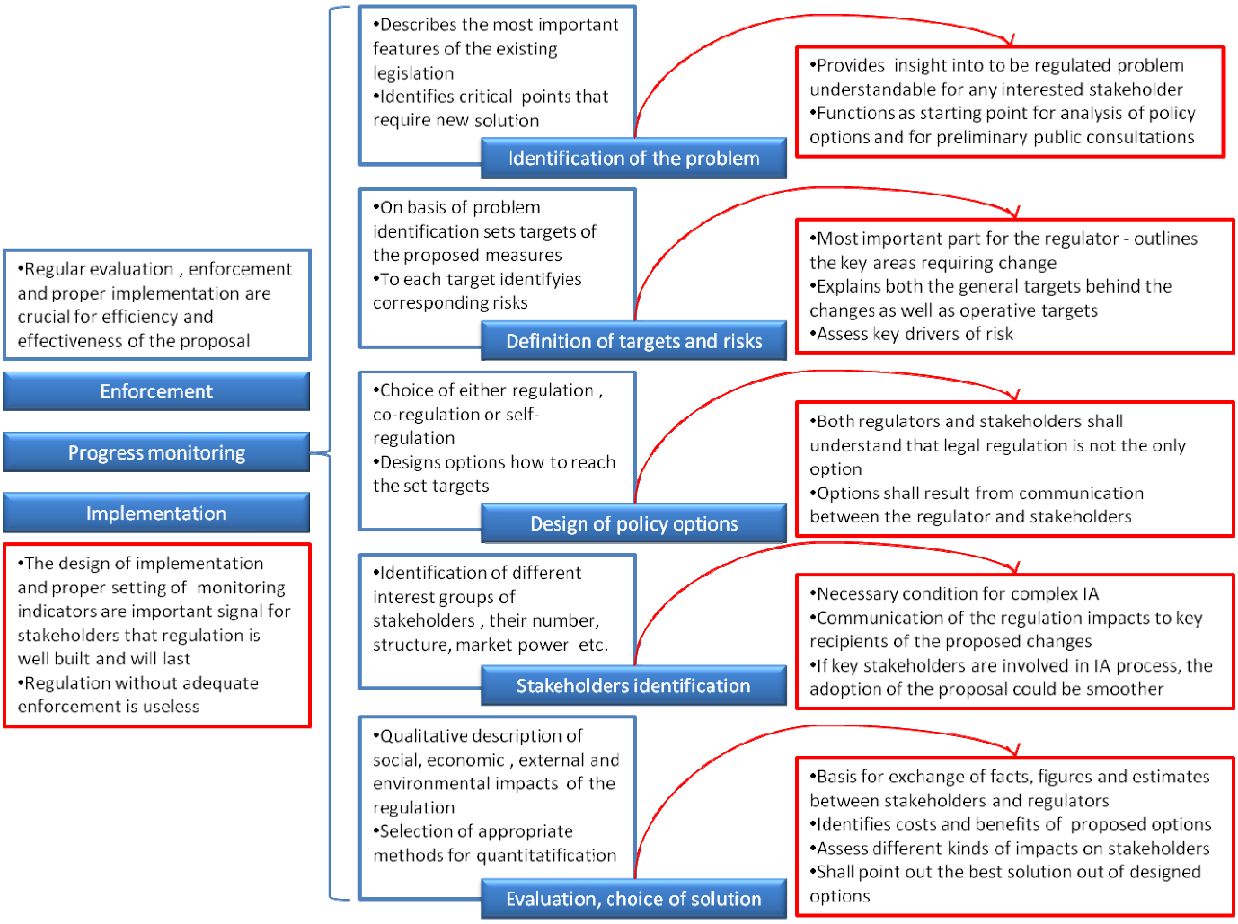
Before I proceed to the description of the carbon trading mechanisms and to the model, I shall complete the introduction to the IA procedure by a short description of its structure. The IA (RIA) shall serve as a well thought-out argument for political debate as well as a tool for communication with stakeholders of the assessed regulation. Therefore its structure is one of its most important features – it fortifies the message of the IA and it allows comparison between different IA (RIA). The prescribed form of IA (RIA) is structured in the following arrangement:

- Identification of the problem, analysis of the current situation

- Definition of targets, assessment of major risks
- Design of policy options
- Identification of key stakeholders
- Evaluation of the options (quantitative, qualitative), choice of solution
- Implementation, enforcement and monitoring of the regulation

Each of the above listed elements has its significance and role within the impact assessment procedure as suggests Figure 9.

Figure 9: Structure of IA (RIA) – description and key impacts on stakeholders



Source: Author based on modification of SEC(2005)791

This thesis – which is in fact a limited version of an IA – will focus above all on the problem identification, identification of stakeholders and evaluation parts of IA. The problem identification will be comprised from description of the EU ETS and of emission trading in general and also of a brief synopsis of the legislation to the EU ETS adopted so far. The identification of stakeholders will be limited to an overview of the pre-selected focus group – the power generators and their position within the EU ETS. The evaluation of impacts will be focused on the insight into the regulatory uncertainty and on the specific form it takes in the EU ETS framework.

3 Emission trading fundamentals

This chapter shall serve as an introduction into the theory and praxis of carbon markets and of emission trading in general. I will not focus on the environmental impacts of the emission trading nor will I discuss the pros and cons of the emission trading (market-based mechanism) in relation to the so called command-and-control approach. Instead, I try to summarize the regulatory and institutional drivers of the emission markets and highlight the elements that destabilize these markets (above all the EU ETS) and result in the increased regulatory uncertainty that is the key topic of this thesis.

3.1 EU ETS overview

The EU ETS started in January 2005. Setting up the EU-wide carbon dioxide emission trading scheme was the largest ever implementation of economic tools into the protection of the environment. It accounted e.g. for 17% of energy-related carbon dioxide emissions worldwide (Buchner, Ellerman; 2007). The emission trading within the EU ETS is divided into so called Phases; for each Phase a cap is set – the total amount of emissions that could be allocated to individual installations. Phase I. of the EU ETS started in January 2005 and finished in December 2007, Phase II. took off in January 2008 and will end in December 2012.

In the first two phases EU ETS has involved 4 sectors[15] and - within these - installations with installed capacity larger than 50 MW (Phase I.), 20 MW (Phase II.), respectively. Involved is from the greenhouse gases[16] only carbon dioxide, other greenhouse gases might be included in the upcoming phases. The EC allocates the total amount of allowances to the national states on basis of the National Allocation Plans. The NAPs are periodically revised based on the results of allowance trading and past market results are foundation for decision of the EC about the cap set for

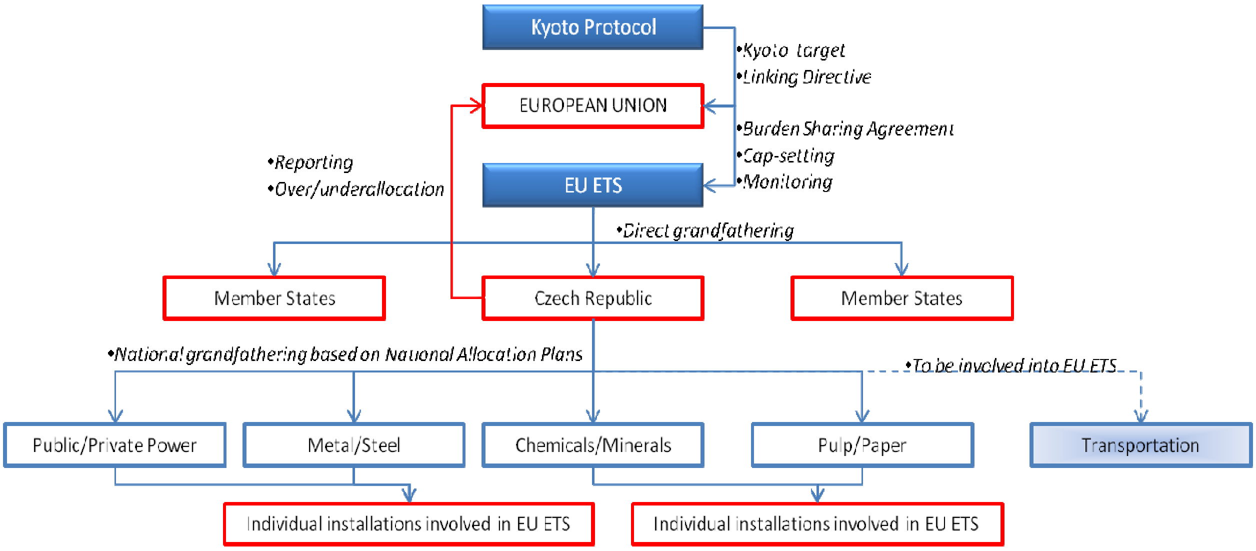
---

[15] In fact, there are several ways of grouping the EU ETS sectors; I will use here either 4 sectors (Energy, Chemicals&Minerals, Metal&Steel, Pulp&Paper) or 8 sectors according to the Czech National Allocation Plan (Public Energy, Private Energy, Chemicals, Metal&Steel, Minerals, Pulp&Paper, Coke, Refineries).

[16] Among other greenhouse gases belongs according to the Kyoto Protocol methane, nitrous oxide, ozone and hydro fluoro compounds (HCF).

next Phase. The non-compliance fine is EUR 100 per CO_2 tonne in Phase II. (EUR 40 per CO_2 tonne in Phase I.).

Figure 10: Scheme of EU ETS



Source: Author

The EU ETS with its mandatory cap-and-trade system of tradable allowances is only one type of market-based mechanisms involved in the climate change mitigation. A so called Linking Directive (2004/101/EC) connects the EU ETS with project-based mechanisms of Kyoto Protocol (see 3.2). The content of the Linking Directive regulates the interchangeability of the EU ETS allowances (EUAs) for credits from Joint Implementation and Clean Development Projects (ERU/CER). Other market-based emission trading mechanisms that are not directly linked to the EU ETS are credits and allowances stem either from voluntary initiatives (VER) or from obligatory regional initiatives (as is suggested in Figure 22).

As any international market, EU ETS relies on the trust of investors in the market and its regulatory framework. The price of carbon in the EU ETS is induced by artificial scarcity created by setting a cap on total carbon dioxide emissions that can be emitted by participating installations. Thus the cap is in my opinion the most important price driver and determinant of the EUA prices behavior.

As I described above and illustrated in Figure 10, the cap is set in a two-step manner. The general cap for the European Union is based on the European Climate Change Program (ECCP II.) and concretized by the EU Directive on Emission Trading (2003/87/EC) and by the Burden-Sharing Agreement that breaks down the overall EU commitment into individual targets of EU 15 Member States (see Figure 11). The EU ETS carbon cap corresponds with the obligation to reduce the greenhouse gas emission of the European Union by 8% until 2012, in compliance with the EU commitment under the United Nations Convention on Climate Change (UNCCC) and its amendment – the Kyoto Protocol (3.2).

Figure 11: Greenhouse gas emission reduction target under European Burden Sharing Agreement (1990 – 2012)

AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	EU15
-13,0%	-7,5%	-21,0%	-21,0%	15,0%	0,0%	0,0%	25,0%	13,0%	-6,5%	-28,0%	-6,0%	27,0%	4,0%	-12,5%	-8,0%

Source: www.carbontrust.co.uk

The second step of cap setting is then the allocation within particular country to the participating industries and installation. This micro-allocation is administrated by the national governments in compliance with the National Allocation Plans (NAPs) approved by the European Commission.

In theory, both the macro- and micro parts of the emission allocation process shall be stringent in order to guarantee the compliance with the EU Kyoto target, but the reality of cap negotiation in Phase I. and II. significantly differed from the theory. Figure 12 gives a hint on, how the NAP problems with the cap-setting looked like in Phase I. The amount of emissions allocated to Member States for Phase I. exceeded the total verified amount of emissions by more than 358 mil. EU allowances (EUA) and attracted attention to some problematic elements of the EU ETS.

Figure 12: Overview of the verified emissions and NAP1 and NAP2 allocations

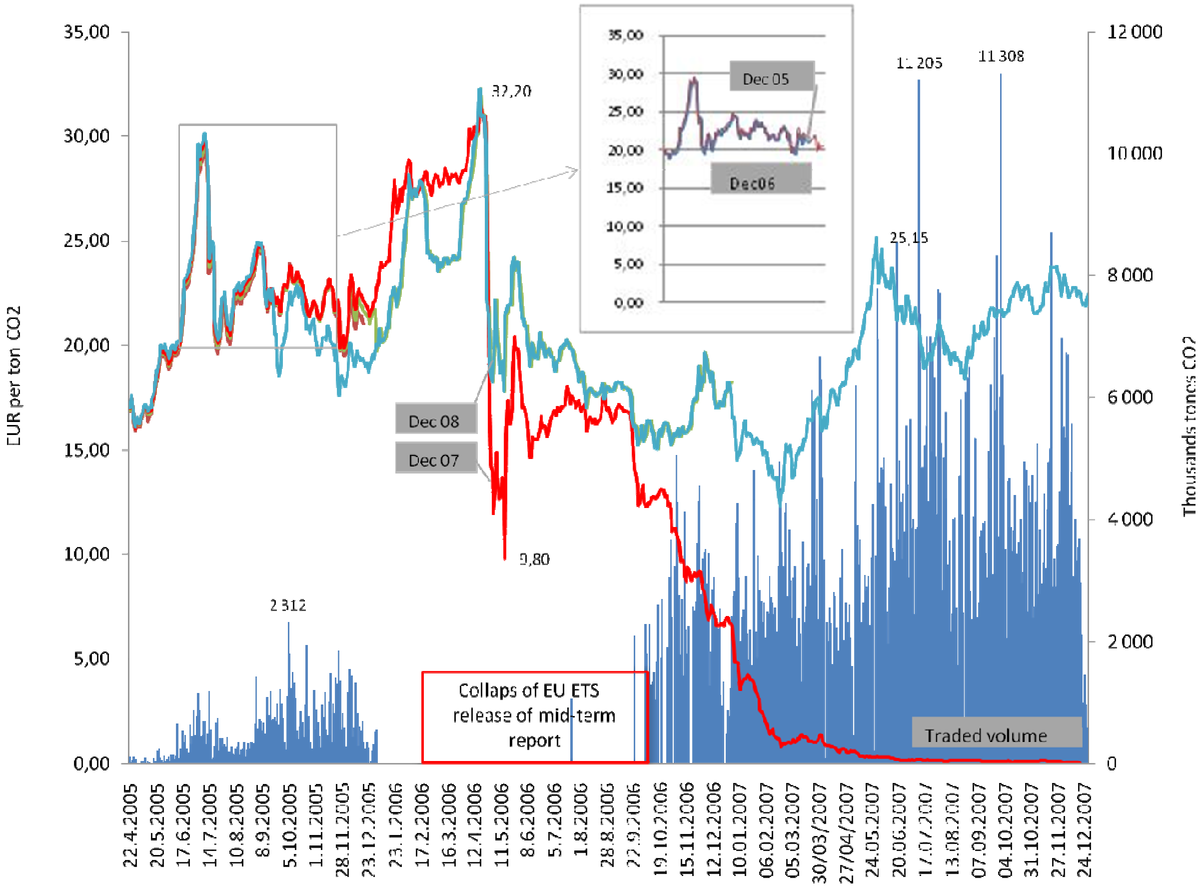
Country	Difference Allocation - Verified emissions (total Phase I.)	Average annual allocation NAP1	Average annual allocation NAP2	Difference NAP2-NAP1%
AT	1 194 699	32 900 512	30 729 906	-6,60%
BE	23 410 311	62 114 734	58 507 703	-5,81%
CY	1 368 911	5 701 075	5 479 780	-3,88%
CZ	37 889 613	97 267 991	85 445 875	-12,15%
DE	55 158 625	498 390 019	453 070 175	-9,09%
DK	10 415 914	33 499 530	24 500 000	-26,86%
EE	16 797 961	18 953 000	12 717 058	-32,90%
ES	-13 375 591	178 838 295	151 914 743	-15,05%
FI	16 235 386	45 499 284	36 157 688	-20,53%
FR	79 849 892	154 909 186	132 800 000	-14,27%
GR	9 250 680	74 400 198	69 087 549	-7,14%
HU	16 139 665	31 660 904	26 908 852	-15,01%
IE	1 567 543	22 320 000	20 243 031	-9,31%
IT	-10 586 402	223 070 435	195 746 486	-12,25%
LT	17 676 661	12 265 395	8 851 304	-27,84%
LU	2 191 417	3 358 323	2 488 299	-25,91%
LV	5 036 186	4 560 191	3 283 303	-28,00%
MT	-1 668 557	762 822	2 143 061	180,94%
NL	29 899 870	88 942 336	85 813 458	-3,52%
PL	91 131 481	237 838 568	208 515 395	-12,33%
PT	13 745 201	38 161 413	34 810 329	-8,78%
SE	15 104 184	23 209 832	22 802 439	-1,76%
SI	-380 326	8 743 680	8 298 937	-5,09%
SK	16 177 860	30 489 902	32 629 361	7,02%
UK	-75 760 681	224 831 370	212 069 329	-5,68%
Total	**358 470 503**	**2 152 688 995**	**1 925 014 061**	**-10,58%**

Source: Author, data European Commission

In this thesis I will spotlight three of the most problematic parts of the EU ETS and just mentioned some of the other issues. Firstly, there is the problem of the meeting point between the mentioned macro-allocation, which uses the top-down approach (from EC estimate through decision about proposed NAP to Member States), and the micro-allocation based on the bottom-up method (from installations to national governments to NAP proposal to the EC). The collision of these two contradictory approaches takes place in the designing and negotiating of the NAP. Each Member State develops within the limits set by the Burden-Sharing Agreement and EU Kyoto Commitment its own projections of emissions from all four participating and from non-trading sectors of the economy. Based on these forecasts, the national governments specify, how many allowances each sector will obtain. The Member States are not required to approach their emission reduction target necessarily directly, but rather by any manner that is suitable with regard to their specific conditions and the development of their economy. According to Betz et al. (2004) this respect for the individual needs of the Member States threatens to undermine the stringency of the target of the emission trading and in late spring 2006 this apprehension proved to be founded, when the EU ETS collapsed (see Figure 13).

Some Member States turned out to be very generous in projections of growth of their industries probably in order to assure excess allowances for their national companies and increase thus their competitiveness (for overview of NAP see Figure 12).

Figure 13: The collapse of EU ETS in mid-2006



Source: Author, data ECX

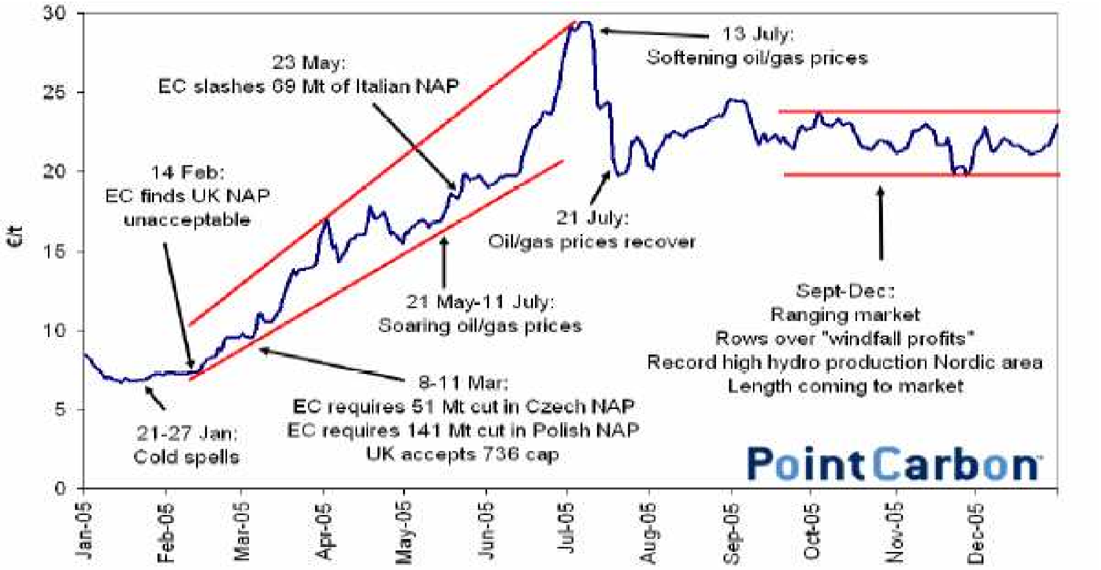
After the publication of the preliminary assessment of the first half of Phase I.in May and June 2006 the carbon prices collapsed as shown in Figure 13, proving that the immature carbon market is vulnerable to external regulatory and information shocks. Therefore, inconsistency in NAP proposals raise concerns about efficiency of the carbon markets[17] and are viewed as one of the major impediments to a continuous and founded price forming of EUA.

---

[17] Market efficiency ~ no windfall profits, markets following to the random walk; detailed study on the potential EU ETS windfall profits provide for instance Sijm, Neuhoff, Chen (2006).

The key role of NAP is illustrated in Figure 14 and Figure 15. The vulnerability of the carbon markets to regulatory changes combined with the discontinuous flow of information about the actual over- or under-allocation intensifies the reactions of EU ETS market actors on any new piece of information. The NAP that contain at least some data regarding the expectation and attitude of Member States towards the EU ETS thus create a very strong signal for the investors. Especially in 2007 as could be seen in Figure 15 an important role was played by the EC. In 2006, Neuhoff et al. (2006) admitted that if the NAP2 proposals had been successful in obtaining again more EUA than necessary (over-allocation), it would have created perverse incentives for market agents and other significant market distortions endangering the stability of carbon trading as whole. The fact that the EC was aware of the importance of NAP is illustrated by the strict approach it adopted towards the NAP2 (NAP for Phase II.). From November 2006 until December 2007 the EC assessed all 27 NAP2 and in most cases decided about substantial reductions to the proposed EUA allocations (see again Figure 12).

Figure 14: Regulatory influence on NAP1 prices in 2005, inter-linkage with fundamentals



Source: PointCarbon

A second fundamental feature or problem that characterizes the EU ETS is the free distribution (grandfathering) of the majority of EUA. Only minor percentage of assigned allowances will be auctioned[18] in the first two phases. The grandfathering as an allocation method is a frequent subject of criticism in the literature. The most often quoted reasons for critique could be summarized as follows:

- grandfathering does not generate any substantial income to the national budgets (compared to paid allocation via auctions) that would help to overcome the distribution effects of the EU ETS[19]
- grandfathering is decreasing the macroeconomic efficiency of the emission trading scheme (Hepburn et al. (2006))
- grandfathering does not provide effective price signals as auctioning would. It is though necessary to mention that according to e.g. Ellerman (1998) the free allocation was chosen both in the U.S. and in the EU because of its political feasibility[20] (from Phase III. on it is, however, expected that a major share of EUA will be auctioned -meaning that the political feasibility of auctioning is not expected to be from 2013 an overtly important issue).

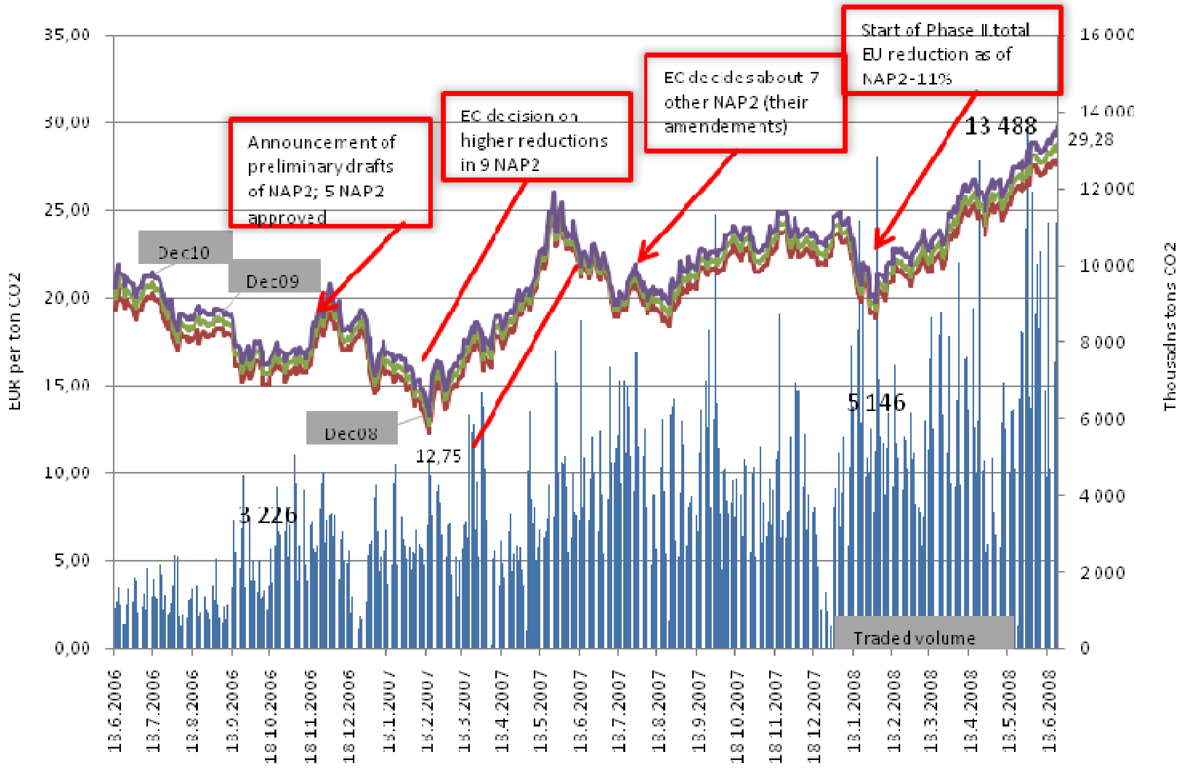
---

[18] In Phase I. Member States could auction up to 5% of assigned EUAs, in Phase II. it is up to 10%.

