TOWARDS A GLOBAL CARBON MARKET

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THE CLEAN DEVELOPMENT MECHANISM'S CURRENT STATE AND FUTURE PROSPECTS

Diploma Thesis to obtain the academic grade 'Diplom Wirtschaftsingenieur' at the University of Flensburg

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Abstract

The Clean Development Mechanism (CDM) established under the Kyoto Protocol is the only instrument that includes developing countries into the international carbon market. However, the mechanism faces serious shortcomings, including high transaction costs and low environmental and economic effectiveness. Moreover, developing countries play a growing role in regard to greenhouse gas emissions and they need to increasingly decarbonize their economies. This raises the question how the CDM can be modified in an international climate agreement post 2012. For this thesis, various options for reforming the CDM are discussed. Particular emphasis is put on China as a key player in terms of emissions as well as political and economical weight. Sectoral no-lose intensity targets are identified as one promising option to include newly industrialized countries such as China into a post-Kyoto agreement, even though the instrument raises some questions in regard to economic and environmental effectiveness.

Executive Summary

The goal of this thesis is to understand mechanisms for integrating developing countries into a global climate regime after 2012 when the Kyoto Protocol phases out. Newly industrialized countries such as China are particularly important, as they show tremendous growth rates, both in economic development and greenhouse gas (GHG) emissions. In order to achieve ambitions climate policy targets, such as the EU 2°C goal, it is crucial to include these countries into global greenhouse gas mitigation efforts.

In the Kyoto Protocol, the Clean Development Mechanism (CDM) is the only instrument that allows the integration of developing countries into global mitigation efforts. While developed countries that are grouped under Annex B of the Kyoto Protocol have signed binding emission reduction commitments, developing countries can theoretically increase their GHG emissions without any limitations. However, measures to decrease GHG emissions in developing countries can be credited under the CDM on a project-by-project level, with credits being sold to Annex B countries in order to fulfill their commitments.

Approximately 1,000 projects are currently registered under the CDM (as of May, 2008), generating GHG credits that are equivalent to 215 Mt CO_{2e} per year. Moreover, 3,000 projects are in the project pipeline, meaning that they are running through the registration process that is supervised by the UNFCCC Executive Board to ensure environmental effectiveness and sustainable development requirements of CDM projects. However, although being successful in integrating developing countries to the global carbon market to some extent, important shortcomings of the current CDM are identified:

i. The CDM sets no incentives for structural changes of the economy towards decreasing GHG emissions.
ii. The project-by-project approach leads to high transaction costs.
iii. The environmental integrity of the CDM is difficult to guarantee.
iv. The CDM has been more efficient in allocating cost efficient GHG emission reductions than delivering sustainable development.

v. Newly industrialized countries, namely China, India, Mexico and Brazil account for three quarters of the expected credits; least developed countries are underrepresented.

Even though the shortcomings of the instrument are obvious, it must not be forgotten that the CDM has promoted a large market with established institutions. In regard to the post-2012 era it should be useful to build on the experiences that have been gained through the CDM.

There are four major choices that need to be made when designing new policy instruments that provide alternative options for integrating developing countries into an international carbon market:

- *Absolute or Relative:* For a post-2012 CDM as well as for a post-Kyoto agreement in general it needs to be clarified whether targets shall be relative or absolute, e.g. in form of an absolute cap on GHG emissions or relative to a specific parameter, as for example carbon emissions per unit GDP.
- *Binding or non-Binding:* It is an important question whether emission targets shall be binding, as is the case for Annex B countries of the Kyoto Protocol today; alternatively one can think of non-binding targets, meaning that non-fulfillment of a commitment would not be linked to any consequences.
- *Economy-wide or Sectoral:* It is frequently discussed whether a future instrument shall be designed to cover the whole economy, or alternatively, whether it might be more reasonable to focus on specific sectors, for example highly emitting industry sectors.
- *Project-based or Policies and Measures:* Currently the CDM is a project-based instrument. It would however also be conceivable to upscale the mechanism, including the possibility to credit policies and measures in a post-2012 scheme.