[19] By distribution effects I mean the above mentioned shift of allowance prices from producers to customers etc. Auctioning would enable the governments to decrease distortionary taxes (like labor tax) and thus alleviate the incomes of workers (customers), who in fact pay the price of EUAs. Same concept is used for instance by the Environmental Tax Reform etc.

[20] Potential transformation of the EU ETS grandfathering into auctioning usually raises strong opposition from the participating companies that fear increasing costs and loss of competitiveness.

Figure 15: Carbon market development since May 2006



Source: Author; data ECX

Third problem with the allowance allocation and with the system of NAP in general is that they to some extent prevent the EU carbon market from continuous price formation and therefore increase the volatility of the market and distorting the long-term price signals (Hepburn et al.; 2006). It could be tentatively expected that within each phase the release of a mid-term or final report will have significant impact on the EUA prices[21].

There are, as mentioned above, of course several other issues related to the outlooks of the EU ETS. Among the most important belong the uncertainty regarding the linkage of the EU ETS and Kyoto Protocol (see 3.2), the inclusion of the

---

[21] It had negative impact on EUA prices in Phase I., but it may result in increase of EUA prices in Phase II. given the mentioned strict approach of the EC towards national emission reduction targets.

transportation sector, the addition of other greenhouse gases and the possibility of exclusion of small companies[22] from the EU ETS.

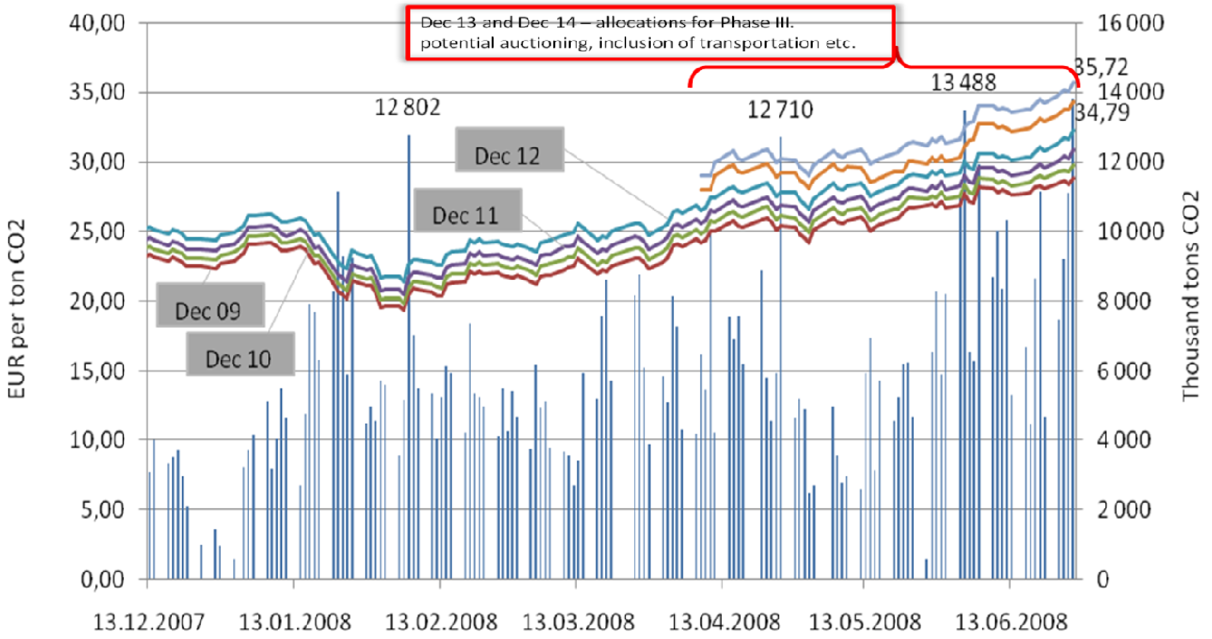
Bataller et al. (2006) provided empirical analysis of the carbon emission price drivers and discovered that the prices on the energy markets and to some extent also extreme weather influence significantly the carbon markets. The weather influences the carbon price rather indirectly, through increase in the energy demand. The extreme weather was examined for Germany and both extremely hot and extremely cold day dummies were found significant on the 1% level. According to a PointCarbon (2004), in case of frequent extreme climatic events, weather maybe an important factor influencing the short-term carbon prices.

The prices in the energy markets are of course an important driver of EUA prices. As described in Roques et al. (2005), the carbon dioxide emissions are highly correlated with trading prices of fossil fuels and thus distorting the investment decisions of the electrical utilities (will be discussed in following chapters). The relationship between fossil fuels and EUA is not a one-way street, however. The price of allowance changes the relative prices of the fossil fuels, but the changing prices of fossil fuels have impact on the carbon markets driving thus the prices of allowances. The example from the U.S. SO_2 demonstrated that even expectation of the market price of allowances may influence the perception of coal prices, resulting in certain investment behavior that influences back the allowance prices. As described in Montero, Ellerman (1998), the expectation of very high prices of SO_2 emission allowances before the launch of the U.S. Acid Rain Program (see 3.3) led a large share of participating electric utilities to switch to low-sulfur coal (regardless to the higher costs) and this activity on the macro-level decreased back the prices of SO_2 allowances. This example points out the fact that fossil fuel prices and technology prices could be perceived as endogenous factors influencing the prices of emission allowances.

---

[22] See e.g. Chvalkovska (2006) for evidence from Czech Republic, or Gangadharan (2000), who examined the transaction costs of the US NO_x emission trading initiative RECLAIM (see Figure 21) and discovered that the transaction costs can prohibit active participation in the trading system.

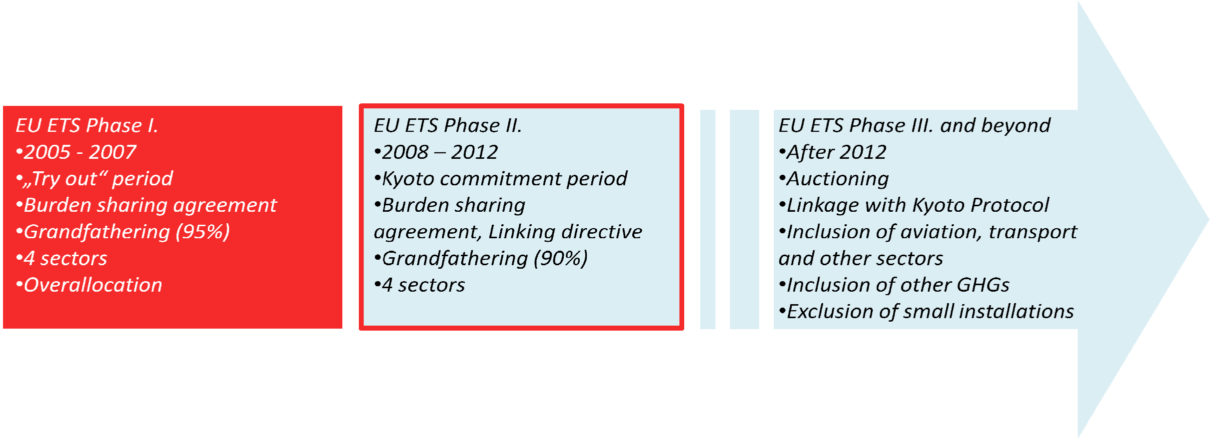
Figure 16: Market development from the end of 2007, including the Phase III. futures



Source: Author, data ECX

As was already illustrated, the EU ETS has undergone a significant development since its launch in 2005 – the progress does not comprise only the EUA prices and volumes, but also the means of trading on the EU ETS market. During Phase I. EUA were traded mostly through OTC contracts with physical delivery, most of these contracts took place directly between large companies. Purchase and sale of EUA on carbon or electricity exchanges was effectuated as a spot or forward trading and there were only few established broker companies – such a Vertis Environmental Finance, Evolution Markets, Natsource or PointCarbon. At the end of 2006, futures were the only carbon derivates traded in larger quantities. The intended synergy between the first Kyoto period and between Phase II. enhanced a rapid growth of the carbon markets worldwide.

Figure 17: Progress of the EU ETS



Source: Author based on public EC information

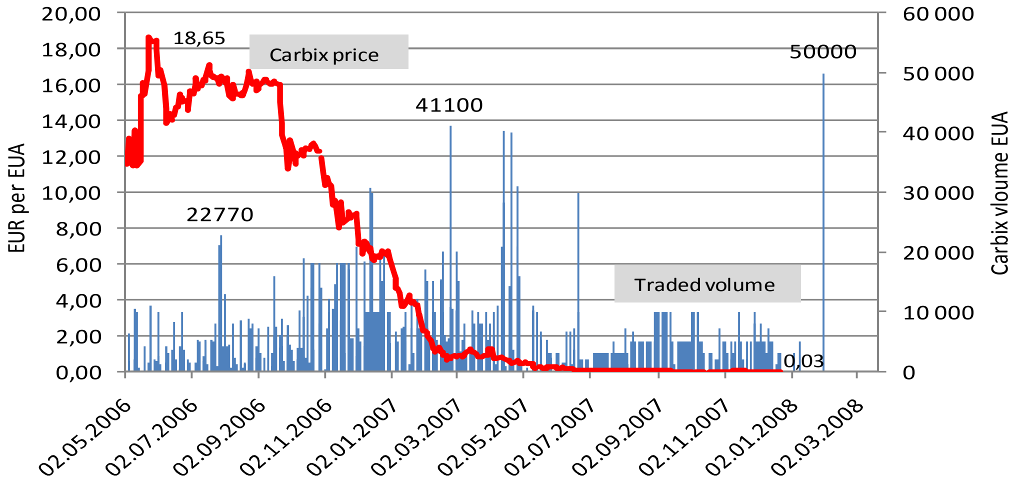
In mid-2008, carbon is traded in both spot and future market in form of either EUA or CER contracts (see for example Figure 19 and Figure 18). In mid-2008 appeared next to the standard forward and spot contracts also carbon options on EUA and CER. Figure 20 shows the results of trading of this instrument on the European Climate Exchange (ECX) in London. For comparison on how the situation in carbon options looked like in Phase I. of the EU ETS see for instance Uhrig-Homburg, Wagner (2006).

The most important specialized carbon exchanges in the EU are (according to Paolella, Taschini; 2006 and author's findings):

- European Carbon Exchange based in London (since 2005)
- European Energy Exchange (EEX) based in Leipzig (since March 2005)
- Scandinavian Nordpool (since April 2005)
- French Powernext (since June 2005)
- SendeCO$_2$ based in Barcelona (from the end of 2005)

Besides, the Member States can of course still use the OTC clearing services of operators of national emission registries (such as is the Czech Power Market Operator) and of broker companies – both EU-based and global ones.

Figure 18: Carbix[23] trading on EEX (EUA spot)



Source: Author, data EEX

3.2 Kyoto Protocol GHG markets

From the global point of view, the EU ETS is part of the global climate change mitigation initiative launched by the United Nations Framework Convention on Climate Change (UNFCCC). This convention signed 1992 in Rio de Janeiro attracted general attention to the fervently discussed Greenhouse Effect (more to that e.g. Nordhaus; 1993). UNFCCC is constructed as a political document that does not specify means for achieving the climate change mitigation. In December 1997 UN adopted the Kyoto Protocol (that entered into force in February 16, 2005), which established the outline of a global greenhouse gas emission trading scheme. The target of the Kyoto Protocol is to reduce the emissions of participating countries jointly by - 5,2% less than they were in 1990 (base-year). The deadline for this commitment is the year 2012 (therefore is Phase II. of the EU ETS called sometimes also the Kyoto Commitment Period). In case of every emission trading mechanism, the fundamental aim of the Kyoto Protocol is to help to its parties to reduce greenhouse gas emissions by an optimal, cost-effective means. This should be done via trading emission reduction credits originating from emission reduction projects. Countries with high Kyoto compliance costs can obtain emission reduction credits by participating on emission reduction project in a country (which is also party to the

---

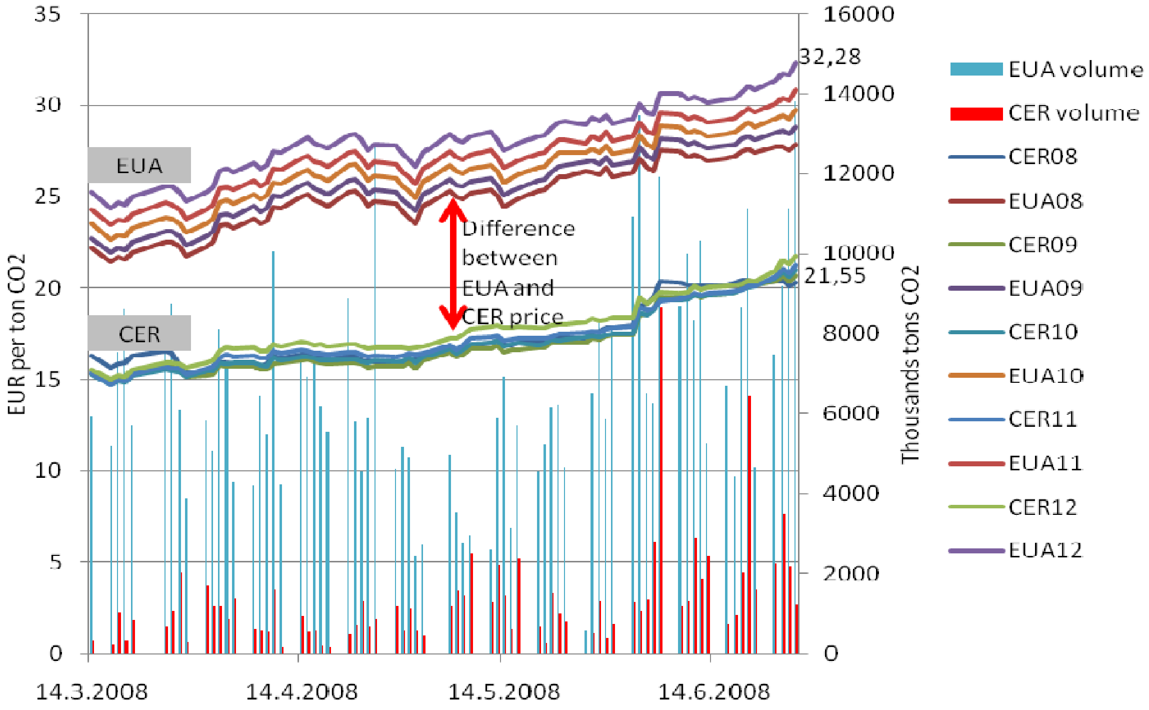
[23] Index for EU emission allowances which is calculated on each exchange day in an intra-day auction on the EEX Spot Market at 10:30 (www.eex.com/en/Extras/Glossary)

Protocol) that has relatively lower compliance costs. This interchange is beneficial for both countries – the former will reduce its compliance costs, the latter will gain income from selling the emission reduction credits from the project. The Kyoto Protocol implemented two flexible emission trading mechanisms – the Clean Development Mechanism and the Joint Implementation. These mechanisms enable Parties to the Protocol to carry-out emission curbing projects to either Annex B countries (Joint Implementation) or to non-Annex B countries (Clean Development Mechanism). Kyoto Protocol is so far the largest ever collective greenhouse gas emission reduction plan.

Joint Implementation projects are projects effectuated under Article 6 of the Kyoto Protocol. Countries listed in Annex B of the Protocol (developed countries that have emission reduction targets under the Kyoto Protocol) can invest money into emission reduction projects in other Annex B country and receive Emission Reduction Units (ERU) equivalent to one tonne of carbon dioxide. Earning the ERU is, however conditioned by an approval of the host country and fulfillment of certain eligibility requirement controlled by the JI Supervisory Committee. In July 2008 there were only 5 registered JI projects world-wide – one hosted by Bulgaria, one by Ukraine and three by New Zealand – as the JI was launched firstly in January 2008 and the verification procedure is rather time demanding.

The Clean Development Mechanism is defined under Article 12 of the Kyoto Protocol. This mechanism differs from JI by the parties involved in the project. Whereas in JI the host party as well as the investor are Annex B countries, in case of CDM the host country is always a non-Annex B country (developing countries, prevailingly). From CDM projects the investor receives saleable Certified Emission Reduction (CER) credits, again equivalent to one tonne of carbon dioxide. The CER are also subjected to verification that shall prove that the CDM project in question provides additional emission reductions higher than in similar non-CDM projects. In July 2008 there were more than 1 100 CDM projects registered by CDM Executive Board (for full overview see e.g. Haites; 2007), with estimated average annual reduction of more than 200 mil. tonnes of carbon dioxide[24], another 70 were by that time in the registration process. More than a half of the annual amount of CER comes from projects in China (51,51%), followed by India (14,2%), Brazil (8,8%), Republic of Korea (6,69%), Mexico (3,37%) and Argentina (1,89%). Largest investors into the CDM projects were UK (35,69%), Switzerland (18,32%), the Netherlands (11,69%), Japan (10,21%) and Sweden (4,89%).

Figure 19: Price difference between EUA Futures and CER Futures traded on ECX



Source: Author, data ECX

The Kyoto Protocol and the EU ETS are interconnected via the already mentioned Linking Directive that sets maximum quota for transfer of CER/ERU into the EU ETS. It is expected that during Phase II. – based on the National Allocation Plans of EU 27 – it would be possible to exchange 5% to 20% of CER/ERU into EUA. Figure 19 shows the price difference between EUA futures and CER futures –increase of the maximum quota would probably lead to a fall in EUA prices[25].

---

[24] http://cdm.unfccc.int/Statistics/index.html

[25] The maximum quotas are, however, not the only problem affecting the movement between the Kyoto mechanisms and EU ETS. Only in June 2008 – six months after the official launch of the first Kyoto Commitment

There are several articles and papers describing the potential impacts of merging the CDM/JI market with the EU ETS. Muller (2007) describes the potential pitfalls stemming from cheap emission credits and removal of these through CDM/JI project related tax. Jepma (2003) summarizes the main threads connected with the imperfect regulation of the link between EU ETS and Kyoto markets. Böhringer, Moslener, Sturm (2006) assess the risk of linking EU ETS with Kyoto markets stemming from the excess emissions (so called "hot air") available in Russian Federation, Ukraine and other post-soviet countries, where large portion of industry collapsed after the fall of USSR (and thus their current emissions are lower than in 1990 – which is the base-line year). Dewees (2001) compares the economic effectiveness of the cap-and-trade system (like EU ETS) versus the emission reduction credit system (such as is Kyoto) and discovers that if the external permit limit is set efficiently, the cap-and-trade is more effective. Lastly, the EC in SEC(2007)7 estimated that without access to CDM/JI the price of carbon will be according to estimates SEC(2007)7 8 to 11 times higher than with access.

Figure 20: Summary of carbon option trading on ECX

Type of option	CER Options	EUA Options
Contact Month	XII.08 - XII. 12.	XII.08 - XII. 10.
Trade Type*	ESF only	ESF prevails
Volume	20 550 000**	158 010 000***
min Strike Price (€)	12,00	7,00
max Strike Price (€)	24,00	50,00
Implied volatility	42,5%	43% - 51,75%
max Settlement Price (€)	6,53	6,59
min Settlement Price (€)	0,31	0,03

**EFS (Exchange for Swap) Contracts represent cleared bilateral option trades.*

***16.5. - 25.6. 2008*

****2.1. - 25.6. 2008*

Source: Author, data ECX

The CER and ERU that can be obtained from the Kyoto projects function on different theoretical basis than the EUA. As described in Dewees (2001), the ERC[26] (CDM, ERU

Period, 37 Annex B countries were able to start initialization to the International Transaction Log (ITL). The ITL is an operator that verifies the transfers of emission credits from one country to another. Functioning connection between the national registry of emission reductions and the ITL is a necessary condition for trading the CER/ERU. Open question is still also the interconnection of ITL with the EU ETS operator – Community Transaction Log (CITL).

[26] Emission Reduction Credits – general term referring to project-based/activity-based emission permits

– jointly called Emission Reduction Credits) are unlike the allowances (EUAs) not based on the cap-and-trade scheme, but on activity-level based baseline. This means that whereas in a cap-and-trade scheme the growth of industry activity cannot influence the amount of emissions allocated, in ERC scheme it can.

The different basis of ERC is reflected in the method of valuation of these credits. Whereas there are still some disagreements on the appropriate way of the EUA valuation[27], the ERC are project-based credits and as such they can be evaluated with use of standard methods of project valuation[28] (Ellerman; 2003b). The difference between the ERC and EUA results in an emerging development of hedging strategies, where an EU-based carbon intensive business could be hedged against increase in EUA prices by e.g. an option on CER credits from CDM project in developing countries (see Figure 20) and vice versa. The amount of such hedging is, however, limited by the Linking Directive and by the EC Decisions in order to prevent the mentioned inflow of cheap ERC from non-EU ETS countries.

According to Ellerman (2003a), there are – apart from all above mentioned issues – still following bottlenecks in the Kyoto carbon trading system:

- CDM/JI projects have to be registered with the designed national authorities of both countries through time and money demanding procedure[29]
- standard requirements for CDM/JI are difficult to fulfill
- there is still uncertainty regarding the features of the Kyoto Protocol - inclusion of other greenhouse gases has a serious impact on the price of CDM/JI projects – because for instance the technology for reduction of HFCs (hydro fluorocarbons) is cheaper than technology for carbon reduction –

---

[27] In the literature there could be found four different ways, how to evaluate the EUA. Firstly, the EUA can be addressed as a commodity Secondly, EUAs can be perceived as a company stock. As such, it shall be evaluated in respect with its expected profits. Lastly, EUAs can be also depictured as a company asset (or factor of production) and again evaluated according to its future cash-flows or by its risk premium (such as capital asset pricing model etc.). The risk of EUAs is from a large part non-diversifiable market risk and vastly dependent on the institutional framework.

[28] Internal rate of return, discounted cash flows etc.

[29] http://www.kyotoenergy.net/carbon_advisor.html

therefore inclusion of other greenhouse gases significantly decreases the price of ERCs from CDM/JI projects

From the above listed problems the first two – treating the transaction costs related with CDM/JI projects – used to be frequently discussed before the launch of the trading. The amount of CDM project applications submitted to UNFCCC (as was mentioned at the beginning of this subchapter, however, suggests that despite some administrative barrier, the investors will find its way to get the CER.

The third named issue became a topic of the day after several CDM companies[30] focused on methane or HCF emission reduction entered the global Kyoto market. The reduction of methane or HCF (that form a relatively small part of the total greenhouse gas emissions) is – Cnet (2008)– cheaper than reduction of carbon dioxide emissions – thus credits from such projects would be produced and sold on very low prices destabilizing thus the carbon markets.

3.3 Lessons learned from the US

The original idea to use tradable emission permits as a tool for emission reductions comes from the US, where a system of tradable emission permits was adopted already in the eighties of last century. Traded were not the greenhouse gases as in the EU ETS, but gaseous pollutants - sulfur dioxide (SO_2), urban ozone and nitrogen oxides (NO_x). Most of the US emission programs started as local initiatives encompassing only one specific region or state. The most important cap-and-trade US program covers, however, whole US; the US Acid Rain Program is focused on sulfur dioxide reduction (Kruger, Pizer, 2003), it was introduced by means of amendments to the federal Clean Air Act in 1990 (the program was, however, launched no sooner than in 1995). The US Acid Rain Program involves about 3 000 large combustion boilers of companies from various sectors of the industry – starting from heat and power over chemicals up to pulp and paper. The system of permits allocation is (similarly to EU ETS) grandfathering, the system allows banking and

---

[30] Climate Change Capital , Green Gas International, Marubeni Corporation, Eco Securities, AES AgriVerde, Arreon Carbon, Ecoinvest Carbon etc.

borrowing between individual phases (first phase lasted from 1995 till 2000, second phase started from 2001 on). Compared to the EU ETS the US Acid Rain Program requires significantly larger emission reductions (EU ETS target is in general about -8%, Acid Rain Program levies on participating installations reduction about - 50%). Whereas the EU ETS suffered (in its Phase I. between 2005 and 2007) from over-allocation (that caused the above discussed price collapse; Figure 13), the US Acid Rain Program was about 16 mil. tonnes of sulfur dioxide short (and that caused a massive installation of scrubbers and switch to low-sulfur coal made by the participating utilities – as suggests e.g. Shockley, 2006). Also the way of setting, monitoring and enforcing the compliance with the allocated cap differs in the EU and US scheme. The US emission trading system is centralized under federal jurisdiction; the administration of EU ETS seems to be more influenced by political negotiation between the sovereign Member States (Buchner, Ellerman, 2007). Another important difference between the EU ETS and the Acid Rain Program used to be that in the European Program, banking and borrowing between Phase I. and Phase II. was not allowed. This shall, however, change – banking shall be part of the EU ETS from Phase II. on.

The following Figure 21 provides an overview of the five most important US-based emission trading projects and of EU ETS.

Figure 21: Overview of 5 most important US emission trading programs and of EU ETS

Program	Type	Emissions	Source	Scope	Year
EPA Emission Trading System	Reduction Credit , Averaging	Various	Stationary	US	1979
Acid Rain Program	Cap-and-trade, Reduction Credit	SO2	Power generation	US	1995
RECLAIM	Cap-and-trade	NOx, SO2	Stationary	L.A. basin	1994
Averaging, Banking and Trading	Averaging	Various	Mobile	US	1991
Northeast NOx Budget Trading	Cap-and Trade	NOx	Stationary	Northeast of US	1999
EU ETS	Cap-and-Trade	CO2	20MW+	EU27	2005

Source: Ellerman, Joskow, Harrison (2003)

There are several lessons to be learned from the US experience with emission trading under the acid Rain Program. Kruger, Pizer (2003) wrap them up as follows:

- there were significant benefits from inter-temporal flexibility provided to the program by the possibility of banking
- free allocation of permits was crucial for obtaining support from power generation companies for the program
- strict monitoring and automatic fines for non- compliance are essential for the credibility of the emission trading

Montero and Ellerman (1998) add further conclusions regarding the expected versus real prices of emission permits:

- first estimates of the permit prices based on the underlying theory (that prices of permits will equal to the marginal costs of compliance with the emission reduction cap) made before the launch of the Acid Rain Program exceeded USD 300 per ton of sulfur dioxide
- the market price of permit for one ton of sulfur dioxide after the launch of the program was, however, not more than USD 131 and later on decreased even further
- the most accurate explanation of this large difference stresses out the role of exaggerated expectations of the participating companies that invested massively into scrubbers or switched to low-sulfur coal
- besides above mentioned measures for sulfur dioxide emissions reduction, there were also massive opt-ins made by companies with low marginal costs of compliance that were not obliged by law to join the program

The US experience with the emission trading demonstrates some important traits of emerging markets with pollution. Firstly, it is obvious that market participants tend to have exaggerated expectations regarding the scarcity of pollution allowances. The price overestimation results in a deep swing of the prices, when market participants obtain accurate information about the market.

Secondly, the participating companies are obviously more inclined to accept the emission trading scheme then allocation is made by grandfathering (for free), auctioning is politically more difficult (despite its higher environmental and economic effectiveness[31]).

Last, but not least follows the conclusion that strict compliance monitoring and greater transparency of the system provide unambiguous signals to the market participants and thus prevent market swings that could destabilize the market.

3.4 Overview of other carbon markets (adopted from Haites; 2007)

In this final section of this chapter I will mention some of the important non-EU ETS, non-Kyoto carbon emission trading schemes. The schemes mentioned below are not, however, a full list of all past and existing carbon trading initiatives. For instance in the EU well before the EU ETS, Denmark and UK had their own national emission trading systems, a whole chapter could be also used for description of the carbon trading in California and in other parts of the US, New Zealand has also an established emission trading system. Following remarks on selected carbon trading schemes will thus serve only as an insight into the size and scope of the global trading that was – according to the World Bank estimates[32] - worth USD 30 billions in 2006 and shall reach USD 400 billions in 2010.

Norway

Norway as a close partner of the EU and a member of the European Economic implemented in January 2005 consequently with the EU ETS its own carbon trading system for 51 Norwegian installations producing annually approximately 7 mil. tonnes of CO_2. Similarly to the EU ETS, the allocation in 2005 and 2006 was higher than the actual verified emissions. In January 2008 the Norwegian emission trading

---

[31] Burtraw, Palmer, Kahn (2005)

[32] http://www.environmental-finance.com/onlinews/0503car.htm

system joined the EU ETS after approval of the NAP of Norway by the EFTA Surveillance Authority[33].

Chicago Climate Exchange

Chicago Climate Exchange (CCX) was launched in 2003 as the largest voluntary integrated system that provided space for reduction of emissions of six major greenhouse gases (GHG, see footnote 16). Members of the Chicago Climate Exchange (CCX) made a voluntary, legally-binding commitment to reduce their GHG emissions by 1% per year from their 1998-2001 baseline, a 4% reduction during 2006. According to the CCX webpage, the benefits from CCX Membership are as follows:

- establish an early track record in reductions and experience with growing carbon and other GHG market
- gain leadership recognition for taking early, credible and binding action to address climate change
- drive policy developments based on practical experience
- prove concrete action on climate change to shareholders, rating agencies, customers and citizens
- reduce emissions using the highest compliance standards
- mitigate financial, operational and reputational risks in advance (in case that the US will ratify the Kyoto Protocol)

The CCX is interconnected with the ECX and with Montreal Climate Exchange. Traded are spot and future (up to 2010) carbon contracts.

New South Wales&Australian Capital Territory Greenhouse Gas Abatement Scheme (GGAS)

Despite the fact that Australia is one of the countries refusing the conditions of the Kyoto Protocol, New South Wales (NSW) belonged to first-movers in carbon trading. The Greenhouse Gas Abatement Scheme started in NSW already in 2003 when the first cap was set on the carbon dioxide associated with electricity consumption. The

---

[33] http://ec.europa.eu/environment/climat/emission/citl_en.htm

electricity retailers and industries supplied directly by the grid have had to purchase greenhouse gas abatement certificates equal to the emissions associated with the electricity they sell/use. Abatement certificates can be generated by accredited projects that reduce emissions or enhance removal of greenhouse gases. Thus the GGAS resembles a mixture of Kyoto and of cap-and-trade mechanisms. In January 2005, NSW was joined in climate change mitigation efforts by the Australian Capital Territory (ACT) increasing thus the scope of the scheme.

During 2005 about 10 million certificates were generated by 206 accredited projects and about 8 million were used for compliance. Almost 13 million certificates are forecasted to be needed for 2006 compliance. About 20 million certificates were traded during 2006 at an average price of US$11.25. This price is close to the non-compliance penalty.

Voluntary Market

Many companies and non-profit organizations offer to offset emissions from vehicle use, air travel, and other energy consumption for individuals and entities not subject to a regulatory obligation to reduce their emissions[34]. The integrity of the offsets offered varies significantly with regard to the:

- additionality of the project (making sure the project is not claiming reductions that would already occur)
- actual existence of the emission reductions (making sure the project activity is monitored and the emission reductions claimed are verified)
- exclusion of double-counting (making sure the same emission reductions are not sold to several buyers)
- permanence of the reduction, and
- existence of community benefits.

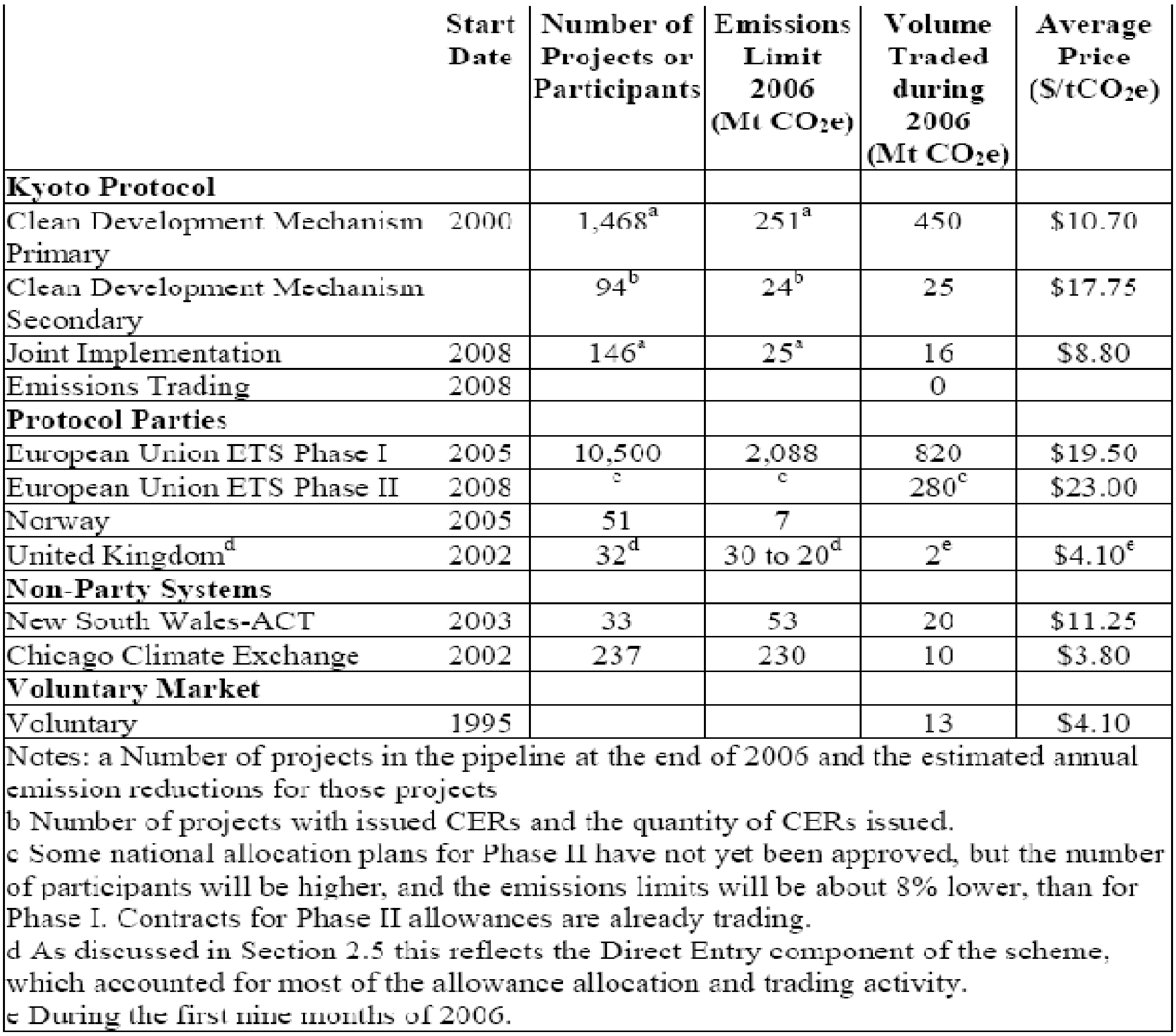
---

[34] www.carbonfootprint.com, www.terrapass.com, www.cleanair-coolplanet.org etc.

Among the voluntary initiatives it is also worth to mention the Royal Dutch/Shell Group that already in 2000 started its pilot internal emission trading system (STEPS) that allowed trading between several group entities located in Annex B countries. STEPS ran from 2000 to 2002 and enabled Royal Dutch/Shell to gain the understanding of the principles, benefits and risk related to emission trading. Since 2003 Royal Dutch was involved in the UK Emission Trading Scheme (now under EU ETS) and was also actively developing its own CDM projects.

For more detailed overview of climate mitigation initiatives of multinational companies see the web page of the Pew Climate Center (www.pewclimate.org).

Figure 22: Overview of existing carbon markets



	Start Date	Number of Projects or Participants	Emissions Limit 2006 (Mt CO_2e)	Volume Traded during 2006 (Mt CO_2e)	Average Price ($/t$CO_2e$)
Kyoto Protocol					
Clean Development Mechanism Primary	2000	1,468[a]	251[a]	450	$10.70
Clean Development Mechanism Secondary		94[b]	24[b]	25	$17.75
Joint Implementation	2008	146[a]	25[a]	16	$8.80
Emissions Trading	2008			0	
Protocol Parties					
European Union ETS Phase I	2005	10,500	2,088	820	$19.50
European Union ETS Phase II	2008	[c]	[c]	280[c]	$23.00
Norway	2005	51	7		
United Kingdom[d]	2002	32[d]	30 to 20[d]	2[e]	$4.10[e]
Non-Party Systems					
New South Wales-ACT	2003	33	53	20	$11.25
Chicago Climate Exchange	2002	237	230	10	$3.80
Voluntary Market					
Voluntary	1995			13	$4.10

Notes: a Number of projects in the pipeline at the end of 2006 and the estimated annual emission reductions for those projects

b Number of projects with issued CERs and the quantity of CERs issued.

c Some national allocation plans for Phase II have not yet been approved, but the number of participants will be higher, and the emissions limits will be about 8% lower, than for Phase I. Contracts for Phase II allowances are already trading.

d As discussed in Section 2.5 this reflects the Direct Entry component of the scheme, which accounted for most of the allowance allocation and trading activity.

e During the first nine months of 2006.

Source. Haites (2007)

4 Power plants and uncertainty

4.1 Introduction into the real option theory

The real option model is an alternative approach towards the investment valuation. The model tries to capture in detail an important element of the investment decision making – the uncertainty. The uncertainty could concern the future development of the markets and especially the uncertainty about the future development of the regulatory framework. The latter is often not fully captured in any of the traditional investment valuation model (such as are the Discounted Cashflow Valuation or the Relative Valuation approach[35]). Laurikka, Pirilä (2005) discovered that in case of investments where the uncertainty is large[36] (such as is construction of new power plant) the application of the traditional valuation methods may lead to systematic bias in the valuation.

As any model, the real option model is not completely universal. Based on Dixit, Pindyck (1994) I have identified some basic, underlying principles under which the use of the real option model could be more advantageous than use of the simpler DCF. The basic principles behind the real option model are as follows:

- Investment is continuous procedure timing is crucial for the success or failure of the investment.
- Substantial part of the investment costs is irreversible – sunk - from the very beginning of the investment process; the higher is the share of initial irreversible costs, the stronger is the impact of the uncertainty on the investment.
- Flexibility and adaptability of the investment decrease the impacts of the uncertainty on the investment.

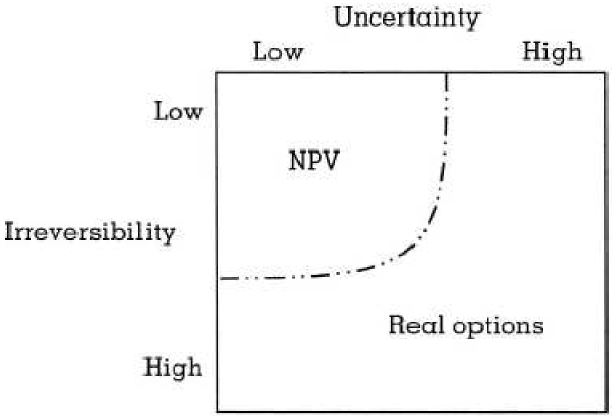
---

[35] http://pages.stern.nyu.edu/~adamodar

[36] Harchaoui, Lasserre (2001) tested the efficiency of the real option model in evaluation of irreversible investments and their empirical results supported the hypothesis that in case of large, long-term investments (they were testing investments into mining and mineral extraction) the real option model is an accurate valuation tool.

Figure 23 adopted from Adner and Levinthal (2004) depictures graphically the limits of use of the real option model. In case that the investment does not contain a significant share of irreversible costs and/or is not tightly bound to uncertain factors the use of real option is unnecessary. An extensive insight into the categorization of managerial risks (uncertainty) is also provided in Denton et al. (2003).

Figure 23: Boundaries of Applicability for Net Present Value and Real Options



Source: Adner, Levinthal (2004)

The real option model compares the possibility to invest into a project to a call option held by an investor. The underlying asset is the project itself (or the present value of the discounted cash flows from the project), the exercise date is the moment, when the project is launched. Depending on the type of project, the real option can resemble American-, European-, Bermuda-style or some exotic option used on financial markets.

In this thesis I will handle two types of the real option models. For the numerical example I will use a modification of the Binomial option- pricing model inspired by Shockley (2006), for the description of the theory and potential further application of real option models in the IA (RIA) and in regulation in general, I will show some modified versions of continuous real option models based on Black-Scholes (1972) model (and later on developed by Merton; 1973).Most of the newer models that I use in this thesis were developed by Dixit, Pindyck (1994) and Deng, Johnson, Sogomonian (2001).

There are various types of real options. Brealey – Meyers (2003) describe on page 617 following types:

- the option to expand the project if the pilot investment is successful (option to keep the project open)
- the option to shrink or abandon the project
- option to change inputs or outputs of the project (flexibility)
- option to postpone the investment (timing)

In this thesis I will focus above all on the investment timing, because from all the above named basic types of real options it best applies to the investment decision-making of the power utilities under the EU ETS.

In this chapter I will firstly describe the relation between power generation and regulatory uncertainty and also the power plant types that were taken into account in the numerical model presented in this thesis. Later on, I will focus on the data inputs and assumptions used in the numerical model. The following chapter contains description of the results of the numerical model and the insight into the continuous real option models and their potential further applications.

4.2 Power generation and regulatory uncertainty

In Member States that have high share of coal or lignite on their total energy mix[37], the power generation sector is one of the most carbon intensive sectors. The aim of the EU ETS is to reduce the greenhouse gas emissions – not only by the adoption of technical measures that decrease carbon intensity of production – but also by shifting production of certain goods or services to less carbon intensive segments of production. In the EU ETS context of power generation this means that the utilities not only adopt technical measures to decrease their carbon emissions (e.g. carbon capturing and sequestration etc.), but also that production from certain carbon-inefficient utilities (e.g. old hard-coal and lignite power plants) will be shifted to

---

[37] Such as is the Czech Republic, where coal and lignite in 2000 according to the Czech Energy Policy formed more than 70% on the total fuels used for power generation.

power plants with low carbon intensity (such as are gas-fired power plants, nuclear power plants or power plants based on renewable resources)[38]. Because the EU ETS is a market-based mechanism, the trigger for this production reallocation shall be the EUA prices.

As was discussed in the previous chapter, the results of Phase I. of the EU ETS were rather ambiguous – due to the price collapse in May 2006. The forceful reaction on the information regarding the over-allocation in 2006 discovered the vulnerability of emission trading on changes in its regulatory framework.

At the beginning of this chapter I have described three basic principles under which the real option model valuates investment better than traditional static approach. Investing into power generation assets is a long term investment decision, consists in major part from sunk costs and its timing and potential flexibility (peak-load versus base-load deployment, multi-fuel etc.) are crucial for the profitability of the utility – so it fits exactly into these principles. Figure 24 describes in a graphical way the relationship between regulatory uncertainty, time and investment into power generation assets. I define short run as time period between 2 and 4 years. This time period corresponds with the election cycle in most EU countries, standard legislative process on the EU level including IA could take roughly this time, within this period could be granted a legal permission EIA, IPPC etc. for power plant construction. Two to four years is also an estimated (EGÚ, 2005) construction time of a biomass power plant; a construction of a small hydropower plant, of a SCGT or of a wind park shall last even shorter.

The medium run is in this thesis defined as a period up to 8 to 12 years – a time that corresponds to most action plans and update times of long run policies. During this time, governments in most EU countries change at least two times, the elections to the European Parliament take place at least once similarly to presidential elections and elections to regional governments (if applicable). Within this time-horizon

---

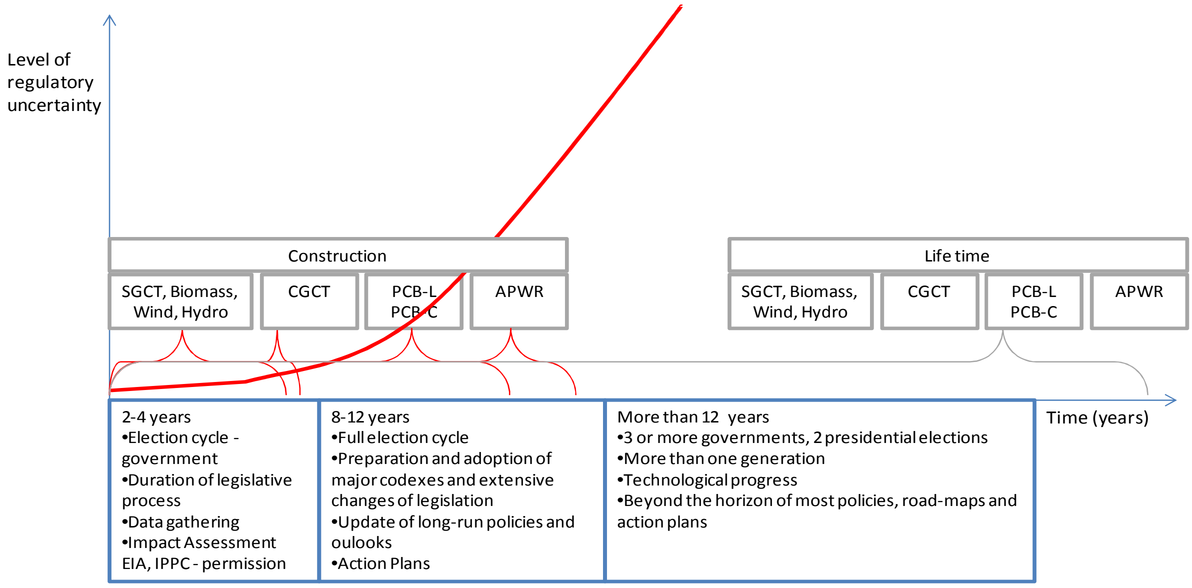
[38] Analogously to the US experience mentioned in Shockley (2006)

extensive legislative works or changes in the judicial interpretation of laws and regulations (from the first instance trial until the Supreme Court decision or decision of some European or international court[39]) could occur. Into the medium run belongs according to EGÚ (2005) the construction time of CCGT (more than 3 years) and of PCB-L and PCB-C (about 5 - 7 years).

As a long run I consider time period exceeding 12 years. In this time horizon occur in most EU countries at least three parliamentary and two presidential elections (if applicable). Twelve years can mean significant improvements in technology and science. Despite the common labeling of long-term policies, road-maps and other political documents, planning beyond a twelve years horizon is often beyond their scope – within this time can be replaced a whole generation of politicians and officials. The construction of a nuclear power plant lasts between 7 - 15 years so it belongs to the long term category.

As could be seen, only the construction of a power plant itself can be question of a medium to long run time horizon – the life time of a power plant is estimated (EGÚ, 2005) – depending on the type of power plant – between 20 to 40 years.

Figure 24: Regulatory uncertainty in time related to the average power plant construction time



Source: Author

---

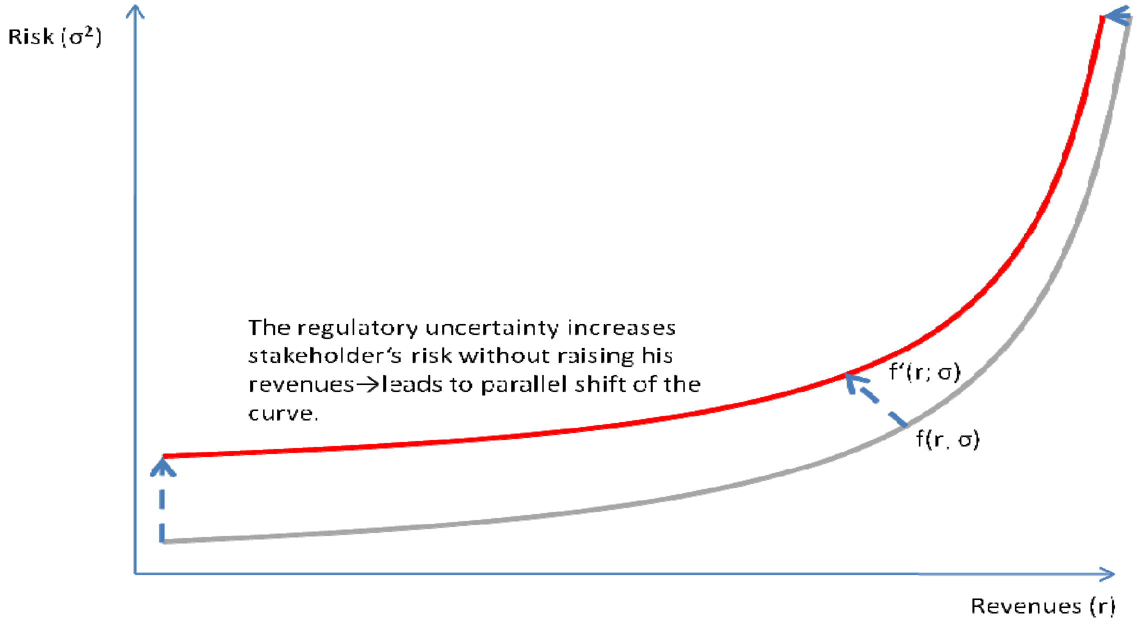
[39] If applicable; depending on law system and efficiency of national administration of justice.

The situation illustrated by Figure 24 is one of the answers on the question, why investors in Europe do not invest into construction of new power plants despite the obvious market gap in this segment. The demand for electricity is growing, but the construction of new sources is not progressing in sufficient speed to satisfy it (suggested for instance by Weber, Swider; 2004).

The regulatory uncertainty is usually not mentioned among the costs of changes of regulation and yet it is in my opinion one of the most important aspects of the whole legislative process. Frequent changes of law as well as of other normative act or action plans, policies etc. increase the uncertainty of stakeholders and the riskiness of their actions. This increase of riskiness is usually not compensated by increase in revenues and thus the regulatory changes factually increase costs of stakeholders' actions. The relationship between risk and revenues and the schematic illustration of the regulatory uncertainty are depictured in Figure 25. The shape of the curve is a result of the assumption that there is a trade-off between risk and revenues, which is a standard assumption used in finance (Brealey, Myers; 2003).

An appropriately conducted IA (RIA) could decrease the regulatory uncertainty and thus the costs that the regulatory risk imposes on investors. Because of the positive effects of IA defined in previous chapters of this thesis, IA contributes to stabilization of the regulatory framework and its improvement. Stable regulatory framework enables stakeholders of the regulation to form more accurate expectations and long-term plans. Although the implementation of IA does not fully remove the regulatory uncertainty, it works at least as a partial counterweight, which shifts the curve depictured in Figure 25 to some extent back to its initial position.

Figure 25: Trade-off between risk and revenues and impact of regulatory uncertainty



Source: Author

The real option approach described in this thesis shall provide a general idea on how important are the costs of the regulatory uncertainty in size and scope and advise thus a new method that could be incorporated into the IA (RIA).

4.3 Nuclear power plant

Nuclear power plants are source of electricity that vastly differs both from the renewable sources as well as from the "traditional" fossil fuel power plants. From the climate change perspective – carbon dioxide emissions from nuclear power plants are close to zero and thus the nuclear power plants seem to be appropriate solution for power generation in the carbon constrained economy. In the EU production of electricity from nuclear power plants displaces annually according to COM(2005)35 about 300 mil. tonnes of CO_2 that would be otherwise produced from thermal power plants. Any stringent climate change mitigation policy is in this respect favorable for their development.