Design options can be combined with respect to different requirements. For example, from an economic point of view an economy-wide, binding and absolute cap would be most efficient. However, it has not been proven to be politically feasible so far to establish binding and absolute emission targets in developing countries as they fear that binding targets may inhibit their economic growth. Therefore, alternatives need to be discussed.

Five different proposals can be distinguished that have been proposed for a post-2012 CDM, namely Sustainable Development Policies and Measures (SD-PAMs), Programmatic CDM, Policy CDM, Sectoral CDM and no-lose Intensity Targets.

In contrast to SD-PAMs, which aim to mainstream climate change in development policy, the programmatic, policy and sectoral CDM would be implemented in the institutional framework that is established by the current CDM. While the programmatic CDM would allow for bundling projects with similar objectives, therefore reducing transaction costs, the policy CDM would permit the integration and crediting of policies into the CDM. The sectoral CDM can be understood as a baseline for an entire sector, rather than being on the project-by-project level. Sectoral no-lose intensity targets build on the sectoral CDM but go beyond the idea of the current instrument. First, the baseline would be an intensity target rather than an absolute target for a specific sector, as for example steel, cement or electricity. Moreover, the target is supposed to be non-binding, meaning that there would not be a penalty for developing countries that do not meet their target. Credits would be generated in case the actual intensity of a sector is lower than the negotiated intensity target.

In principle, all outlined possibilities aim to upscale the current instrument in regard to its scope and its expected volume of credits. However, sectoral no-lose intensity targets get closest to the idea of national binding targets. Moreover, there are reasons to believe that sectoral no-lose intensity targets have the potential to overcome important shortcomings of the CDM, especially in regard to transaction costs. Most importantly, sectoral no-lose intensity targets also have the capacity to incentivize larger-scale decarbonization, while other proposals might lead to a stabilization of absolute emissions, at best. Furthermore, proposals other than sectoral no-lose intensity targets would basically continue the current CDM structure, therefore not fundamentally overcoming its weaknesses.

For this thesis, the implications of sectoral no-lose intensity targets in the Chinese electricity sector have been analyzed. As a starting point for the analysis, emission trends in China are analyzed using a Kaya decomposition analysis. China is identified as a key contributor to rising global GHG emissions in the last decades, a trend mainly driven by its outstanding economic development. In recent years increasing energy– and carbon intensity also play an important role, due to shifts in the industry sector towards more emission intensive industries. In general, the Chinese energy system highly relies on the use of coal, a very emission-intensive fuel. The Chinese electricity sector particularly contributes to the increasing demand in coal. A detailed analysis of the sector reveals that it is characterized by a large amount of old and inefficient power plants and a market structure that is not providing sufficient incentives for efficient power generation. However, the Chinese government currently promotes more efficient power plant technologies as well as carbon-neutral technologies, for example renewable energy, nuclear energy and Carbon Capture and Storage (CCS) in order to meet a number of domestic political targets, including reducing air pollution, securing energy security and increasing economic efficiency.

The analysis of emission trends and the institutional framework of the Chinese energy sector reveals that sectoral no-lose intensity targets would be part of a broader policy effort driven by different goals. Domestic programs aiming to reduce air pollution or to increase energy security can also be beneficial in regard to mitigating climate change. The same is true for developing low carbon technologies. In addition to these measures, sectoral no-lose intensity targets can introduce an additional incentive for decarbonization by providing international finance through the international carbon markets.