The boom of nuclear power plants is, however, restrained by factors not related to the emission trading. They are using a specific high-end technology that can be produced only by a limited number of companies[40] that can thus influence the prices. The entire nuclear fuel production chain is submitted to sever regulation due to concerns about security (potential abuse of the fuel for construction of nuclear weapons), environmental safety (damages caused on environment by radiation especially from improper storage of nuclear waste etc.) and about other risks related to human health, transportation of the enriched fuel etc.

Nuclear power plants are also extremely vulnerable to the uncertainty about the future development of the regulatory framework. The construction of a nuclear power plant requires between 7 (EGÚ 2005) to 15 years and due to the high initial investment cost (EGÚ 2005 estimate was approx. CZK 70 mil. per MW of installed capacity[41]) have also long pay-back time. Also, it is feasible to build only large nuclear power plants due to technical features of the technology.

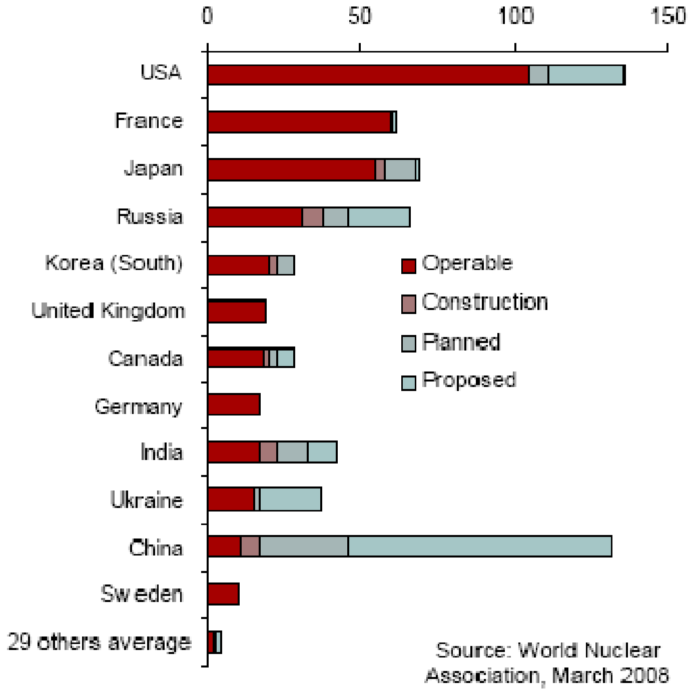
On the other hand, the nuclear power plants are reliable source of electricity and once built they could be considered as a long-term (life-cycle exceeds 40 years; EGÚ 2005) solution of power supply. This explains the renewed interest of both EU and non-EU countries in the nuclear energy (according to Reuters 2008 there were in January 34 nuclear power plants under construction – in Argentina, Bulgaria, China, Finland, France, India, Iran, Japan, Pakistan, Russia, Taiwan, Ukraine and in United States; several other countries – such as is Czech Republic or UK contemplate the possibility of construction of nuclear power plant – se also Figure 26). The increased interest in nuclear power might be the reason for rapid increase in uranium prices (Figure 27).

---

[40] Such as is the Russia Tvel Corporation (fuel production), AREVA NP (construction of reactors), UniStar Nuclear Energy, LLC (technology) or the US Westinghouse Electric Company

[41] Estimate for Advanced Pressurized Water Reactor (APWR)

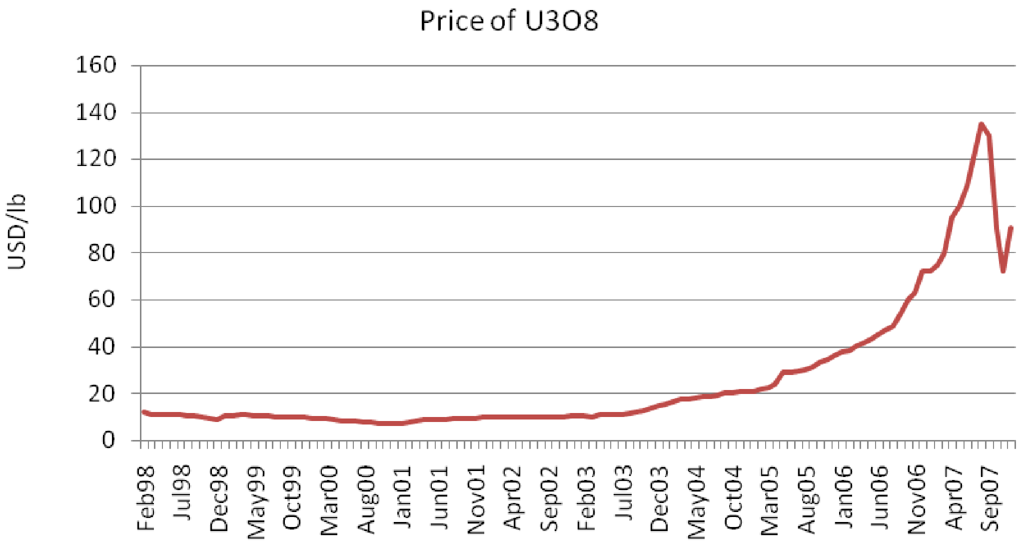
Figure 26: Overview of nuclear power plants worldwide as of May 2008



Source: World Nuclear Association

The nuclear power plants are a textbook example of an investment, where the real option model should be applied. Roques et al. (2005) model how the value of leaving open the nuclear option declines with the increasing prices of fossil fuels and of carbon. In their study they compare the nuclear power plant with the Combined Cycle Gas Turbine and realize that high capital cost, uncertain construction cost, potential construction and licensing delays, and economies of scale are the main features that make nuclear power technology unattractive to private investors in liberalized electricity markets. As the main driver for the current renewed interest in the nuclear power was identified the security of supply concerns and the aim on fuel mix diversification. Graber, Rothwell (2005) examine the option value of a project focused on development of opportunities for nuclear power plant construction. They realize that the high costs connected with such commitment (the duration of this development project is estimated as approx. 56 months) are outweighed by the gained option to construct the nuclear power plant in the future. Kiriyama, Iwata (2005) analyze the value of an investment in power generation assets that do not emit CO_2 in the carbon constrained world. They compare the nuclear power plant with other energy sources not dependent on fossil fuels – with wind and photovoltaic power plants. They discover that under all evaluated scenarios of the CO_2 price developments the nuclear power plant is a better option than the wind and photovoltaic power plants.

Figure 27: Uranium prices 1998 till 2007



Source: The Ux Consulting Company, LLC; www.uxc.com

I decided that I will not involve the nuclear power plant valuation into the numerical model applied in this thesis. The reason is twofold. Firstly, it is the recent extreme development of prices of uranium (see Figure 27) that causes problems in estimation of the future uranium price development that is necessary for the real option modeling. Secondly, the costs of nuclear power plant depend heavily on the price of the selected technology. It is therefore rather difficult to estimate some "average" investment costs of the nuclear power plant and such analysis out of the scope of this thesis.

4.4 Combines Cycle Gas Turbine (CCGT)

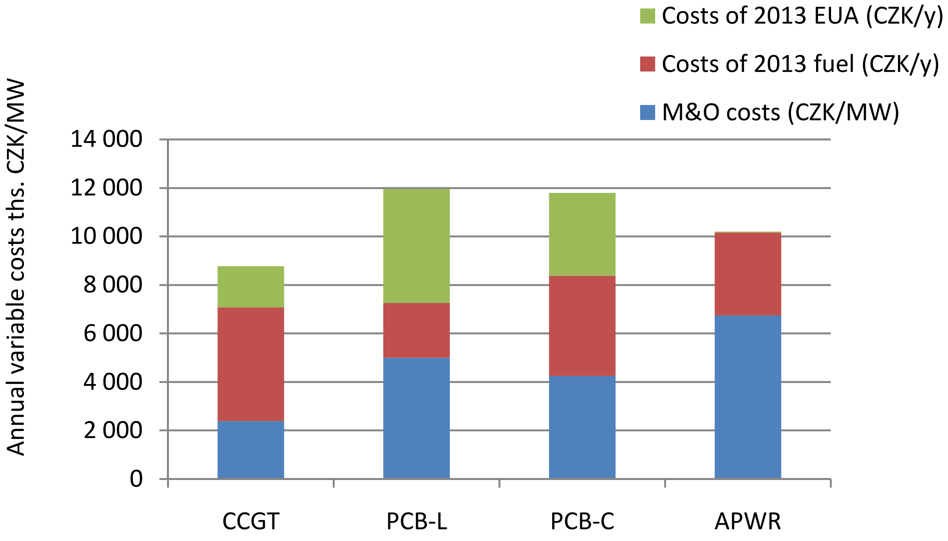
The CCGT plant takes only 3 – 5 years to construct[42], has relatively low initial investment costs per kW ("sunk costs") and is flexible (could be switched on and off according to peak-load hours). Its good efficiency and low minimum technical capacity (the CCGT plant could be relatively small – about 120 MW) are its other

---

[42] Still, the average estimated lifetime of a CCGT plant is about 25 – 30 years – therefore it fits in the conditions (principles) for application of the real option model.

positive features. In the carbon constrained world the CCGT has also a comparative advantage compared to other fossil fuel plants – for 1 MWh of electricity it produces only 0,43 tonnes[43] of CO_2 – it is thus less vulnerable to the climate change regulations than the PCB-C or PCB-L plants (that produce 0,9 tonnes of CO_2 per MWh, 1,25 respectively).

Figure 28: Estimate of annual variable costs of different power plant types (as of 2013)



Source: Author, data modified from EGÚ (2005)

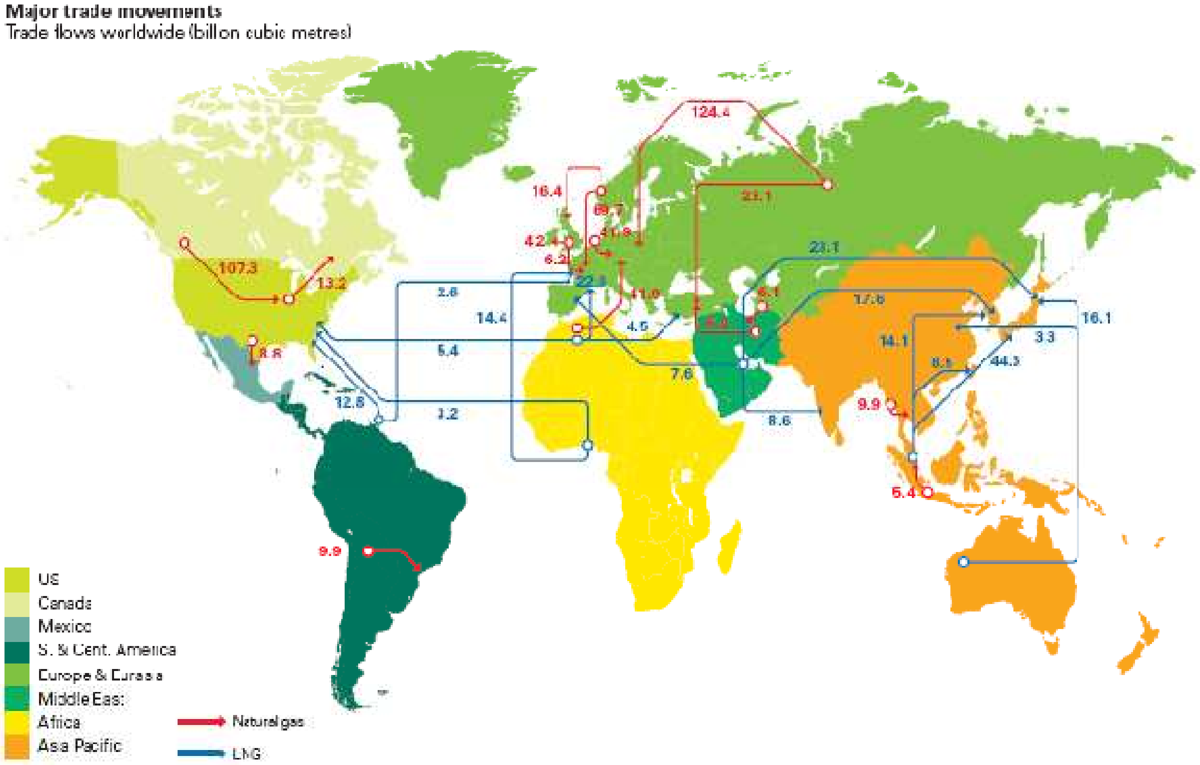
The crucial disadvantage of the CCGT plants is their high vulnerability on natural gas prices. As suggests Figure 28, the fuel costs form major part of the total variable costs of CCGT plant. The natural gas is an imported good and therefore sensitive not only on exchange rate fluctuation rate, but above all on the changes in geopolitical conditions. Figure 29 illustrates the current situation on the global natural gas market. Most of the proven natural gas reserves are located in the former USSR countries and in the Middle East. Most of the increasing natural gas consumption is – on the other hand – located in Europe and in the US. This leads to increasing dependency on fuel imports from countries often governed by rather unstable, non-democratic regimes. The potential impacts of political disputes were illustrated in winter 2006, when due to a quarrel over the gas prices Gazprom cut off supplies to Ukraine after Ukraine siphoned off supplies of Russian gas that had been destined

---

[43] David (2006)

for its markets in Europe. EU countries that do not dispose with sufficient natural gas storage capacity such as Hungary, where 85% of household depend on electricity and heat from gas-fired plants – experienced severe consequences of this situation (Dempsey, 2007).

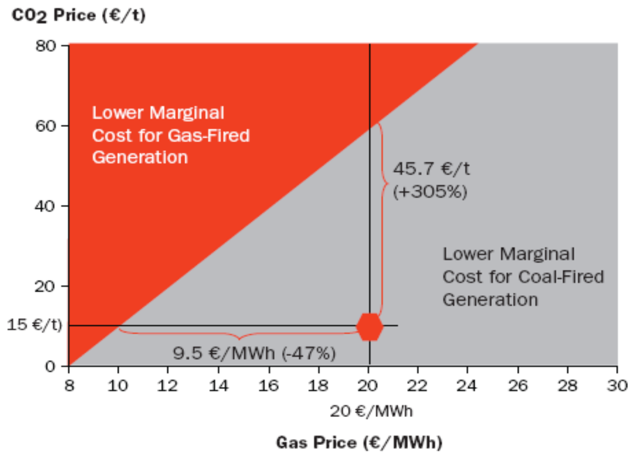
Figure 29: Natural gas trade movements



Source: BP (2008)

Despite the fact that the sunk costs of CCGT are considerably lower than the costs of a nuclear power plant, there is a considerable amount of literature on the real option application on the CCGT. Laurikka (2005) investigates the relationship between the value of flexibility of natural gas power plants (option to alter the operation scale, to switch between products etc.) and the climate policy. The findings in this study support the hypothesis that the climate policies increase the option value of flexibility in power generation. As most flexible resulted the cogeneration heat and power plant (CHP) and a multi-fired power plant (plant that can combust more than one fuel). Wickart, Madlener, Jakob (2004) develop a model that shall explain the investment decision of large industrial companies, when they are deciding between construction of private CHP plant or simple thermal unit and electricity from the grid. Focus of the analysis is to examine the Swiss CHP regulation. The authors discovered that Swiss regulatory framework in fact to some extent hinders the development of large CHP plants that could potentially endanger the Swiss emission reduction targets (given the large share of nuclear and hydro power plants on the Swiss fuel mix). Fleten, Näsäkkälä (2003) analyzed the investment in gas-fired power plants under stochastic development of natural gas and electricity prices. They discovered that by the time of the investment decision the option to abandon the project does not have a significant value unlike the timing and flexibility option. Hirschl, Schlaak, Waterlander (2007) examined the investor's choice between the CCGT and PCB-C as depictured in Figure 30. The CCGT results more economical only in case of low gas prices and relatively high EUA price (NPV scenarios, IRR valuation methods). Teisberg (1993) shows with use of the real option model why companies rather invest into smaller, shorter-lead plants (such as are the small gas-fired plants) rather than in large projects. Alstad, Foss (2004) provide a complex analysis of the investment decision to build a CCGT power plant in Tjeldergodden in Norway. Analyzed is above all the option to postpone the investment given the future development of natural gas and electricity prices.

Figure 30: The Marginal Costs Economics of Combined Cycle Gas Turbine vs. Hard Coal Plants



Source: Hirschl, Schlaak, Waterlander (2007)

4.5 Pressurized hard coal boiler (PCB-C), pressurized lignite boiler (PCB-L)

The PCB-L and PCB-C are the most traditional type of power plant. They are robust base-load electricity sources usually built right next to hard coal or lignite mine because of transportation costs reduction. The fact, that both types of coal-fired plants usually use domestically produced fuel could be considered as their major advantage, especially given the current concerns of the EU about the security of supplies and increasing dependency of the EU on imported fuels. The initial investment costs of PCB-C and PCB-L lie somewhere in the middle between the CCGT and nuclear power plant. EGÚ (2005) estimated the investment costs as approx. CZK 38,5 mil. (PCB-C) and CZK 43 mil. (PCB-L) per MW of installed capacity. The construction time is expected to be about 5 – 7 years.

On the other hand, there are several disadvantages connected to the PCB-C and PCB-L power plants. First of all, they are extremely vulnerable to climate change policies. According to David (2006) the PCB-C plants emits 0,9 tonnes of CO_2 per MWh, the PCB-L emits 1,25 tonnes of CO_2 per MWh. They are also less efficient than the CCGT, based on EGÚ (2005) the difference in efficiency between CCGT and PCB-C exceed 10%. The coal-fired power plants are also subject to sever environmental regulation regarding the amounts of emitted pollutants (see in previous chapter – the Acid Rain Program).

From Figure 28 could be seen that the fuel costs of power plants form smaller share on total variable costs of the plant than in case of the CCGT. This is, however, conditioned by the immediate availability of the fuel. In case that the government imposes for example stricter mining limits on the mine supplying a coal-fired power plant, the fuel price could rapidly rise.

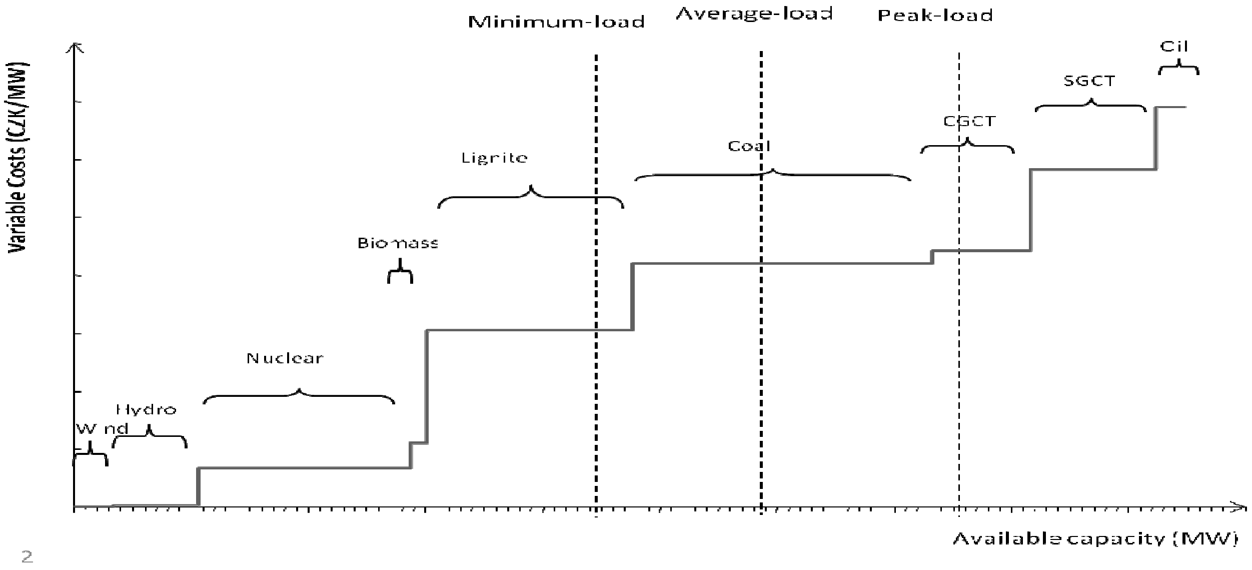
Recently – as a reaction on the carbon limitations – appeared several new coal combustion technologies. Reedman, Graham, Coombes (2006) compare the advanced coal technologies deployed in Australia with use of the real option model. The compared technologies are:

- Supercritical pulverized-fuel black-coal power plant
- Black-coal-fuelled integrated gasification combined cycle power plant (IGCC)

- Supercritical pulverized-fuel black-coal power plant fitted with post-combustion capture of carbon dioxide
- A black-coal-fuelled integrated gasification combined-cycle power plant fitted with pre-combustion capture of carbon dioxide

The Australian study demonstrated that especially the carbon capture technologies have a high value of the option to wait because of the initial costs of the technology. Sekar et al. (2005) also assesses the option to either postpone an investment into new coal combustion technology – IGCC – with the standard pulverized coal technology in the US. The analysis – similarly to the Australian – discovered that in most of the designed scenarios the pulverized coal technology stayed cheaper. The IGCC became more economical only under quite extreme future carbon regulation.

Figure 31: Merit order curve for power sector in the Czech Republic



Source: Svoboda (2007)

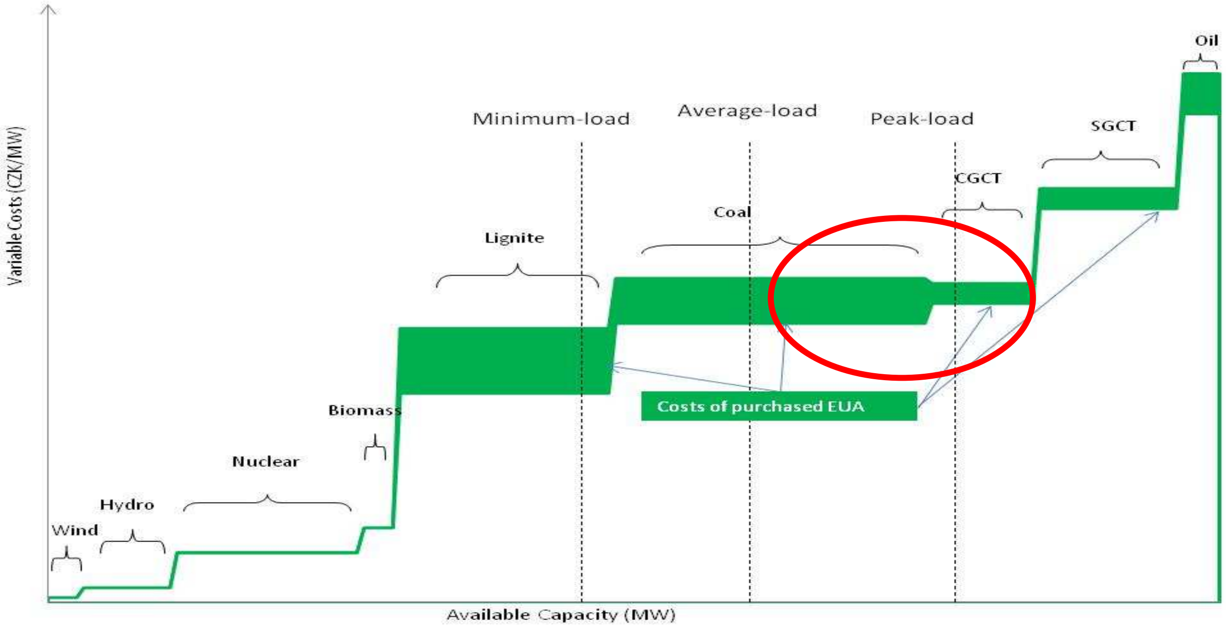
In this thesis I will in major part focus on the relationship between the CCGT and the PCB-C[44]. As suggests Figure 31, in the current situation (demonstrated on the example of the Czech Republic) the PCB-C is more cost-efficient than the CCGT that is profitable only in peak-load operation mode. In case of an increase in EUA prices the merit order curve may change as suggested in Figure 32. For the numerical

---

[44] The PCB-L has low efficiency and due to the low quality of lignite as fuel, I will not take into account the variant of construction of new PCB-L.

model in this thesis is the circled part of the merit order curve in Figure 32 the matter of interest. The key aim is to find out at what level of EUA price causes the drafted switch and whether there is a value to the option to delay the decision regarding construction of either CCGT or PCB-C.

Figure 32: MOC under increased EUA prices



Source: Author based on Svoboda (2007)

5 Numerical model

5.1 Assumptions of the numerical real option model

- Model applied

As I already mentioned in chapter 4.1 the numerical model used in this thesis is based on the standard binomial option-pricing model that was originally designed by Cox, Ross, Rubinstein (1979). I was inspired by the modification published in Shockley (2006). Shockley (2006) used the dynamic valuation of investment decision of a Bowen power plant in Georgia under the price uncertainty within the US SO_2 emission trading. The company had three main options – either to buy the necessary allowances or switch to low sulfur coal or install a scrubber. The real option model was used in this case for design of an optimal dynamic strategy of the power plant in this situation. I applied a similar model on the situation of an investor, who is now considering building a power plant.

The numerically assessed real option is structured as a European-style option that can be exercised only once a year at certain date. Thus the option can make only one upward/downward step per year. The EUA is assumed to only take a step up or down, but not both simultaneously. Tested implied volatility of EUA prices in Phase III. and beyond are set as 20% (Shockley 2006), and 50%.

The equations describing the steps are:

- Upward step $U=e^{\sigma * t}$, where σ is the volatility, t=1 year
- Downward step D=1/U.

The probability of the upward movement is as follows:

- Probability of an upward step q=(exp(risk-free interest rate)-D)/(U-D); where the risk free rate is 5% (discount rate)
- Probability of a downward step 1-q=(U-exp(risk-free interest rate)/(U-D).

The model is structured as a basis for managerial decision as of July 10, 2008[45].

The assessed problem is structured as a cost minimization problem that could be described in the following notation:

min C (initial investment, M&O, fuel, EUA)

s.t. power plant type
power plant operation mode
EU ETS Phase III. allocation structure
EUA price (2013 and beyond).

Power plant types assessed are the Combined Cycle Gas Turbine (CCGT) and the Pressurized Hard Coal Boiler (PCB-C). The reason for this choice is the proximity of costs of these two power plant types as suggested in Figure 32. Second reason for this choice are data problems connected with estimation of lignite prices for year 2013. Lignite is usually traded with use of long-run OTC contracts and prices set in these contracts are kept as business secret. There are no lignite futures or other type instrument traded on commodity exchanges.

The CCGT and PCB-L do not operate in the same way. PCB-C is a typical base-load source; switching a PCB-C power plant on and off according to electricity demand is not possible from technological reasons[46]. The CCGT is a classic peak-power plant. It is operating only during hours with highest electricity demand and the rest of the time it is switched off. Figure 32 suggests that in case of increased EUA prices or in case of increase of electricity demand (see Figure 33) it may happen that CCGT will have to be deployed as base-load plants as well. Therefore I decided to examine two potential operation modes of the assessed power plant types:

---

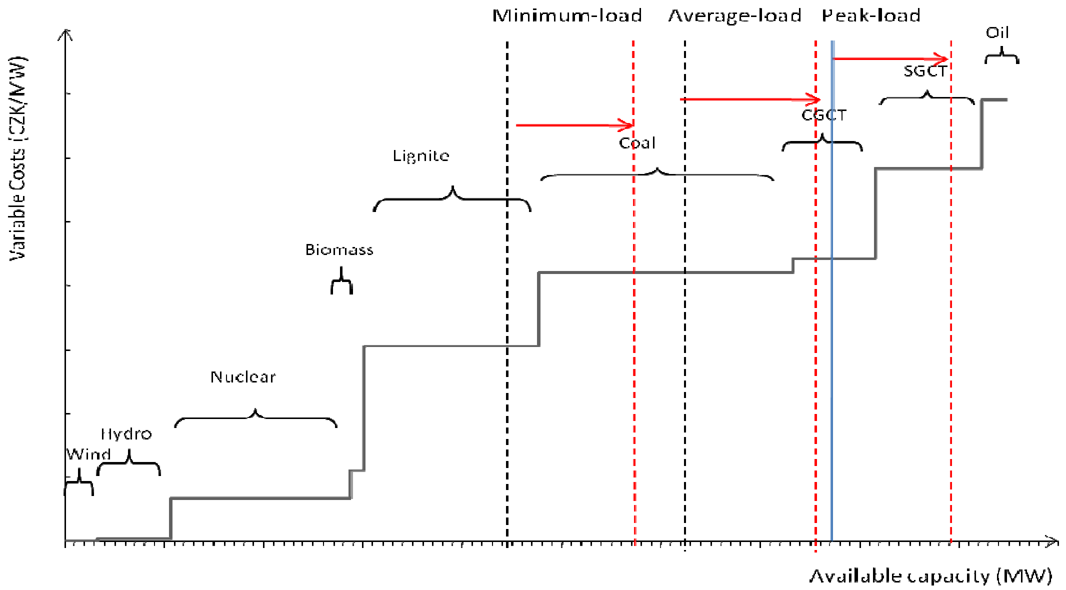
[45] All data adopted from Carbon and Energy exchanges as well as the exchange rate adopted from the Czech National Bank exchange rate are set as of July, 10, 2008 in order to avoid problems with calculation of long-term price averages of commodities traded in foreign currencies under current appreciation of the Czech crown.

[46] The coal-fired boiler has a very long start up time. Switching the coal-fired boiler on and off would thus be very expensive and would further decrease the efficiency of the PCB-C plant.

- both power plants as base-load sources – 5 000 hours per year per MW installed (4 867 t.a.[47] hours CCGT, 4 667 t.a. hours PCB-C), base-load electricity prices
- PCB-C as base-load – 5 000 hours per year per MW installed (4 667 t.a. hours resp.), base-load prices and CCGT as peak-load – 3 000 hours per year per MW installed (2 920, resp.), peak-load prices

The Phase III. and beyond (Phase III.+) allocation structures illustrate the amount of EUA that the individual installations will have to purchase due to auctioning or substantial emission reduction targets. Based on recent statement of the EC (EurActive 2008a) I decided to use for this model as benchmark amounts 50% EUA to be purchased and 100% EUA to be purchased (no grandfathering alternative).

Figure 33: Merit order curve for Czech Republic – example of increase of electricity demand without increase of available capacity



Source: Author, Merit order curve (Svoboda, 2007)

The EUA prices (Phase III.+) I model with use of the above described binomial option-pricing model. As a starting point I use the EUA 2013 Future traded on ECX as of July 10, 2008 (see footnote 45):

---

[47] Technically attainable amount of hours per year.

- EUA13 (10th July 2008)=EUR 34,65
- carbon intensity ratio 0,9 tonnes of CO_2 per MWh (PCB-C) and 0,43 tonnes of CO_2 per MWh (CCGT)[48]
- exchange rate (10th July 2008, Czech National Bank)= 23,465 CZK/EUR.

In the model I assume that compliance with the EU ETS will be always more advantageous than non-compliance. This means that as soon as the EUA market prices will be too close to the non-compliance fine, the EC will raise the fine appropriately.

- Investment parameters of the power plants assessed

The investment parameters of the assessed power plants were adopted from the EGÚ (2005) report and are summarized in the Figure 34 below. Costs of both power plants are computed for one MW of capacity installed. [49]

Figure 34: Technical parameters of investment into new power plant

Type of unit	CCGT	PCB-C
	Combined cycel gas turbine	Pressurised hard coal boiler
Fuel	Natural gas	Hard coal
Investment price (CZK/MW)	20 714 000	38 547 000
M&O costs (CZK/MW)	2 394 195	4 253 814

Source: EGÚ (2005)

The lifetime of both power plants is set as 30 years[50], the construction time as 4 years[51] (the estimated period 2013 – 2043).

The payment of the investment price is calculated as a 30 years (=T) credit with r=8% interest rate with standard annuity (A):

---

[48] David (2006)

[49] The usual size of CCGT is according to EGÚ (2005) 300 MW of installed capacity, of PCB-C 600 MW of installed capacity.

[50] EGÚ suggests 25 years in case of CCGT, but for instance Roques et al. (2005) estimate the CCGT lifetime as 30 years.

[51] EGÚ suggests 5 years construction time of PCB-C, but for purposes of the model 4 years for all three types of power plants fit better (besides – one year difference is a relatively insignificant for the model).

$$A = \frac{r(1+r)^T PV}{(1+r)^T - 1}$$

where PV is the investment price as in Figure 34.

The inflation applied in the model is the long-term inflation target of the Czech National Bank 3% (= π); the discount rate applied is i=5% (as in Shockley 2006)[52].

The estimated present value of annual costs of PCB-C and CCGT without the EUA will be computed as follows:

$$PV\ costs = \sum_{t=1}^{30} \frac{M\&O\ costs * (1+\pi)^t}{(1+i)^t} + \frac{Annuity}{(1+i)^t} + \frac{Fuel\ costs * (1 + growth\ rate)^t}{(1+i)^t}$$

- Fuel and electricity costs

Since the power plant construction time is 4 years for all three types in the model, we need to apply fuel, electricity and EUA prices as of the year 2013. All the fuel and electricity prices were adopted from trading prices on EEX (ECX) in July 10, 2008 (see footnote 45):

- Natural Gas EGT[53] Year Future 2013 (10th July, 2008)= 40,99 EUR/MWh
- Phelix Base-load Year Future 2013 (10th July, 2008)=93,5 EUR/MWh
- Phelix Peak-load Year Future 2013 (10th July, 2008)=138,5 EUR/MWh
- Exchange rate (10th July 2008, Czech National Bank)= 23,465 CZK/EUR
- ARA[54] Coal Year Future 2013 (10th July, 2008)=200 USD/tonne
- Average hard coal conversion rate[55] = 27 GJ/tonne
- Unit hard coal consumption[56] = 8 GJ/MWh
- Exchange rate (10th July 2008, Czech National Bank)= 14,938 CZK/USD

---

[52] The depreciation and taxes were not taken into account.

[53] E.ON Gas Trading

[54] Amsterdam-Rotterdam-Antwerp

[55] BP Historical Data 1861 - 2007

[56] EGÚ(2005)

The hard coal conversion from USD/tonne is expressed as follows:

ARA Coal Year Future 2013 price*Unit hard coal consumption*Exchange rate/Average hard coal conversion rate=200*8*14,938/27=885,2148 CZK/MWh.

The electricity prices are used to compute an estimate of opportunity costs of the investors stemming from postponement of power plant construction. The estimate is of the annual opportunity costs per one MW of capacity installed is as follows:

t.a.hours per year per MW*electricity price* efficiency of the power plant.

The EGÚ (2005) estimates the CCGT netto efficiency as 54,2% and of PCB-C 45%.

- Price growth, relative prices

Figure 35 depictures the past average annual fuel price growths. The coal and gas prices more or less follow the price development as oil. In the model I am using 10%, 15% and 20% reference growths of prices.

Figure 35: Average past fuel growth

Type of growth	since 1984	since 1998	since 2000	since 2003	Average
Average growth of oil prices (%)	3,57%	14,26%	17,44%	20,54%	17,41%
Average growth of LNG prices (%)	6,37%	20,15%	17,30%	20,72%	19,39%
Average growth of UK gas prices (%)		19,00%	16,38%	20,60%	18,66%
Average growth of coal prices (%)	7,24%	11,56%	17,39%	25,73%	18,23%

Source: BP Historical Data 1861 - 2007

- The regulatory uncertainty

As I discussed above, one of the reasons why I decided to use the real option model to assess the EU ETS impacts is that despite the general awareness of the lack of new power generation capacities there is no construction boom. Investors seem to be rather reluctant to invest into new power plants also because of the constantly changing environmental legislation. In the EU the specific source of this regulatory uncertainty is the future development of the EU ETS. The aim of this simple binomial option-pricing model is to find out to what extent there is an option to postpone the power plant construction due to EU ETS and under what conditions (parameter values). Based on this analysis I would like to derive some conclusions related to the relationship between the current power market situation and the EU ETS regulation.

5.2 Procedure (based on Shockley, 2006)

In the numerical model the investor has every year (from July 10th, 2008 – see footnote 45) three options how to invest. Either she will invest into the CCGT power plant or into the PCB-C power plant or she will postpone the decision. In this model, the investor decides only based on costs of each of the projects.

The model is focused on testing of changes in the EUA prices, which is modeled with use of the Binomial-pricing model.

The costs of each power plant type are linked with the modeled EUA prices through the carbon intensity factor. The EUA costs of CCGT and PCB-C are shown in Figure 36. The difference is given by the carbon intensity ratio, which is – as discussed in 5.1 – 0,43 tonnes of CO_2 per MWh for CCGT and 0,9 tonnes of CO_2 per MWh for PCB-C.

The EUA costs are further merged with the M&O and fuel costs and with the Annuity and resulting cumulative costs are adjusted by the probabilities (q; 1-q) from the Binomial option-pricing model (see 5.1).

The result is a comparison table, where the probability-adjusted cumulative costs of each option are compared. This is a cost-minimization problem, so selected is always the minimum. An example of a final table depicturing Situation 1 (natural gas, electricity and coal price growth 15%) is Figure 39. The investor can wait until the year 2012 in order to obtain more information about the future development of EUA prices (the opportunity costs are lower than the actual costs of the power plant).

This numerical model is used here as an illustration that the time structure of the investment related to some factor with uncertain future development can provide a whole different picture than standard static methods (see Figure 37).

Analogously, the same model could be used to evaluate the option to terminate the production (provided that the investor has chosen a "wrong" option). In that case the model would take into account the costs of the power plant termination and the estimation of losses incurred through the "wrong" choice. The investor would compare the revenues from building the power plant now with costs of losses if the power plant will not be (due to EUA prices increase) profitable in the future.

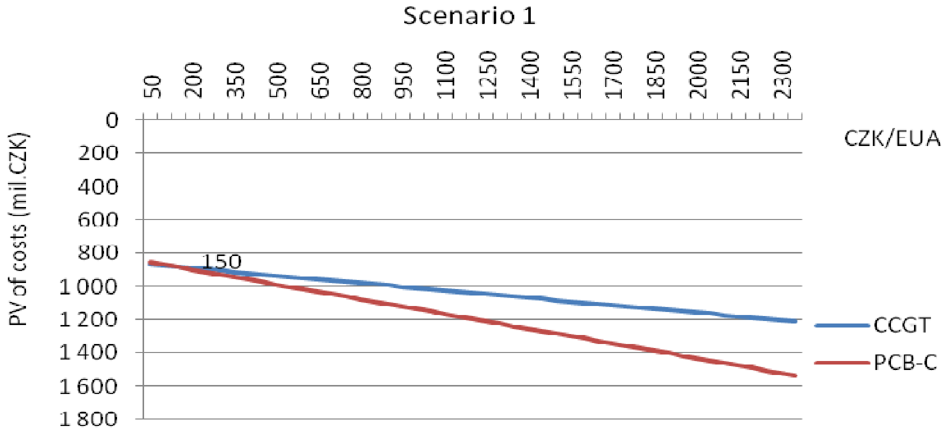
Figure 36: Costs of EUA modeled for the numerical model (σ=20%, no-grandfathering)

PCB-C	2013	2014	2015	2016	2017	2018	2019	2020	2021
	3 414 861	4 170 921	5 094 376	6 222 286	7 599 918	9 282 563	11 337 751	13 847 962	16 913 943
		2 795 852	3 414 862	4 170 923	5 094 378	6 222 289	7 599 922	9 282 568	11 337 756
			2 289 051	2 795 854	3 414 864	4 170 925	5 094 381	6 222 292	7 599 926
				1 874 117	2 289 052	2 795 855	3 414 866	4 170 927	5 094 383
					1 534 398	1 874 118	2 289 053	2 795 857	3 414 868
						1 256 259	1 534 398	1 874 119	2 289 054
							1 028 538	1 256 260	1 534 399
								842 096	1 028 539
									689 450

CCGT	2013	2014	2015	2016	2017	2018	2019	2020	2021
	1 701 468	2 078 178	2 538 293	3 100 279	3 786 690	4 625 074	5 649 079	6 899 802	8 427 439
		1 393 044	1 701 469	2 078 179	2 538 294	3 100 280	3 786 691	4 625 076	5 649 082
			1 140 529	1 393 045	1 701 470	2 078 180	2 538 295	3 100 282	3 786 693
				933 786	1 140 529	1 393 046	1 701 470	2 078 181	2 538 297
					764 520	933 787	1 140 530	1 393 047	1 701 471
						625 936	764 520	933 787	1 140 530
							512 473	625 936	764 521
								419 578	512 473
									343 521

Source: Author

Figure 37: Static analysis of the Scenario 1 (electricity, coal and natural gas price growth 15%)



Source: Author

Figure 38: Results of EUA price modeling with use of Binomial option-pricing model (σ=20%)

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	…	2038	2039	2040	2041	2042	2043
813,1	993,1	1212,9	1481,5	1809,5	2210,1	2699,5	3297,1	4027,1	4918,7	6007,8	7337,9	8962,5	10946,9	…	120669,7	147386,3	180018,1	219874,7	268555,6	328014,6
	665,7	813,1	993,1	1212,9	1481,5	1809,5	2210,1	2699,5	3297,1	4027,1	4918,8	6007,8	7337,9	…	80887,3	98796,0	120669,8	147386,4	180018,2	219874,8
		545,0	665,7	813,1	993,1	1212,9	1481,5	1809,5	2210,1	2699,5	3297,1	4027,1	4918,8	…	54220,4	66225,0	80887,4	98796,1	120669,8	147386,5
			446,2	545,0	665,7	813,1	993,1	1212,9	1481,5	1809,5	2210,1	2699,5	3297,1	…	36345,0	44391,9	54220,4	66225,0	80887,4	98796,1
				365,3	446,2	545,0	665,7	813,1	993,1	1212,9	1481,5	1809,5	2210,1	…	24362,8	29756,8	36345,0	44392,0	54220,5	66225,0
					299,1	365,3	446,2	545,0	665,7	813,1	993,1	1212,9	1481,5	…	16330,9	19946,6	24362,8	29756,8	36345,1	44392,0
						244,9	299,1	365,3	446,2	545,0	665,7	813,1	993,1	…	10946,9	13370,6	16330,9	19946,6	24362,8	29756,8
							200,5	244,9	299,1	365,3	446,2	545,0	665,7	…	7337,9	8962,6	10946,9	13370,6	16330,9	19946,6
								164,2	200,5	244,9	299,1	365,3	446,2	…	4918,8	6007,8	7337,9	8962,6	10946,9	13370,6
									134,4	164,2	200,5	244,9	299,1	…	3297,1	4027,1	4918,8	6007,8	7337,9	8962,6
										110,0	134,4	164,2	200,5	…	2210,1	2699,5	3297,2	4027,1	4918,8	6007,8
											90,1	110,0	134,4	…	1481,5	1809,5	2210,1	2699,5	3297,2	4027,2
												73,8	90,1	…	993,1	1213,0	1481,5	1809,5	2210,1	2699,5
													60,4	…	665,7	813,1	993,1	1213,0	1481,5	1809,5
														…	446,2	545,0	665,7	813,1	993,1	1213,0
															299,1	365,3	446,2	545,0	665,7	813,1
															200,5	244,9	299,1	365,3	446,2	545,0
															134,4	164,2	200,5	244,9	299,1	365,3
															90,1	110,0	134,4	164,2	200,5	244,9
															60,4	73,8	90,1	110,0	134,4	164,2
															40,5	49,4	60,4	73,8	90,1	110,0
															27,1	33,1	40,5	49,4	60,4	73,8
															18,2	22,2	27,1	33,1	40,5	49,4
															12,2	14,9	18,2	22,2	27,1	33,1
															8,2	10,0	12,2	14,9	18,2	22,2
															5,5	6,7	8,2	10,0	12,2	14,9
																4,5	5,5	6,7	8,2	10,0
																	3,7	4,5	5,5	6,7
																		3,0	3,7	4,5
																			2,5	3,0
																				2,0

Source: Author; EUA price 2013 (ECX, 10th July.2008)

Figure 39: Example of final comparison table – Situation 1 (electricity, coal and natural gas price growth 15%)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	...	2038	2039	2040	2041	2042	2043
CCGT	4 607 353	9 653 501	15 180 235	21 233 324	23 942 666	25 809 847	27 915 248	30 302 668	33 025 140	36 146 958	39 746 142	43 917 450	48 776 059	54 462 050	...	309 877 131	368 704 823	440 054 723	526 672 858	631 911 707	759 864 354
PCB-C		9 653 501	15 180 235	21 233 324	22 692 022	24 282 412	26 049 765	28 024 318	30 242 549	32 748 528	35 595 577	38 848 289	42 584 998	46 900 793	...	226 597 064	266 993 338	315 832 609	374 958 096	446 619 666	533 563 763
Do-nothing			15 180 235	19 992 374	21 491 293	23 172 092	24 799 293	26 497 094	28 377 323	30 470 493	32 813 370	35 450 328	38 435 006	41 832 331	...	170 772 759	198 814 084	232 564 027	273 260 639	322 414 684	381 869 925
				19 075 321	20 370 991	21 803 493	23 395 449	25 174 096	27 127 024	28 943 480	30 948 400	33 172 606	35 653 183	38 434 838	...	133 352 605	153 112 159	176 747 421	205 090 788	239 157 586	280 186 493
					19 620 029	20 886 094	22 274 724	23 804 980	25 499 733	27 386 488	29 498 382	31 645 804	33 788 470	36 157 431	...	108 269 123	122 477 239	139 332 428	159 395 166	183 348 679	212 026 044
						20 271 143	21 523 479	22 887 234	24 378 584	26 016 854	27 825 192	29 831 394	32 068 909	34 578 067	...	91 455 160	101 942 036	114 252 405	128 764 471	145 938 845	166 336 724
							21 019 904	22 272 050	23 627 055	25 098 761	26 703 619	28 461 243	30 395 087	32 533 269	...	80 184 423	88 176 877	97 440 762	108 232 100	120 862 282	135 710 253
								21 859 680	23 123 290	24 483 345	25 951 806	27 542 803	29 273 090	31 162 600	...	72 629 421	78 949 813	86 171 579	94 468 839	104 052 956	115 180 714
									22 785 607	24 070 819	25 447 851	26 927 154	28 520 993	30 243 813	...	67 565 151	72 764 727	78 617 619	85 243 048	92 785 328	101 419 351
										23 794 295	25 110 039	26 514 473	28 016 847	29 627 932	...	64 170 469	68 618 739	73 554 047	79 058 815	85 232 409	92 194 832
											24 883 598	26 237 844	27 678 908	29 215 094	...	60 977 741	65 684 053	70 159 834	74 913 399	80 169 536	86 011 452
												26 052 414	27 452 381	28 938 361	...	57 920 337	61 949 026	66 418 991	71 404 879	76 775 791	81 866 608
													27 300 535	28 752 861	...	55 870 898	59 445 363	63 360 432	67 668 441	72 432 135	77 726 921
														28 628 516	...	54 497 118	57 767 106	61 310 218	65 163 831	69 372 420	73 989 071
															...	53 576 245	56 642 138	59 935 919	63 484 940	67 321 431	71 483 514
																52 958 966	55 888 049	59 014 698	62 359 546	65 946 612	69 803 989
																52 545 191	55 382 567	58 397 185	61 605 172	65 025 044	68 678 170
																52 267 829	55 043 733	57 983 254	61 099 500	64 407 297	67 923 510
																52 081 908	54 816 606	57 705 788	60 760 538	63 993 210	67 417 647
																51 957 282	54 664 358	57 519 796	60 533 325	63 715 639	67 078 557
																51 873 742	54 562 303	57 395 123	60 381 019	63 529 577	66 851 258
																51 817 744	54 493 893	57 311 551	60 278 925	63 404 856	66 698 894
																51 780 207	54 448 037	57 255 532	60 210 490	63 321 253	66 596 762
																51 755 045	54 417 299	57 217 981	60 164 617	63 265 212	66 528 301
																51 738 179	54 396 694	57 192 809	60 133 867	63 227 647	66 482 410
																51 726 873	54 382 883	57 175 937	60 113 254	63 202 467	66 451 649
																	54 373 624	57 164 627	60 099 437	63 185 587	66 431 029
																		57 157 045	60 090 176	63 174 273	66 417 206
																			60 083 967	63 166 689	66 407 941
																				63 161 605	66 401 731
																					66 397 567

Source: Author

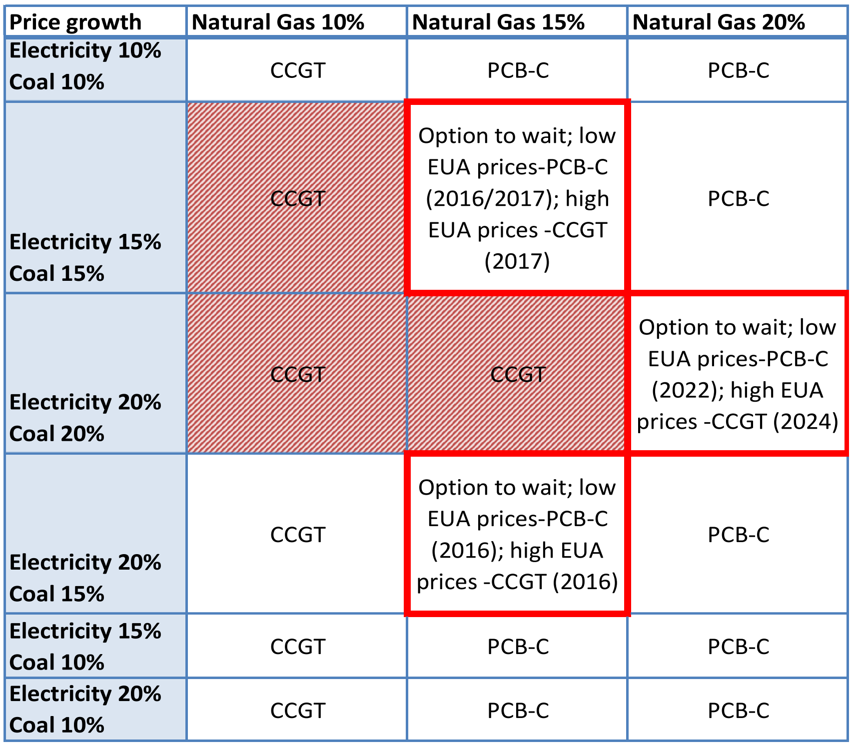
5.3 Results

I have analyzed a set of potential combinations of natural gas, electricity and coal prices under different operation modes, volatilities and EU ETS Phase III.+ structures. In the Situations 1-4 below I provide summary of the results in tables, sample Excel tables of the model are listed in 5.2 above.

Situation 1:

- base-load operation mode for both power plants
- no-grandfathering (100% EUA to be purchased)
- 20% volatility

Figure 40: Situation 1 – matrix of results



Price growth	Natural Gas 10%	Natural Gas 15%	Natural Gas 20%
Electricity 10% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 15% Coal 15%	CCGT	Option to wait; low EUA prices-PCB-C (2016/2017); high EUA prices -CCGT (2017)	PCB-C
Electricity 20% Coal 20%	CCGT	CCGT	Option to wait; low EUA prices-PCB-C (2022); high EUA prices -CCGT (2024)
Electricity 20% Coal 15%	CCGT	Option to wait; low EUA prices-PCB-C (2016); high EUA prices -CCGT (2016)	PCB-C
Electricity 15% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 20% Coal 10%	CCGT	PCB-C	PCB-C

Source: Author

The results of Situation 1 are summarized in the matrix of results in Figure 40. The option to postpone the investment decision appears only, when the growth of prices of natural gas and of coal follow the same trend. As was discussed in the section concerning differences between power plants (Figure 28), CCGT and PCB-C differ in the composition of costs. Whereas CCGT has larger share of fuel costs on the total present value of costs of the plant, PCB-C has larger share of the EUA costs on the present value of total costs of the plant. If the relative gap between the fuel prices does not change, the only factor that could lead to a switch in cost-effectiveness between these two types of power plants are the costs of EUA. The growth in the prices of both fuels has to be a substantial one; otherwise the CCGT will become due to its low initial costs less costly than the PCB-C regardless on the EUA costs (see natural gas 10%, coal 10%, and electricity 10% in Figure 40). In case of the options, the higher is the growth of electricity the higher get the opportunity costs of the option (the costs of postponement of the investment decision), even though the difference in case of option to wait with 20% and 15% electricity growth (natural gas 15%, coal 15%) is not that substantial (one year change).

The option to postpone the investment decision is, however, not present in cases when the relative prices of coal and natural gas change. If natural gas becomes more expensive than coal, the preferred investment choice will be the PCB-C. There are 8 cases in Situation 1 under which the PCB-C is the preferred option, whereas there are only 7 cases, where CCGT is the preferred alternative, from which I consider three cases as highly improbable situations (the red-shaded cells). Figure 35, however, shows that it is possible for coal prices to grow more steeply than the natural gas prices. Completely implausible combinations were excluded from the matrix of results. Herewith I mean any combination, where the growth of electricity prices is lower than the growth of prices of both fuels[57].

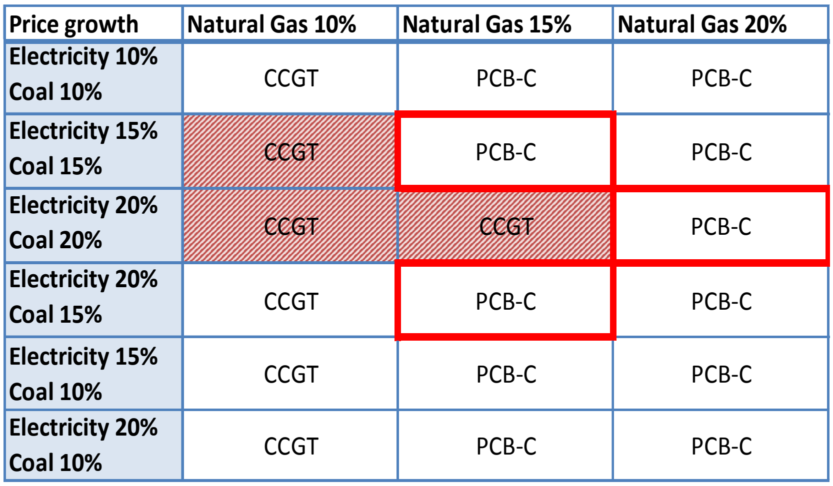
<u>Situation 2:</u>

- base-load operation mode for both power plants
- 50%-grandfathering (50% EUA to be purchased)
- 20% volatility

---

[57] The price of electricity is dominantly formed by prices of fossil fuels. Besides it includes margin and other costs related to the electricity generation, transmission, distribution etc. It is a common sense assumption that in long-run the electricity cannot grow more slowly than the prices of fuels for its production.

Figure 41: Situation 2 - matrix of results



Price growth	Natural Gas 10%	Natural Gas 15%	Natural Gas 20%
Electricity 10% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 15% Coal 15%	CCGT	PCB-C	PCB-C
Electricity 20% Coal 20%	CCGT	CCGT	PCB-C
Electricity 20% Coal 15%	CCGT	PCB-C	PCB-C
Electricity 15% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 20% Coal 10%	CCGT	PCB-C	PCB-C

Source: Author

Situation 2 drafts the situation, when in Phase III.+ half of the required EUA would be grandfathered and the remaining 50% would have to be purchased. In such case there is no option to wait (the option ceases to exist when less than approx. 66%EUA has to be purchased[58]; the lower is the non-grandfathered EUA share, the more preferred are the PCB-C) and the PCB-C plant is preferred in 11 cases. Again, the higher is the electricity price growth the faster increase the opportunity costs and the sooner has the investor the incentives to build the power plant.

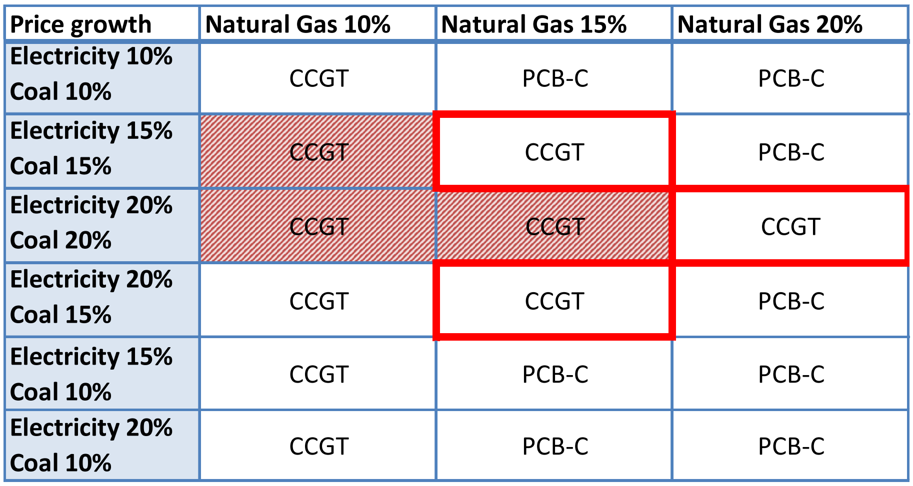
Situation 3:

- peak-load operation mode CCGT, base-load operation mode PCB-C
- no-grandfathering (100% EUA to be purchased)
- 20% volatility

---

[58] Therefore the matrix of results would be the same for 80% grandfathering (20% EUA target).

Figure 42: Situation 3 – matrix of results



Price growth	Natural Gas 10%	Natural Gas 15%	Natural Gas 20%
Electricity 10% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 15% Coal 15%	CCGT	CCGT	PCB-C
Electricity 20% Coal 20%	CCGT	CCGT	CCGT
Electricity 20% Coal 15%	CCGT	CCGT	PCB-C
Electricity 15% Coal 10%	CCGT	PCB-C	PCB-C
Electricity 20% Coal 10%	CCGT	PCB-C	PCB-C

Source: Author

The results of Situation 3 support what was already discussed above in the power plants section of this thesis – CCGT is currently advantageous only as a peak plant that is switched on only in case of high demand. The introduction of more stringent targets on the emission reduction within the EU ETS will only intensify this state of affairs – CCGT is a more preferred alternative in 10 cases, PCB-C in 8 cases. It is important to notice – in relation to Figure 32 that the options in Figure 40 describe exactly the situation circled in the picture – conditions, when EU ETS would cause a switch between CCGT and PCB-C and under high EUA prices, CCGT may become cost-efficient even as a base-load source.

Also in this case, the relative change of the fuel prices has more significant impact on the investment decision than the EUA prices.

Situation 4:

- peak-load operation mode CCGT, base-load operation mode PCB-C
- 50%-grandfathering (50% EUA to be purchased)
- 20% volatility

The Situation 4 matrix of results does not differ from the Situation 4 as depictured in Figure 42. The EU ETS does not have any significant impact on the relative costs of CCGT and PCB-C under their standard operation modes. The only important factor that could influence the investment decision in Situation 4 identified by this model is the change of the price gap (relative prices) of the fuels.

Situations 1-4 volatility:

The change in volatility does not cause any changes in the matrix of results as presented above, but rather prolongs the option to wait if the EUA prices are maximal. In case of 20% volatility as drafted in Situation 1 the CCGT becomes appealing for investors first in the year 2016 if the EUA prices are high. When the volatility increases to 50% the first year when CCGT starts to be an investment opportunity is also the year 2016, but only if the EUA prices are high, but not maximal. High volatility raises the upper EUA price and in that case the best option is not invest at all.

The causes of increased volatility can be multiple. In case of the EU ETS I have already discussed in this thesis the regulatory drivers of uncertainty. It is important to notice that the volatility can affect both market prices as well as the price expectations. Contradictory information from the regulator can lead to a state of affairs, when the price expectations of two market participants in roughly the same situation can be completely different. This can happen only when the market is not providing sufficient price signals (either due to low liquidity or due to some structural break – such as is the decision about the structure of the next EU ETS phase etc.).

5.4 Conclusions

There are three main conclusions that can be drawn from the demonstration of the numerical application of the real option model. Firstly, it shows the option to wait under the given set of assumptions. Provided that the coal and natural gas prices keep the same relative distance from each other (same relative prices), the EUA price will be the crucial factor influencing the costs of the base-load[59] power plants. In such a case (provided that the growth of fuel prices is high enough[60]) the model discovered that there is an option to postpone the investment decision and wait on more information on the EUA prices. In case of different relative price growths of the fuels, the EUA prices are not in this model the key investment decision driver. The relative increase of one fuel compared to the other outweighs the impact of EUA prices in favor of one of the power plant types.

Secondly, the comparison of Situation 1 and 2 depictures that the EU ETS is a source of multiple uncertainty. Not only the price development, but also the uncertainty related to the structure and principles of the EU ETS influence the outcome of the investment decision-making in the power sector. In this binomial option-pricing model this multiple uncertainty is expressed in form of scenarios (Situations), in the continuous real option models described in this thesis, some of the sources of uncertainty can be incorporated into the option pricing model (rainbow option). The structure of the EU ETS in Phase III.+ has a substantial impact on the investment decision-making only in case that more than 65% of EUA will have to be purchased by the power generator (this is given from the assumptions set in 5.1). Still it should be noticed that even under the no-grandfathering alternative the relative changes in fuel prices outweigh the EUA prices.

This leads me to my third and more general conclusion derived from the model. Even in Situation 1 the PCB-C is a slightly preferred variant. In case that in Phase III.+ some high enough part of the EUA will be grandfathered to power generators, the PCB-C will still keep being the preferred base-load variant[61]. Each day of postponement of the PCB-C construction means substantial opportunity costs for the investor. According to the recent statements of some of the EU Member States, there

---

[59] Further in the concluding part I will discuss only the base-load Situations described in the model. Situations 3 and 4 demonstrated that in case of base-load (PCB-C) and peak-load (CCGT) the CCGT is and will be more convenient source of energy regardless on the EU ETS.

[60] In this particular example the growth of gas and coal prices has to be higher than approx. 13,3%, otherwise the CCGT is cheaper in absolute terms.

[61] Apart from nuclear power plants that are not discussed in this model – see 4.3.

are 40 new coal-fired power plants in Europe in the stage of planning (Murphy 2008, EurActiv 2008b). One of the reasons, why they are not already under construction and why there are only 40 planned coal-fired power plants might be again the regulatory uncertainty (now, for instance the cause could be the discussed obligation to install the carbon capture and storage technologies (CCS[62] – for more see EurActiv, 2008b).

The aim of the EU ETS is to shift the production of electricity to "cleaner" technologies and to the use of cleaner fuels. The possibility to achieve this aim is, however, limited both technologically (high initial investment costs of carbon-clean technologies such as is the CCS) and geopolitically (natural gas – generally perceived as "clean" fuel is imported – increasing thus the EU dependency on other countries). Some investors hence analyzed that even under the EU ETS a PCB-C can still be the best option. The EC as a regulator has now two options. Either it can follow the set path, try to make the EU ETS work as it is, gather data and carefully and transparently prepare necessary changes to the EU ETS system or to come up with some quick upgrade of the EU ETS regulatory framework that would make the PCB-C unprofitable.

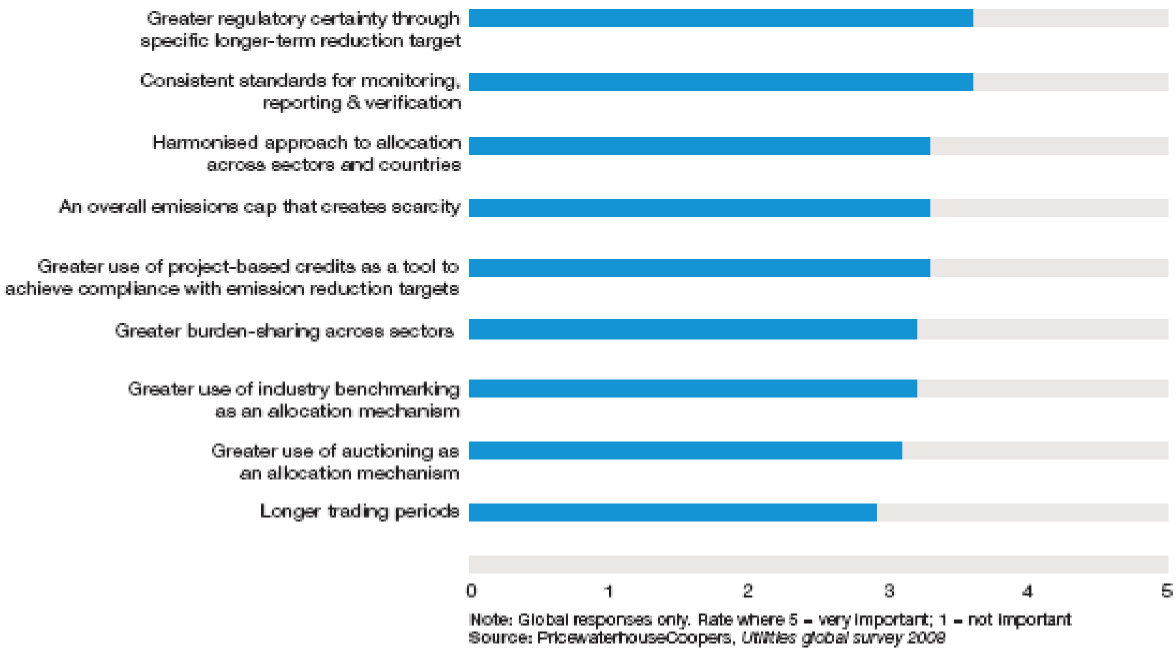
The second approach resembles the standard command-and-control mechanism, because the uncertainty resulting from this approach again raises the costs of investment and thus such regulatory decision effectively means a ban of power generation from coal. The first mentioned approach is in my opinion a way, how to decrease the impacts of new regulation on the regulatory uncertainty and decrease thus the distortive effects on the carbon markets. Part of it should be also an accurate analysis of policy options and their impacts based on consultation with stakeholders of the regulation (IA), which would enable all interested parties to form continuously adjust their expectations regarding the future development of the market.

---

[62] CCS is a technology that is able to separate carbon dioxide from the gases emitted by power plants. The separated carbon dioxide is later in the process compressed and transported to some storage space in some on-shore or off-shore location.

The EU ETS has undergone a fast and turbulent development since its launch in January 2008. So far, its results are ambiguous. On one hand, the global carbon markets is increasing both in terms of liquidity and traded volumes, on the other hand, the carbon regulations has distortive impacts on long-term planning. My opinion is, based on some of the results of this thesis that what the carbon market needs now is to stabilize (and Figure 43 shows that my opinion is shared in the power generation sector globally). Fast adoption of new regulations that would make the investors to adopt the "right" kind of power generation technology by imposing on them restrictions and further obligations will probably in the current situation cause more harm than good.

Figure 43: Which of the following attributes do you see as important in cap-and-trade schemes to address carbon emissions?



Note: Global responses only. Rate where 5 = very important; 1 = not important
Source: PricewaterhouseCoopers, *Utilities global survey 2008*

Source: PWC Utilities Global Survey 2008

6 Stochastic real option models of generation assets

6.1 Valuing the decision to invest

Although the use of real option models goes beyond the borders of the economic theory, they are still most widely used for evaluation of investments. As I already mentioned in 4.1, there several criteria under which the real option model can have better explanatory power than the standard valuation tools. Among the criteria belong the proportion of irreversible costs on the total value of the investment, the length of the pay-back time of the investment and significant uncertainty about the future development of factors that determine the costs or revenues of the investment.

In Chapter 4.2 of this thesis I mentioned that an investment into new power plant is a textbook case, where the real option model is applied and quoted some of the literature on investment valuation by real option in the power generation sector.

Because part of this thesis is also to provide some insight into the models used for assessment of uncertainty, I would like to provide in this chapter an example of a continuous-time stochastic real option model and its potential extensions and use for assessment of the EU ETS. A model that is often quoted in literature in relation to valuation of power generation assets is the spark spread option model described in this chapter. I will provide a summary of the spark spread option model as described in Deng, Johnson, Sogomonian (1999) with an insight into the key steps of computation of the PDE that I modified from Merton (1973).

6.2 Basic Spark Spread Option Model (Deng, Johnson, Sogomonian, 1999)

The spark spread option model is based on the idea that to power generators what matters most is the spread between fuel costs (or costs in general) and the price of electricity. The value of the spread might be denoted as follows:

(1) $\vartheta = S_E - K_H S_F$

where S_E is the spot price of one MWh of electricity, S_F is the spot prices of fuel[63] quantity that could be converted into one MWh of electricity and K_H is the heat rate of the power generation asset (a coefficient that stands for the technological parameters of the boiler that is transforming the fuel into electricity).

The initial assumptions of the spark spread model are following:

- the markets, where electricity and the fuel are traded, work efficiently (no windfall profits etc.) and are deregulated
- there are no transaction costs or differential costs
- trading takes place continuously
- only assets with positive spark spread are operated (this assumption follows from the previous one)
- a complete set of financial instruments is traded in the market (in order to create the replicating portfolio), there are no restrictions on buying and short-selling
- the rate for borrowing and lending is the same
- the option to the project behaves as European-style option written on the spread between price of electricity and of specific fuel (F) at a fixed heat rate K_H

A European-style spark spread call option gives to its holder the right (not the obligation) to pay K_H times the unit price of the fuel F at the option's maturity time (T) and receive the price of one unit of electricity. The pay-off of the option at maturity date is:

(2) $C(S^T_E, S^T_F, T)=\max(S^T_E - K_H S^T_F, 0)$

Analogously, the European-style spark spread put option gives to its holder the right (not the obligation) to pay for one MWh of electricity and receive K_H –times the price of the fuel at maturity time T.

---

[63] I am using a general notation "fuel F", but the Deng, Johnson, Sogomonian (1994) spark spread option model was design to assess the option value of new gas-fired power plants build in the US.

(3) $P(S^T_E, S^T_F, T)=\max(K_H S^T_F - S^T_E, 0)$

The put- call parity can be expressed as:

(4) $C - P= \max(S^T_E - K_H S^T_F, 0) - \max(K_H S^T_F - S^T_E, 0)$

Assuming that

- the risk-free rate (r) is constant
- future spot price of electricity and the future spot prices of fuels at time t discounted by the discount factor e^{-rt} equal to futures prices of electricity and futures prices of fuels, F^t_E and F^t_F, respectively

(5) $F^t_E = e^{-rt} S^t_E$

(6) $F^t_F = e^{-rt} S^t_F$

(7) $C=e^{-rt}\max(F^t_E - K_H F^t_F)$

(8) $P= e^{-rt}\max(K_H F^t_F - F^t_E)$

The put-call parity can be expressed in a following way:

(9) $C_1=P_1+e^{-rt}(F^t_E - K_H F^t_F)$

From (4), (7) and (8) can be derived the lower and upper bounds of the European spark spread call option. F^t_E and F^t_G are the future prices of the electricity and of the fuel F, respectively. The value of a spark spread call option C has then both lower and upper boundary that are given as:

(10) $e^{-rt}\max(F^t_E - K_H F^t_F, 0) \leq C_1 \leq e^{-rt} F^t_E$

In order to estimate the uncertainty about the future development of prices the variables are in stochastic real option models described with use of continuous-time stochastic processes (Dixit, Pindyck, 1994). The simplest continuous-time stochastic process is the Brownian motion (Wiener) process, which I will use for description of the Spark spread option model. Later in this chapter I will describe the potential use of other stochastic processes.

The Brownian motion process B(t) has following properties (Dixit, Pindyck, 1994):

- it is a Markov process – the probability of distribution of all future values depends only on the current value and is unaffected by past values of the process
- it has independent increments (dB(t)) – meaning that the probability distribution for the change of the process in the time is independent of any other non-overlapping time interval
- changes in the process over a finite time interval are normally distributed (in case of prices - and other variables that cannot fall below zero - we would assume that the logarithms of the price are normally distributed) with a variance that increases linearly with the time interval

(11) $dB = \varepsilon_t\sqrt{dt}$; $E(dB)=0$; $var(dB)=dt$; if $\Delta t \to 0$ then $\Delta B \sim N(0, 1)$

Let us assume that:

- the price processes of electricity and fuel futures (denoted as F^t_e and F^t_f) follow the geometric Brownian motion process

(12) $\frac{dF_e}{F_e} = \mu_e dt + \sigma_e dB^e$

(13) $\frac{dF_f}{F_f} = \mu_f dt + \sigma_f dB^f$

where $E[(dB^{e,f})^2]=dt$; $E[dB^e dB^f]=\rho dt$

B^1 and B^2 are the Brownian motion processes (dB are the increments of the Wiener process) with instantaneous correlation ρ. In this model, the coefficients μ_e, μ_f (growth parameters), σ_e, σ_f (proportional variance parameters) are assumed to be constant (whereas in the model with the mean-reverting process they will be functions of time).

The value of the spark spread call option, which matures at time T, is denoted as

(14) $V(x,y,t)\equiv Ce^{-rt}(F_e^{t,T}, F_f^{t,T}, T\text{-}t)$

$F_e^{t,T}$ and $F_g^{t,T}$ are the commodity futures prices at time t with maturity date T.

Based on Merton (1973) the following steps has to be made in order to obtain the partial differential equation (PDE) suggested in Deng, Johnson, Sogomonian (1999):

(15) $\frac{dx}{x} = \mu_x dt + \sigma_x dB^x$ (equation 12 in simple notation 14)

(16) $\frac{dy}{y} = \mu_y dt + \sigma_y dB^y$

$\mu_{x,y}$ are instantaneous expected returns and $\sigma_{x,y}$ are instantaneous variances of the expected returns.

- assumed is no serial correlation

$$dB^y(s,\tau)dB^y(t,\tau) = 0; s \neq t$$

(17) $$dB^y(s,\tau)dB^x(t,\tau) = 0; s \neq t$$

- correlation between future prices with different maturity is possible

(18) $dB\ (t,\tau)dB\ (t,T) = \rho_{\tau,T}dt$

- instantaneous correlation between x and y

(19) $corr(x,y) = \rho$

We assume that the option price function V (14):

- has second derivation in x, y and first derivation in t

Then we can apply Ito’s Lemma (Fundamental Theorem of Stochastic Calculus[64] and derive the option price function V(14):

(20) $dV = \frac{\partial V}{\partial t}dt + \frac{\partial V}{\partial x}dx + \frac{\partial V}{\partial y}dy + \frac{1}{2}\frac{\partial^2 V}{\partial^2 x}dx^2 + \frac{1}{2}\frac{\partial^2 V}{\partial^2 y}dy^2 + \frac{\partial^2 V}{\partial x \partial y}dxdy$

---

[64] Ito’s Lemma (Fundamental Theorem of Stochastic Calculus) expresses, how the value of an option reflects the underlying stochastic processes (for more detail see Dixit, Pindyck, 1994, page 80)

from (15) and (16) we compute dx^2 and dy^2 and substitute into (20):

(21) $$dx^2 = \sigma_x^2 x^2 dt + 2\mu_x \sigma_x dt^{\frac{2}{3}} + \mu_x^2 x^2 dt^2$$

(22) $$dy^2 = \sigma_y^2 y^2 dt + 2\mu_y \sigma_y dt^{\frac{2}{3}} + \mu_y^2 y^2 dt^2$$

if dt→0 then $dt^{2/3}$ and dt^2 go to zero faster than dt and could be ignored[65]

(23) $$dV = V_x dx + V_y dy + V_t dt + 1/2(V_{xx}\sigma_x^2 x^2 dt + 2\rho\sigma_x\sigma_y V_{xy} xydt + V_{yy}\sigma_y^2 y^2 dt)$$

when dx and dy from (15) and (16) is substituted to (23) we obtain:

(24) $$dV = V_x(\mu_x dt + \sigma_x dB^x) + V_y(\mu_y dt + \sigma_y dB^y) + V_t dt + 1/2(V_{xx}\sigma_x^2 x^2 dt + 2\rho\sigma_x\sigma_y xyV_{xy} + V_{yy}\sigma_y^2 y^2 dt)$$

This equation can be simplified if we replace some parts of the expression as follows:

(25) $$dV = \beta V dt + \gamma V dB^x + \eta V dB^y$$

where

(26) $$\beta = \frac{1}{V}(\frac{1}{2}V_{xx}\sigma_x^2 x^2 + \rho\sigma_x\sigma_y xyV_{xy} + \frac{1}{2}V_{yy}\sigma_y^2 y^2 + \mu_x xV_x + \mu_y yV_y - V_y)$$

(27) $$\eta = \sigma_y y V_y \frac{1}{V}$$

(28) $$\gamma = \sigma_x x V_x \frac{1}{V}$$

The elements of the replicating portfolio (used for the option-pricing) could be described as a combination of W_1, W_2 and W_3. Where W_1 denotes the amount of money invested into the electricity futures; W_2 the amount of money invested in the option and W_3 the amount of money invested into the fuel futures. The R denotes the return of the portfolio, dR denotes the instantaneous return to the portfolio and the condition of zero aggregate investment is expressed as:

(29) $$W_1+W_2+W_3=0$$

(30) $$dR = W_1\frac{dx}{x} + W_2\frac{dV}{V} + W_3\frac{dy}{y}$$

Into (30) we substitute for dx/x, dV/V and dy/y

(31) $$W_3= -W_1- W_2$$

---

[65] from now on I will use the simpler notation, where V_x is $\frac{\partial V}{\partial x}$, V_{xx} is $\frac{\partial^2 V}{\partial^2 x}$ etc.

(32) $$dR = \left[W_1(\mu_x - \mu_y) + W_2(\beta - \mu_y)\right]dt + \left[W_1\sigma_x + W_2\gamma\right]dB^x + \left[\eta W_2 - (W_1 + W_2)\sigma_y\right]dB^y$$

The coefficients W1 and W2 can be set in such a way that the resulting dR will be non-stochastic

(33) $$W_1^{'}\sigma_x + W_2^{'}\gamma = 0; \qquad -\sigma_y W_1^{'} + (\eta - \sigma_y)W_2^{'} = 0$$

together with the equilibrium condition

$$(\mu_x - \mu_y)W_1^{'} + (\beta - \mu_y)W_2^{'} = 0$$

A non-trivial solution of the 3*2 linear system exists if and only if

(34) $$\frac{\beta - \mu_y}{\mu_x - \mu_y} = \frac{\gamma}{\sigma_x} = \frac{\sigma_y - \eta}{\sigma_y}$$

From the non-trivial solution and from the definitions of γ, η, β follows:

(35) $$\frac{\gamma}{\sigma_x} = 1 - \frac{\eta}{\sigma_y}$$

(36) $$\frac{\gamma}{\sigma_x} = \sigma_x x V_x \frac{1}{V}\frac{1}{\sigma_x} = 1 - \frac{\eta}{\sigma_y}$$

(37) $$xV_x\frac{1}{V} = 1 - \frac{\sigma_y y V_y}{V\sigma_y}$$

(38) $$\frac{xV_x}{V} = 1 - \frac{yV_y}{V}$$

(39) $$\beta - \mu_y = \frac{\gamma(\mu_x - \mu_y)}{\sigma_y}$$

(40) $$\frac{1}{V}\left(\frac{1}{2}V_{xx}\sigma_x^2 x^2 + \rho\sigma_x\sigma_y xyV_{xy} + \frac{1}{2}V_{yy}\sigma_y^2 y^2 + \mu_x xV_x + \mu_y yV_y - V_t\right) - \mu_y = \frac{xV_x}{V}(\mu_x - \mu_y)$$

(41) $$\underline{\underline{\frac{1}{2}V_{xx}\sigma_x^2 x^2 + \rho\sigma_x\sigma_y xyV_{xy} + \frac{1}{2}V_{yy}\sigma_y^2 y^2 - V_t = 0}}$$

The equation (41) is the linear second-order partial differential equation of the parabolic type used for European-style spark spread valuation.

The draft of crucial steps of solution of the PDE (41) is again based on Merton (1973) and modified in order to obtain the solution in Deng, Johnson, Sogomonian (1999).

The boundary conditions of a European call option with price V are

(42) $V(0,y,t)=0$
(43) $V(x,0,t)=x$
(44) $V(x,y,0)=\max(x-y,0)$

We define an auxiliary variable z,

(45) $z(t)=x/y$

dz(t)/z is defined by (15) and (16) and if applied the same procedure with Ito's Lemma, we obtain

(46) $\frac{dz}{z} = \left(\mu_x - \mu_y + \sigma_y^2 - \rho\sigma_x\sigma_y\right)dt + \sigma_x B^x - \sigma_y B^y$

we define the instantaneous variance of return on z(t) as

(47) $var\ (z) = \sigma_x^2 + \sigma_y^2 - 2\rho\sigma_x\sigma_y$

and new variable v(z,t) independent from y and

(48) $v(z,t)=V(x,y)/y$

if v and var(z) are substituted into (41), (42), (43) and (44) and assuming the homogeneity of v, we will get

(49) $\frac{1}{2}z^2\left(\sigma_x^2 + \sigma_y^2 - 2\rho\sigma_x\sigma_y\right)v_{xx} - v_y = \frac{1}{2}z^2 var(z) v_{xx} - v_y$

The modified boundary conditions for v are

(50) $v(0,t)=0$
(51) $v(x,0)=\max(0, x-1)$

- V is homogenous degree 0 in x,y (see Merton, 1973, 166) and $\tau=var(z)(T-t)$

and insert it into (49), we obtain

(52) $\frac{1}{2}z^2 v_{xx}\tau - v_y = 0$

To solve the equation we further introduce the change-of-variable transformation:

(53) $Z=\ln(z)+(T-t)/2$
(54) $\varphi(Z,\tau)=v\tau/z$

the problem will transform to a form that could be according to Merton (1973, page 167) solved by separation of variables or Fourier transformation and result in the solution of the Black-Scholes PDE:

(55) $V(x,y,\tau)=x\Phi(v_1) - ye^{-rt}\Phi(v_2)$

- Φ is a standard normal cumulative distribution function

$$\Phi_{0,1}(x)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}\exp(-\frac{u^{2}}{2})du \tag{56}$$

and v_1 and v_2 equal to

$$\begin{aligned} v_1 &= \frac{\ln(x/y)+(\sigma_x^2-2\sigma_x\sigma_y\rho+\sigma_y^2)(T-t)/2}{\sqrt{(\sigma_x{}^2-2\sigma_x\sigma_y\rho+\sigma_y^2)(T-t)}} \\ v_2 &= v_1-\sqrt{(\sigma_x^2-2\sigma_x\sigma_y\rho+\sigma_y^2)(T-t)} \end{aligned} \tag{57}$$

If we substitute for V(x,y,t) the original $C=e^{-rt}(F_e^{t,T}, F_f^{t,T}, T-t)$, the result will be the closed form solution of the Black-Scholes partial differential equation – the value of the spark spread European call option (as suggested in Deng, Johnson, Sogomonian, 1999):

$$C(F_e^{t,T},F_f^{t,T},T-t)=e^{-r(T-t)}(F_e^{t,T}\Phi(v_1)-K_H F_f^{t,T}\,\Phi(v_2)) \tag{58}$$

where v_1 and v_2 equal to

$$\begin{aligned} v_1 &= \frac{\ln(F_e^{t,T}/K_H F_f^{t,T})+(\sigma_e^2-2\sigma_e\sigma_f\rho+\sigma_f^2)(T-t)/2}{\sqrt{(\sigma_e{}^2-2\sigma_e\sigma_f\rho+\sigma_f^2)(T-t)}} \\ v_2 &= v_1-\sqrt{(\sigma_e^2-2\sigma_e\sigma_f\rho+\sigma_f^2)(T-t)} \end{aligned} \tag{59}$$

Deng, Johnson, Sogomonian (1999) uses the above spark spread call European option value (58) for valuation of the power generation assets. In order to be able to do that they impose on the model several assumptions:

- considered is only an investment into new power plant
- operational and maintenance costs are assumed to be stable over time
- assumed is that the prices of fuel G and electricity follow the Wiener (mean-reverting, mean-reverting with Poisson jumps) process
- no depreciation of the power plant

Then value V of one unit of capacity of power plant with useful life T has both lower and upper bound (this follows from the definition of the spark spread European call option and from the no arbitrage condition):

$$\int_0^T e^{-rt} \max(F_e^t - K_H F_f^t, 0)dt \leq V \leq \int_0^T e^{-rt} F_e^t dt \tag{60}$$

The estimated value of the power generation asset on a competitive market can be expressed as follows:

$$\underline{\underline{\mathrm{Y} = \int_0^T C(t)dt = \int_0^T e^{-rt}\left[F_e^t \Phi(v_1) - K_H F_f^t \Phi(v_2)\right]dt}} \tag{61}$$

The estimated value of one unit of power generation asset is thus expressed as a right to operate a power plant that generates electricity from fuel F over certain time period.

6.3 Modifications of the valuation of power generation assets

There are several modifications and extensions of the above derived model. Deng, Johnson, Sogomonian (1999) use for modeling of the price of electricity and fuel a mean- reverting process instead of the Brownian motion with a drift.

According to Dixit, Pindyck (1994) the simplest mean-reverting process is the so called Ornstein-Uhlenbeck process, which would in this case look as follows:

$$dF = \kappa(\overline{F} - F)dt + \sigma dB \tag{62}$$

where κ is the speed of reversion and $\overline{\mathrm{F}}$ is the price level to which the price tends to revert. This is also the main difference between the Wiener process - which in the long run could grow indefinitely – and between the mean reverting process – which is anchored to the $\bar{F}$ price level.[66] The expected value and variance of the Ornstein-Uhlenbeck are according to Dixit, Pindyck (1994):

$$\text{(63)} \qquad \mathrm{E}[F_t] = \bar{F} + (F_0 - \bar{F})e^{-\kappa t}$$

$$\text{(64)} \qquad \mathrm{var}(F_t - \bar{F}) = \frac{\sigma^2}{2\kappa}(1 - e^{-2\kappa t})$$

Deng, Johnson, Sogomonian (1999) use a modification of the mean-reverting process in following form

$$\text{(65)} \qquad dF_e = \kappa_e(\mu_e - \ln F_e)F_e dt + \sigma_e(t)F_e dB^e$$

$$\text{(66)} \qquad dF_f = \kappa_f(\mu_f - \ln F_f)F_f dt + \sigma_f(t)F_f dB^f$$

where μ is the long-term mean of the price, κ is the speed of reversion and the variance parameters σ are time-dependent; dB are again two Wiener processes with instantaneous correlation ρ.

The price processes in the mean-reverting form are again inputted to the partial differential equation (41) and solved and solved analogously to the solution for Brownian motion processes. The solution would be then again $C_1(F_e^{t,T},F_f^{t,T},T-t)=e^{-r(T-t)}(F_e^{t,T}\Phi(v_1)-K_H F_f^{t,T}\,\Phi(v_2))$, but the value of v_1 and v_2 would in this case be[67]:

$$\begin{aligned} & v_1 = \frac{\ln(F_e^{t,T} / K_H F_g^{t,T}) + \upsilon^2(T-t)/2}{\sqrt{\upsilon^2(T-t)}} \\ \text{(67)} \qquad & v_2 = d_1 - \sqrt{\upsilon^2(T-t)} \\ & \upsilon^2 = \frac{\int_t^T \left[\sigma_e^2(s) - 2\rho\sigma_e(s)\sigma_f(s) + \sigma_f^2(2)\right]ds}{T-t} \end{aligned}$$

---

[66] Hence the mean-reverting process satisfies the Markov property, but does not have independent increments.

[67] „the mean-reversion parameters of the futures price of electricity and generating fuel do not enter the pricing formula of a spark spread option since the futures contracts of electricity and generating fuels are traded securities and therefore the mean-reverting effects are eliminated through the construction of the replicating portfolio using traded future contracts"; Deng, Johnson, Sogomonian (1999; page 4)

The main advantage of use of the mean reverting process in the formulation of the real option value is that it provides more realistic approach towards modeling of the future development of fuel and electricity prices. In the numerical model in this thesis I have assumed that the fuel prices will follow a linear trend. This assumption is of course simplifying, but so would be in fact the application of the Brownian motion process. The Brownian motion process with a drift assumes that the fuel and electricity prices will grow indefinitely. The mean-reverting process, on the other hand, assumes that there is certain factor that anchors the prices in the long-run. Dixit, Pindyck (1994) suggest that in case of raw commodities – such as are also the fossil fuels, their price might be related to the long-run marginal production costs. In such case the mean-reverting process would be able to better capture this element in the estimation of price development.

In my opinion, the above described spark spread option model could be also used for assessment of the option value of the power generation assets in relation to the prices of EUA. Similarly to fuel, EUA can be also bound to the volume of production of the power plant and influence the variable costs of the power plant. The transformation factor in case of EUA will again be the technology used in the power plant, but now it would include the carbon intensity factor. The estimation of the real option based on EUA prices will be, however, complicated by the regulatory uncertainty influencing the EUA prices. By the mere look at Figure 13 illustrates that the fluctuations in EUA prices caused by regulatory factors (factors external to the market) most likely could not be described by any of the above described processes.

There is, however, a process that could describe the price development of EUA including the price shifts related to changes in the regulatory framework. The process uses a combination of a Brownian motion process and of Poisson-jump process. This combination reflects that the variable follows prevailingly some continuous stochastic process with occasional discrete jumps. According to Dixit, Pindyck (1994) the jumps can be of fixed or random size and their arrival times follow a Poisson distribution. The common notation is that λ stands for mean arrival rate during certain time interval. For an infinitesimally short interval dt this means that λdt represents the probability that an event will occur, 1- λdt is the probability that the event will not occur. The jump process can thus be described as:

$$(68) \qquad dq = \begin{matrix} 0 & probability(1-\lambda dt) \\ 1 & probability(\lambda dt) \end{matrix}$$

combined with the geometric Brownian motion the process would be

$$(69) \qquad dx=f(x,t)dt+g(x,t)dq$$

where f(x,t) and g(x,t) are some known non-random functions. In case of EUA the infrequent jumps in the model could illustrate the destabilization of the markets caused by negotiation of the NAP or by changes of the allocation method. Thus the model would have to capture jumps that arrive in quite regular time periods, but are of unknown size. This approach would, however, require further research.[68]

In this thesis I have tried to provide a broad introduction into the real option theory. The numerical model used in Chapter 5 is an example of a managerial real option model that could be formed with use of spreadsheets. Such models are not overtly demanding on data, but provide only rough overview of the assessed situation. Therefore I decided to include to this thesis for completion also an example of a stochastic continuous-time real option model including some of its extensions and couple of my own ideas to the topic.

---

[68] Stochastic models with jumps and spikes (although not for EUA modeling) were applied e.g. by Deng (1999b) or Ethier (1999).

7 Conclusion

In this thesis I tried to bring together three different topics – the regulatory uncertainty, the assessment of impacts of regulation and to some extent also the real option theory - and use them for the assessment of impacts of the EU Emission Trading Scheme (EU ETS) on one group of its stakeholder groups – on power generators. The primary impulse for choice of this topic was the EU-wide discussion concerning the belated investments into new power generation capacities across Europe.

In the first part of the thesis I described a newly adopted EU legislative procedure that is focused on the assessment of economic, environmental and social impacts (a so called Impact Assessment, IA). This procedure has several effects that have a positive impact on the quality of regulatory proposals and it already to some extent proved its potential to trigger a synergy between policy making and applied economic research. I demonstrated this statement on the example of IA to the EU ETS. I included the description of IA into this thesis because it is – in my opinion – a procedure that has a potential to decrease the regulatory uncertainty of stakeholders of regulation and enable them to form stable, long-term plans and expectations.

Second part of this thesis was focused on identification of the key drivers of the regulatory uncertainty related to the outlook of carbon markets. The EU ETS has undergone fast and turbulent development since its launch in January 2005 and becomes increasingly interrelated and interdependent with the global carbon markets such as are the Kyoto markets and other systems of emission trading. In this thesis I focus on the problematic issues of the EU ETS – mainly on its vulnerability to changes in its regulatory framework and on the abundance of new legislation regulating it. From comparison of the EU ETS with the US emission markets could be derived that some swings of prices and inaccurate price expectations of the market participants are common obstacles on the way to stable and functioning market, provided that the market in order to overcome these hindrances sets some stable and market-friendly regulatory framework.

The limits and rules regulating the future development of the EU ETS are, however, frequently changing causing thus problems to the EU ETS stakeholders. In the third part of this thesis I hence focus on a specific segment of the stakeholders –on power generators - in order to illustrate the problems they are facing in relation to the EU ETS. The increasing amount of regulation that shapes the EU ETS increases the risks of long-term investments into carbon intensive EU ETS sectors. This is caused by the fact that under constantly changing rules of game it is difficult for the investors to set their long-term investment plans, yet the power generation sector and especially the construction of new power plants requires a proper and comprehensive planning. The necessity of investment planning under multiple sources of uncertainty resulted at the end of last century into development of real option models. These models are based on option-pricing methods known on financial markets and they can be applied among others also on the valuation of generation assets.

The real option model is an interesting and versatile tool for various types of investment valuation. The numerical model contained in this thesis is the managerial application of the real option theory. The aim was to find out, to what extent it is the uncertainty about the future development of carbon (EUA) prices and about the future structure of the EU ETS that hinders the investments into new power generation capacities. The focus of my interest was the possibility (illustrated in Figure 32 and Figure 33) that increasing prices of EUA and increasing electricity demand may lead to use of gas-fired power plants in the base-load operation mode. I was particularly interested to find out whether due to the EU ETS the gas-fired power plants may replace in base-load operations the hard coal-fired power plants. From this reason I focused my analysis on these two power plant types (and not on e.g. nuclear power plants that are another important base-load source). The analysis discovered that the relative fuel prices have more substantial impact on the choice between gas-fired and coal-fired power plants than the EU ETS and that the option to postpone the investment decision (given the assumptions of the model) is present only when the price growth of coal and natural gas follow roughly the same trend. The impact of increase of the expected volatility of EUA prices and of the size of the initial investment prolongs in the model the option to postpone the investment decision. Under current relative prices of the 2013 coal and natural gas futures, however, it seems that the EUA could be a decisive factor in the investment decision-making of the power generators provided that there will be only minimal or no grandfathering in Phase III.+. If the relative prices of coal and gas will follow the same trend and there will be only minimal grandfathering from 2013 on, both coal-fired and gas-fired power plants could be a cost-efficient base-load source and therefore in this case the option to wait is valuable.

In case that the EUA will be grandfathered or the relative prices of gas increase relatively to coal, the coal-fired power plants will become more convenient base-load source than the gas-fired power plants (and vice versa in case of increase of price of coal relatively to gas). The finding that even under stringent regulation of the EU ETS the coal-fired power plants can be a good option could explain the recently renewed interest in construction of new coal-fired power plants world-wide.

The renaissance of electricity from coal-fired boilers is, however, to some extent blocked by new sources of regulatory uncertainty (e.g. potential obligation to install to all new coal-fired power plants expensive carbon capture and storage technologies etc.), which again increase the costs of market stakeholders. Therefore in my opinion it is now recommendable for the EC to step out from this vicious circle and stabilize the EU ETS. This could be done simply by setting a clear road map of EU ETS development and complement it with a thorough analysis (that would include the costs of changes of legislation) of the EU ETS and its impacts. This should relieve from the market part of the costs caused by the regulatory uncertainty and enable the investors to construct new sources of electricity.

In the end of this thesis there is an example of a continuous-time stochastic real option model and of its extensions. In my opinion the real option theory has a potential to evolve into efficient tool for assessment of the regulatory uncertainty useful for both regulators and regulation stakeholders.

8 Literature

8.1 Impact Assessment (IA)

- A Comparative Analysis of Regulatory Impact Assessment in Ten EU countries (2004), Dublin, A report prepared for the EU directors of Better Regulation Group, Formez, www.betterregulation.ie
- CORDOVA-NOVION, C. et al.; 2007: Business Enabling Environment in Southeast Europe: Increasing Sub-National Competitiveness - RIA systems in the SEE countries; Global Distance Learning Network, Belgrade, December 2007
- DEN ELZEN, M.G.J.; LUCAS, P.; GIJSEN, A.; 2007; The emissions targets and costs for the European countries under the 20% reduction target; MNP report 500114009/2007, Netherlands Environmental Assessment Agency, Bilthoven, the Netherlands
- GARG, A.;KARBA, M.; 2004: Regulatory Impact Assessment: Key to Good Governance; SAFIR Newsletter, page 8 – 13; available at http://www.teriin.org/division/regdiv/rp/docs/ft03.pdf
- JACOBS, C. ;2005: The role of regulatory impact assessment in democratization: selected cases from the transition states of Central and Eastern Europe, Paper No. 101, Centre on Regulation and Competition WP Series, March 2005
- KIRKPATRICK, C.; 2002: Regulatory Impact Assessment in Developing Countries; In: "Enterprise Impact News," Issue 9, June 2002, Enterprise Development Impact Assessment Information Service (EDIAIS); available at http://www.enterprise-impact.org.uk/pdf/EINJune02.pdf
- MEJSTŘÍK, M.; 2008: Přínosy a uplatnění hodnocení dopadů regulace (Regulatory impact assessment): teorie a praxe; panel discussion to the topic „Kvalita výstupu legislativního procesu v ČR a možnosti jejího zlepšení prostřednictvím analýzy dopadu regulace (RIA)", Institute of Economic Studies, Charles University, 16. 1. 2008, http://www.eeip.cz/cz/docs/4-Mejstrik_Ria_panel16_1_2008.pdf

- MEJSTŘÍK, M. ET AL.; 2008: Hodnocení dopadů (Impact Assessment) Evropské Komise: Status quo; Conference „EU v objetí regulace: Jak dále?“, Institute of Economic Studies, Charles University, and eStat, 14. 5. 2008, http://www.eeip.cz/cz/docs/070526_Konference_sbornik.pdf
- OECD; 2003: Regulatory Performance: Ex-post evaluation of Regulatory Policies, Paris 2003; http://www.oecd.org/dataoecd/34/30/30401951.pdf
- OECD; 2005: Guiding Principles for regulatory quality and performance; Paris; August 2005
- RENDA, A. ; 2006; Impact assessment in the EU (The state of art and the art of state), Centre for European Policy Studies CEPS), Brussels
- SVOBODA, P. ; 2004: Úvod do evropského práva; C.H. Beck; Prague, 2004, 1st issue
- THE EVALUATION PARTNERSHIP LIMITED; 2007: Evaluation Report to the Impact Assessment; April 2007; Brussels; available at http://ec.europa.eu/governance/impact/key_en.htm
- TICHÝ, L. ET AL.; 2006: Evropské právo; C.H. Beck; Prague; 2006; 3rd issue
- VLEK, S.P.H.; VOGELS, M.E.S.; 2000: AERO A Netherlands policy analysis model on global environmental issues; NLR-TP-200-244; Nationaal Lucht- en Ruimtervaartlaboratorium
- VYCHODIL, O.; 2005: Making RIA Meet Its Purpose: A Long Way to Go in the Czech Republic, Prague, November 2005
- WESTWOOD, J.; 2008: Energy – beyond $120 oil; All-Energy, Aberdeen, May 2008, Douglas-Westwood Company

EU documents, EC statements:

- COM(2003)403
- COM(2005)30
- COM(2005)35
- COM(2005)97
- COM(2005)459

- COM(2006)583
- COM(2006)818
- COM(2007)2
- COM(2007)19
- COM(2007)856
- COM(2008)16
- COM(2008)17
- COM(2008)30
- COM(2008)32
- COM(2008)33
- COM(2008)35
- SEC(2003)785
- SEC(2004)1377
- SEC(2005)79
- SEC(2005)180
- SEC(2005)791
- SEC(2005)1184
- SEC(2006)1224
- SEC(2006)1685
- SEC(2007)7
- SEC(2007)8
- SEC(2007)60
- SEC(2007)61
- SEC(2007)1723
- SEC(2007)1724
- SEC(2007)1725
- SEC(2008)54
- SEC(2008)55
- SEC(2008)84
- SEC(2008)85
- SEC(2008)120

Useful links:

- http://ec.europa.eu/governance/impact
- http://www.ria.mvcr.cz
- http://www.mvcr.cz/gremium
- http://peseta.jrc.ec.europa.eu/methods.html
- www.tremove.org

Other:

- Czech Governmental Decree number 950/2000
- Czech Governmental Decree number 650/2001
- Czech Governmental Decree number 640/2002
- Czech Governmental Decree number 237/2004
- Czech Governmental Decree number 1072/2004
- Czech Governmental Decree number 420/2005
- Czech Governmental Decree number 877/2007
- Czech Governmental Decree number 927/2007

8.2 Emission trading fundamentals

- BATALLER ET Al.; 2006; CO2 prices, energy and weather; July 2006; http://ssrn.com/abstract=913964
- BETZ, R. ET AL., 2004. Designing national allocation plans for EU-emissions trading - a first analysis of the outcomes . Energy & Environment, 15(3), pp. 375-426.
- BETZ, R., ROGGE, K. and SCHLEICH, J., 2006. EU emissions trading: an early analysis of national allocation plans for 2008–2012. Climate Policy, 6, pp. 361-394.
- BÖHRINGER, C. and LANGE, A., 2005. Mission Impossible !? On the Harmonization of National Allocation Plans under the EU Emissions Trading Directive. Journal of Regulatory Economics, 27(1), pp. 81.

- BÖHRINGER, C., MOSLENER, U.; STURM, B.; 2006; Hot air for sale: A quantitative assessment of Russia's Near-term Climate Policy Options; ZEW Discussion Paper No. 06 – 16;
- BOHRINGER, C. and VOGT, C., 2003. Economic and Environmental Impacts of the Kyoto Protocol. The Canadian Journal of Economics / Revue canadienne d'Economique, 36(2), pp. 475-494.
- BORAK, S., HÄRDLE, W., TRÜCK, S. and WERON, R., 2006. Convenience Yields for CO_2 Emission Allowance Futures Contracts. SFB 649 Discussion Papers, Sonderforschungsbereich 649, Humboldt University, Berlin, Germany.
- BOTTERUD, A., BHATTACHARYYA, A. and ILIC, M., 2002. Futures and spot prices-an analysis of the Scandinavian electricity market, Proceedings of North American Power Symposium 2002, October 14-15, 2002 2002, .
- BUCHNER, B., CARRARO, C. and ELLERMAN, A.D., 2006a. The Allocation of European Union Allowances: Lessons, Unifying Themes and General Principles.
- BUCHNER, B. and ELLERMAN, A.D., 2007. The European Union Emission Trading Scheme: Origins, Allocation, and Early Results. Review of Environmental Economics and Policy, 1(1), pp. 66-87.
- BUCHNER, B. and ELLERMAN, A.D., 2006b. Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005 Emissions Data. FEEM Working Paper, November(139.06),.
- BUCHNER, B. and ELLERMAN, D., 2006c. Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005 Emissions Data, Fondazione Eni Enrico Mattei, Working Papers.
- BURTRAW, D., KAHN, D. and PALMER, K., 2006. CO2 Allowance Allocation in the Regional Greenhouse Gas Initiative and the Effect on Electricity Investors. The Electricity Journal, 19(2), pp. 79-90.
- BURTRAW, D., PALMER, K., BHARVIRKAR, R. and PAUL, A., 2002. The Effect on Asset Values of the Allocation of Carbon Dioxide Emission Allowances. The Electricity Journal, 15(5), pp. 51-62.

- BURTRAW, D., PALMER, K. and KAHN, D., 2005. Allocation of CO_2 Emission Allowances in the Regional Greenhouse Gas Cap-and Trade program. Resources for the Future Discussion Paper, (25), pp. 1-61.
- CARLSON, C., 1998. Sulfur Dioxide Control by Electric Utilities: What Are the Gains from Trade? World Bank Policy Research Working Paper, (1966),.
- CHICHILNISKY, G. and HEAL, G., 1993. Global Environmental Risks. The Journal of Economic Perspectives, 7(4), pp. 65-86.
- CHVALKOVSKÁ, J.; 2006; Assessing impacts of the implementation of EU ETS with special focus on the position of Czech Republic; Bachelor thesis; Institute of Economic Studies, Charles University in Prague
- CNET; 2008; EcoSecurities founder says carbon markets work; May 19, 2008; http://news.cnet.com/8301-11128_3-9947454-54.html
- COLBY, B.G., 2000. Cap-and-Trade Policy Challenges: A Tale of Three Markets. Land Economics, 76(4), pp. 638-658.
- COPELAND, B.R. and TAYLOR, M.S., 2004. Trade, Growth, and the Environment. Journal of Economic Literature, 42(1), pp. 7-71.
- DELARUE, E.D. and D'HAESELEER, W.D., 2007. Price determination of ETS allowances through the switching level of coal and gas in the power sector. International Journal of Energy Research, 31(11), pp. 1001-1015.
- DEWEES, D.N., 2001. Emissions Trading: ERCs or Allowances? Land Economics, 77(4), pp. 513-526.
- ELLERMAN, A DENNY (REVIEW OF: KERR,SUZI, ED), 2002. Review of: Global emissions trading: Key issues for industrialized countries. Journal of Economic Literature, 40(4), pp. 1281.
- ELLERMAN, A.D., 2005a. A Note on Tradable Permits. Environmental and Resource Economics, 31(2), pp. 123-131.
- ELLERMAN, A.D., 2005b. US Experience with Emissions Trading: Lessons for CO2 Emissions Trading. In: B. HANSJURGENS ED, ed., Emissions Trading for Climate Policy: US and European Perspectives. Cambridge and New York: Cambridge University Press, pp. 78-95.

- ELLERMAN, A.D., 2003a. Are cap-and-trade programs more environmentally effective than conventional regulation? Center for Energy and Environmental Research, 03-015 WP.
- ELLERMAN, A.D., 2003b. Lessons from Phase 2 Compliance with the US Acid Rain Program.
- ELLERMAN, A.D., 2003. Tradable Permits--A Market-Based Allocation System for the Environment. CES info Forum, 4(1), pp. 3-7.
- ELLERMAN, A.D. and BUCHNER, B.K., 2007. Symposium: The European Union Emissions Trading Scheme: The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. Review of Environmental Economics and Policy, 1(1), pp. 66-87.
- ELLERMAN, A.D. and DUBROEUCQ, F., 2004. 'Sources of Emission Reductions: Evidence for US SO2 Emissions 1985-2002'.
- ELLERMAN, A.D. and MONTERO, J., 2005. The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program.
- ELLERMAN, D., 1998. Obstacles to global CO_2 trading: a familiar problem. 42.
- FISHER, C., 2003. Combining Rate-based and Cap-and-Trade Emission Policies. Resources for the Future Discussion Paper, (32), pp. 1-19.
- GANGADHARAN, L., 2000. Transaction Costs in Pollution Markets: An Empirical Study. Land Economics, 76(4), pp. 601-614.
- HAITES, E.; 2007; Carbon Markets; Magaree Consultants Report prepared for United Nations Climate Change Secretariat, Bonn, August 2007
- HEPBURN, C. ET AL., 2006. Auctioning of EU ETS phase II allowances: how and why? Climate policy, 6, pp. 137-160.
- HONKATUKIA, J., MÄLKÖNEN, V. and PERRELS, A., 2006. Impacts of the European Emission Trade System on Finnish Wholesale Electricity Prices. VATT Discussion Papers, (405),.
- HOWARTH, R.B., 2003. Discounting and Uncertainty in Climate Change Policy Analysis. Land Economics, 79(3), pp. 369-381.

- JAMIESON, D., 1996. Scientific Uncertainty and the Political Process. Annals of the American Academy of Political and Social Science, 545(Challenges in Risk Assessment and Risk Management), pp. 35-43.
- JEPMA, C.J., 2003. The EU emission trading scheme (ETS): how linked to JI/CDM? Climate policy, 3, pp. 89-93.
- JOHNSTON, A., 2006. Free allocation of allowances under the EU emissions trading scheme: legal issues. Climate Policy, 6, pp. 115-136.
- KEMFERT, C., KOHLHAAS, M., TRUONG, T. and PROTSENKO, A., 6. The environmental and economic effects of European emissions trading. Climate Policy, April, pp. 441-455.
- KENNEDY, P.W., 2002. Optimal Early Action on Greenhouse Gas Emissions. The Canadian Journal of Economics / Revue canadienne d'Economique, 35(1), pp. 16-35.
- KLEPPER, G. and PETERSON, S., 2005. Emissions Trading, CDM, JI, and More - The Climate Strategy of the EU. FEEM Working Paper, April(55.05),.
- KLEPPER, G. and PETERSON, S., 2004. The EU emissions trading scheme allowance prices, trade flows and competitiveness effects. European Environment, 14(4), pp. 201-218.
- KOSOBUD, R.F., 1994. Tradable Cumulative CO2 Permits and Global Warming Control. Energy Journal, 15(2), pp. 213-232.
- KRUGER, J.A. and PIZER, W.A., 2003. Greenhouse gas trading in Europe: The new grand policy experiment.
- LISKI, M. and MONTERO, J.P., 2003. A Note on Market Power in an Emission Permits Market with Banking. Working Paper edn. Instituto de Economía, Pontificia Universidad Católica de Chile: .
- LUTTER, R. and SHOGREN, J.F., 2002. Tradable Permit Tariffs: How Local Air Pollution Affects Carbon Emissions Permit Trading. Land Economics, 78(2), pp. 159-170.
- MALONEY, M.T. and BRADY, G.L., 1988. Capital Turnover and Marketable Pollution Rights. Journal of Law and Economics, 31(1), pp. 203-226.

- MONNI, S., SYRI, S., PIPATTI, R. and SAVOLAINEN, I., 2007. Extension of EU Emissions Trading Scheme to Other Sectors and Gases: Consequences for Uncertainty of Total Tradable Amount. Water, Air, & Soil Pollution: Focus, 7(4-5), pp. 529-538.
- MONTERO, J., 2005. Pollution markets with imperfectly observed emissions. RAND Journal of Economics, 36(3), pp. 645-660.
- MONTERO, J.P., ELLERMAN, A.D.; 1998. Explaining low sulfur dioxide emission prices: The effect of expectations errors and irreversibilities. MIT Working Paper edn. Cambridge Massachusetts
- MULLER, A., 2007. How to make the clean development mechanism sustainable—The potential of rent extraction. Energy Policy, 35(6), pp. 3203-3212.
- NEUHOFF, KARSTEN ET AL., 2006. Implications of announced Phase II National Allocation Plans for the EU ETS. Climate Policy, 6(December),.
- NORDHAUS, W.D., 1993. Reflections on the Economics of Climate Change. The Journal of Economic Perspectives, 7(4), pp. 11-25.
- NORDHAUS, W.D., 1991. A Sketch of the Economics of the Greenhouse Effect. The American Economic Review, 81(2, Papers and Proceedings of the Hundred and Third Annual Meeting of the American Economic Association), pp. 146-150.
- NORDHAUS, W.D., 1991. To Slow or Not to Slow: The Economics of The Greenhouse Effect. The Economic Journal, 101(407), pp. 920-937.
- NORDHAUS, W.D. and YANG, Z., 1996. A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. The American Economic Review, 86(4), pp. 741-765.
- PAOLELLA, M.; TASCHINI, L.; An Econometric Analysis of Emission Trading Allowances; Swiss Finance Institute Research Paper No.06 – 26; November 2006, Zurich
- PERRONI, C. and RUTHERFORD, T.F., 1993. International Trade in Carbon Emission Rights and Basic Materials: General Equilibrium Calculations for 2020. The Scandinavian Journal of Economics, 95(3), pp. 257-278.

- POINTCARBON; 2004; What determines the price of carbon; October 14, 2004, www.PointCarbon.com
- REINAUD, J., 2004. Industrial competitiveness under the European Union Emission Trading Scheme. IEA Information Paper, December.
- ROQUES ET AL.; 2005; Nuclear Power: A hedge against uncertain gas and carbon prices; CWPE 0555; November 2005
- SCHELLING, T.C., 1992. Some Economics of Global Warming. The American Economic Review, 82(1), pp. 1-14.
- SCHLEICH, J., EHRHART, K., HOPPE, C. and SEIFERT, S., 2006. Banning banking in EU emissions trading? Energy Policy, 34(1), pp. 112-120.
- SCHMALENSEE, R., STOKER, T.M. and JUDSON, R.A., 1998. World Carbon Dioxide Emissions: 1950-2050. The review of economics and statistics, 80(1), pp. 15-27.
- SIJM, J., NEUHOFF, K. and CHEN, Y., 2006. CO2 cost pass-through and windfall profits in the power sector. Climate Policy, 6, pp. 49-72.
- STAVINS, R.N., 1995. Transaction Costs and Tradeable Permits. Journal of Environmental Economics and Management, 29(2), pp. 133-148.
- SWINTON, J.R., 2002. The Potential for Cost Savings in the Sulfur Dioxide Allowance Market: Empirical Evidence from Florida. Land Economics, 78(3), pp. 390-404.
- TIETENBERG, T., 1992. Environmental and natural resource economics. 3 edn. New York: Harper- Collins.
- TIETENBERG, T., 1985. Emissions trading: An exercise in reforming pollution policy. Washington, DC: Resources for the Future, Inc., Washington, DC.
- UHRIG-HOMBURG, M. and WAGNER, M.W., 2006. Market Dynamics and Derivative Instruments in the EU Emissions Trading Scheme - an Early Market Perspective. http://ssrn.com/abstract=882792 edn.
- VAN KOOTEN, G.C., SHAIKH, S.L. and SUCHANEK, P., 2002. Mitigating Climate Change by Planting Trees: The Transaction Costs Trap. Land Economics, 78(4), pp. 559-572.

- WAGNER, M.W., SEIFERT, J. and UHRIG-HOMBURG, M., 2007. Dynamic Behavior of CO2 Spot Prices - Theory and Empirical Evidence. http://ssrn.com/abstract=903289 edn.
- WELCH, E.W., MAZUR, A. and BRETSCHNEIDER, S., 2000. Voluntary Behavior by Electric Utilities: Levels of Adoption and Contribution of the Climate Challenge Program to the Reduction of Carbon Dioxide. Journal of Policy Analysis and Management, 19(3), pp. 407-425.

EU Documents, EC Statements, International Agreements:

- 2003/87/EC
- 2004/101/EC
- Burden Sharing Agreement
- European Climate Change Program II.
- Kyoto Protocol
- The United Nations Framework Convention on Climate Change

Useful links:

www.carbonfootprint.com

www.cleanair-coolplanet.com

http://ec.europa.eu/environment/climate

www.eex.com

www.europeanclimateexchange.com

www.kyotoenergy.net

www.nordpool.com

www.pewclimate.org

www.PointCarbon.com

www.terrapass.com

www.unfccc.int

Glossary of EU ETS and Kyoto terms:

- http://www.nordpool.com/en/asa/Glossary/Glossary-emission-market

- http://www.nzcx.com/glossary.htm

8.3 Power plants and uncertainty

- ADNER, R.; LEVINTHAL, D.A.; 2004; What is Not a Real Option: Considering Boundaries for the Application of Real Options to Business Strategy; Academy of Management Review; Vol. 2004; No. 29, pp. 74 - 85
- ALSTAD, R.M., FOSS, J.T.; 2004; Investment analyses of CCGT power plants; Master thesis, NTNU; June 2004;
- BLACK,F.; SCHOLES, M.; 1972; The Valuation of option contracts and Test of market efficiency; Journal of Finance; Vol. 27, No. 2; May 1972
- BP; 2008; Statistical Review of World Energy 2008; June 2008
- BRELEY, MEYERS; 2003; Principles of Corporate finance; 7th Edition; McGraw Hill; 2003
- DAVID, J.-H-; 2006; EU Emission Trading The ETS so far: What have we learned?; Deutsche Bank presentation www.db.com
- DEMPSEY, J.; 2007; Largest energy company in Hungary takes practical approach to Russia; March 28, 2007, International Herald Tribune; http://www.iht.com/articles/2007/03/28/business/gas.php
- DENG, S, JOHNSON, B.; SOGOMONIAN, A.; 1999; Spread Options and the Valuation of Electricity Generation Assets; Proceedings of the 32nd Hawaii International Conference on System Science; IEEE 1999
- DENG, S, JOHNSON, B.; SOGOMONIAN, A.;2001; Exotic electricity options and the valuation of electricity generation and transmission assets; Decision Support Systems 30(2001), pp. 383 – 392
- DIXIT, A.; PINDYCK, R.; 1994; Investment under Uncertainty; 1994; Princeton University Press
- EGÚ; 2005; Dlouhodobé bilance elektřiny ES ČR, Souhrnná zpráva o výsledcích řešení projektu v roce 2005; EGÚ Brno a.s.; December 2005
- FLETEN, S.-E.; NÄSÄKKÄLÄ, E.; 2003; Gas fired power plants: Investment timing, operating flexibility and abandonment; MPRA Paper No.217, March 2003

- GRABER, R.; ROTHWELL, G.; 2005; Restoring the nuclear power in the US: A real options approach; EnergyPath Corporation
- HARCHAOUI, T.; LASSERRE, P.; 2001; Testing the option value theory of irreversible investment; International Economic Review; Vol. 42, No. 1; February 2001; pp. 141 - 166
- HIRSCHL, R., SCHLAAK, T.; WATERLANDER, O.; 2006; International Gas Markets Security of Demand and Supply: Different Sides of the same coin?; Booze Allen Hamilton
- KIRIYAMA, E.; IWATA, S.; 2005; Roles of Nuclear Power Systems in the Presence of Uncertainties from Global Warming; Proceedings of GLOBAL 2005; Tsukuba, Japan, Oct 9 – 13, 2005; Paper No. 281
- LAURIKKA, H., 2005. The impact of climate policy on heat and power capacity investment decisions. In: R. ANTES, B. HANSJÜRGENS and P. LETMATHE, eds, Emissions Trading and Business. 1 edn. Heidelberg/NY: Physica Publisher, pp. 17.
- LAURIKKA, H., 2005a. A case study on risk and return implications of emissions trading in power generation investments; In: R. ANTES, B. HANSJÜRGENS and P. LETMATHE, eds, Emission Trading and Business 2. Heidelberg/NY: Physica Publisher, pp. 16.
- LAURIKKA, H. and KOLJONEN, T., 2006. Emissions trading and investment decisions in the power sector—a case study in Finland. Energy Policy, 34(9), pp. 1063-1074.
- LAURIKKA, H.; PIRILÄ, P.; 2005; Investment Appraisal of Heat and Power Plants within an emission trading scheme; Final Report of the INVIS Project; April 2005
- LOBER, D.J. and BAILEY, M., 1997. Organizational Strategy, Managerial Decision-Making, and Market-Based Environmental Policies: Utility Company Bidding Behavior in the Sulfur Dioxide Allowance Trading Auctions. Managerial and Decision Economics, 18(6), pp. 471-489.
- MAJD, S., PINDYCK, R.S. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY. ENERGY LABORATORY, 1985. Time to build, option value,

and investment decisions. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Energy Policy Research.

- MERTON, R. C.; 1973; Theory of rational option pricing; The Bell Journal of Economics and Management Science; Vol.4, No.1, Spring 1973, pp. 141 - 183
- NELSON, R.A., TIETENBERG, T. and DONIHUE, M.R., 1993. Differential Environmental Regulation: Effects on Electric Utility Capital Turnover and Emissions. The review of economics and statistics, 75(2), pp. 368-373.
- PINDYCK, R.S. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY. CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH, 2003. Volatility in natural gas and oil markets. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.
- PINDYCK, R.S. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY. CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH, 2001. The dynamics of commodity spot and futures markets. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.
- PINDYCK, R.S. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY. CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH, 2001. Optimal timing problems in environmental economics. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.
- PINDYCK, R.S. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY. CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH, 2001. Volatility and commodity price dynamics. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research.
- PINDYCK, R.S. and NATIONAL BUREAU OF ECONOMIC RESEARCH, 2006. Uncertainty in environmental economics. Cambridge, Mass.: National Bureau of Economic Research.

- REEDMAN, L.; GRAHAM, P.; COOMBES, P.; 2006; Using a Real-Options Approach to Model Technology Adoption under Carbon Price Uncertainty: An Application to Australian Electricity Generation Sector; The Economic Record; Vol. 82, Special Issue September 2006; pp. S64 – S73
- REUTERS; 2008; RPT-FACTBOX-New nuclear power plants; 8.1.2008 www.reuters.com/article/latestCrisis/idUSL08725535 ; (downloaded 13.7.2008)
- SEKAR, C.S. ET AL.; 2005; Future carbon regulations and current Investments in alternative coal-fired power plant design; MIT Joint Program on the Science and Policy of Global Change; Report No. 129; December 2005
- SIJM, J., 2004. The impact of the EU emission trading scheme on the price of electricity in the Netherlands. Energy Research Centre of the Netherlands, Policy Studies, 15.
- SPENCERBANZHAF, H., BURTRAW, D. and PALMER, K., 2004. Efficient emission fees in the US electricity sector. Resource and Energy Economics, 26(3), pp. 317-341.
- SVOBODA, A.; 2007; Vývoj obchodu s elektřinou ve střední a východní Evropě; Mělník 13.5.2007; ČEZ, a.s.
- TEISBERG, E.O.; 1993; Capital Investment Strategies under Uncertain Regulation; The RAND Journal of Economics; Vol. 24, No. 4; Winter 1993, pp.591 - 604
- WEBER, C.; SWINDER, D.J.; 2004; Power plant investments under fuel and carbon price uncertainty; 6th IAEE European Conference 2004 on Modelling and Energy Economics
- WICKART, M; MADLENER, R.; JAKOB, M.; 2004; Policy implications of risk and uncertainty in industrial large-scale co-generation investment: The case of Switzerland; CEPE, Swiss Federal Institute of Technology, Zurich, September 2004, Switzerland

Useful links:

http://pages.stern.nyu.edu/~adamodar

www.uxc.com

8.4 Numerical model, Stochastic real option models of generation assets

- COX, J.; ROSS, S.; RUBINSTEIN, M.; 1979; Option Pricing: A Simplified Approach; Journal of Financial Economics; September 1979
- DENG, S.; 2000; Stochastic Models of Energy Commodity Prices and Their Applications: Mean-reversion with Jumps and Spikes; PWP-073; University of California Energy Institute; February 2000
- ETHIER, R.; 1999; Valuing Electricity Assets in Deregulated Markets: A Real Options Model with Mean Reversion and Jumps; WP 99-03; Cornell University; February 1999
- EURACTIV; 2008a; G8 backs 50% CO2 cut by 2050; 8.7.2008; http://www.euractive.com/climate-change/g8-backs-50-co2-cut-2050/article-174028 ;(downloaded 17.7.2008)
- EURACTIV; 2008b; Uncertainty over CO2 capture in “fossil future”; May 30; 2008; http://www.euractiv.com/en/climate-change/uncertainty-co2-capture-fossil-future/article-172834; (downloaded 17.7.2008)
- MURPHY, K.; 2008; Europe, and especially Germany, are banking on coal; L.A.Times; May 25, 2008
- PWC Utilities Global Survey 2008
- SHOCKLEY, R.; 2006;An Applied Course in Real Options Valuation; 1st edition; South-Western College Pub; November 2006; chapter 15, 16

Master thesis project

Subject: How will carbon markets influence in the future the long term investment decisions of companies involved? And do carbon markets have a future?

Author: Jana Chvalkovská

Director of the thesis: Ing. Zdeněk Hrubý, CSc.

Academic year: 2007/2008

Master thesis project:

The introduction of the European Union carbon dioxide emission trading scheme (EU ETS) in January 2005 created the largest emission trading market in the world. In 2008 the greenhouse gas emission trading entered into its second phase with the merging of the Kyoto Protocol Mechanisms with the EU ETS. This might be a creation of a new global environmental market – liquid and voluminous, but it may also be the final pinch that bursts the carbon bubble. The aim of this paper is to analyze the relationship between the two markets and disclose the impacts of development of the carbon markets on the investment decisions of companies exposed to the alterations in these markets.

The essential point of the analysis is to determine the drivers of the prices of EUAs and CERs[69] and link the findings with the analysis of the so far existing emission trading markets. Such an examination may provide an important clue to the assessment of the perspectives of the carbon future markets.

The carbon future markets and prices of the carbon emissions that are formed in these markets strongly influence and will continue influencing in the future the long

---

[69] EU Allowance (EUA), Certified Emission Reduction (CER)

term investment decisions of companies in certain industrial branches – most importantly in the sector of power generation.

Hypothesis:

The developments of prices in the carbon markets influence vastly the investment behavior of companies included in the emission trading scheme. The uncertainty induced by the rather ambiguous results of the first phase of the EU ETS, combined with the even greater uncertainty related to the merger of the EU ETS with the new Kyoto Mechanisms market[70] may have severe impact on the long term planning of investments in building of new power generation sources etc. Therefore it is necessary to analyze the drivers of the prices of EUAs and CERs, their potential interactions after the complete merger of the EU ETS and Kyoto markets and the impacts of carbon market volatility on the investment behavior of power generators (that form the largest proportion of the emission permit assignees).

The structure of this paper is as follows:

1. Price drivers of CERs and EUAs
    a. Institutional/Legal
    b. Economic
    c. Technological
2. Uncertainty of the development of the carbon markets
    a. Impact of volatility due to the National Allocation Plans etc.
    b. Impact of merger of the EU ETS and Kyoto market
3. Impact on investment decision of the power generators

Expected Table of Contents:

1. INTRODUCTION
    a. The idea behind carbon trading

---

[70] Meaning the market with Emission Reduction Units (ERUs) or Certified Emission Reductions (CERs) resulting from Joint Implementation and Clean Development Mechanism programs.

    b. Carbon future markets – past and present
    c. Power generation sector
2. LITERATURE OVERVIEW
    a. American Acid Rain Program
    b. EU ETS First Phase
    c. Kyoto Protocol
    d. Carbon future markets – price drivers, volatility, valuation
3. PRICE DRIVERS, VALUATION ISSUES
    a. EUAs
    b. CERs
4. CARBON MARKETS
    a. Volatility
    b. Market dynamics
    c. Predictability, future development
5. INVESTMENT DECISIONS UNDER CARBON-SPECIFIC UNCERTAINTY
    a. Overview of investment under uncertainty
    b. Assessment of impact of carbon prices on power generators
    c. Case Study
    d. Kyoto, auctioning and beyond
6. CONCLUSIONS
7. APPENDICES
8. BIBLIOGRAPHY
9. GLOSSARY

In the **first chapter** this paper shall provide insight into the main ideas of carbon trading and the advantages and disadvantages of this mechanism compared with the traditional command-control regulation.

In the **second chapter**, which is the literature overview, shall be predominantly discussed the past developments of markets with tradable emission rights effectuated both in the framework of the U.S. Acid Rain program and in the Phase I. of the EU ETS. Highlighted will be above all the importance of "lessons learned" from the U.S. emission trading and also the overview of the few sources examining the emission trading in frame of the EU ETS. Literature concerning the future of the Kyoto Mechanisms is scarce and full of contradictory statements – as will be also briefly summarized within this chapter. The aim of the second chapter is above all to review the existing literature concerning the emission trading (with focus on the carbon future markets) and provide the whole spectrum of scientific approaches towards these emerging global markets.

The **third chapter** of this paper is dedicated to the valuation of the tradable carbon emission rights. There are various methods of measurement of the price of carbon including the cost-of-carry model, real option value approach etc. stressing different aspects of the tradable emission permits. In order to be able to choose the right valuation method a thorough analysis of the determinants of the carbon price will be provided.

Carbon markets as such will be discussed in the **fourth chapter** of this paper. In the center of attention will be above all the volatility and uncertainty inherently contained in the institutional framework of these markets and the potential future development of the carbon trading. Essential part of this chapter will be also an overview of the past development of the carbon market in Europe and the expected changes to the carbon trading scheme – such as change of the allocation mechanism from grandfathering to auctioning or the conjunction of the EU ETS with markets established under the Kyoto Protocol.

The **fifth chapter** is then dedicated to the topic of investing under carbon- induced uncertainty with focus on companies from the sector of power generation that are the largest players in the carbon markets. Included will be again the lessons learned from the U.S. emission trading programs as well as a case study demonstrating the practical impacts of carbon trading on managerial decisions.

Chapter six will finally provide a synergy of aspects of the carbon trading mentioned in the paper and answer the questions raised at the beginning of this paper: "How will carbon markets influence the long term investment decisions of companies involved in the future? And do carbon markets have a future?

On the whole, this paper shall contribute to deeper understanding of the consequences of carbon trading on the investment plans of participating companies and it shall also provide some useful insights on the issues connected with the valuation of the tradable emission permits, which is a field rather neglected by the existing economic literature.