When implementing sectoral no-lose intensity targets in the Chinese electricity sector, it is crucial to understand the impacts of the instrument. It can be shown that sectoral intensity targets generally set a price signal on the sectoral carbon intensity, defined as carbon emissions per primary energy supply, as well as the conversion intensity, defined as primary energy per secondary energy, but not on the ‘electricity intensity’, defined as electricity output per unit GDP; in other words they do not set a price signal on the electricity demand side. All influencing factors are relevant for the development of carbon emissions in the electricity sector, which is shown by an extended Kaya decomposition. Thus, sectoral no-lose intensity targets are not fully efficient as they do not put incentives on all relevant factors determining emissions. Generally spoken, a sectoral no-lose intensity target would not set an incentive to decrease the production of a particular energy intensive commodity. Rather, it can be argued that once the sectoral intensity drops below the intensity target, incentives to augment the production of a covered commodity are given, which in turn might lead to rising absolute emissions.

With regard to an international carbon market, it is a crucial question how many certificates would be generated by no-lose intensity targets. Therefore, the IEA World Energy Outlook's reference scenario is used as baseline to conduct a rough estimation of generated credits. On a yearly basis, sectoral no-lose intensity targets for the Chinese electricity sector would generate 60% more credits than the current CDM for all countries until the year 2020, if the Chinese government pledged to decrease its emission intensity in analogy to its current reduction goals. Therefore, concerns that no-lose intensity targets could 'flood' the carbon market seem to be reasonable, having in mind that other countries and other sectors would generate additional credits. However, the amount of generated credits highly depends on the baseline assumptions and the intensity target itself. In order to reflect incentives that might be set by an international carbon price and to generally be able to make a more profound statement on the potential generation of credits, further work including quantitative modeling is necessary.

Drawing a final conclusion, sectoral no-lose intensity targets might be an interesting option to integrate developing countries into a global carbon market. However, important shortcomings of the approach can be identified, including a lack of incentives to use all mitigation options and perverse incentives. Additional efforts in the form of political instruments would be needed to address these issues.

Furthermore, it needs to be kept in mind that due to considerable institutional requirements sectoral no-lose intensity targets would not be applicable in least developed countries. Therefore it is likely that the CDM – in its current form or up-scaled to the policy or sectoral level - will remain after 2012, possibly existing in parallel with sectoral no-lose intensity targets for different economies and sectors at different levels of development.

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List of Abbreviations

AAU	Assigned Amount Unit
Annex B	Annex listing initial national commitments under the Kyoto protocol
Annex I	Annex of the Convention listing industrialized countries undertaking specific commitments under the FCCC
APEC	Asia-Pacific Economic Cooperation
CCAP	Center of Clean Air Policy
CCP	Chinese Communist Party
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CHP	Combined Heat and Power
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
COP	Conference of the Parties to the FCCC
COP/MOP	Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol
DNA	Designated National Authority
DOE	Designated Operational Entity
ECBM	Enhanced Coal-Bed Methane Recovery
EIT	Economies in Transition
EOR	Enhanced Oil Recovery

ERU	Emission Reduction Unit
EU	European Union
EU ETS	EU Emission Trading Scheme
EUA	European Union Allowance
FCCC	See UNFCCC
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Green Investment Scheme
GWP	Global Warming Potential
HFC	Hydro-fluorocarbons
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IGO	Intergovernmental Organization
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
JI	Joint Implementation
KP	Kyoto Protocol
LDC	Least Developed Countries
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land Use Change and Forestry
MAC	Marginal Abatement Cost
MOP	Meeting of the Parties (to the Kyoto Protocol)
Mtce	Mega Tons Coal Equivalent
N_2O	Nitrous Oxide
NDRC	(Chinese) National Development and Research Commission

NGO	Nongovernmental Organization
NIC	Newly Industrializing Countries
NPC	(Chinese) National People’s Congress
OE	Oil Equivalent(s)
PDD	Project Design Document
PFC	Per-fluorocarbons
PPM	Parts Per Million
PRC	People’s Republic of China
SCDM	Sectoral Clean Development Mechanism
SEZ	Special Economic Zone(s) (in China)
SF_6	Sulphur-hexafluoride
TFAP	Technical Finance and Assistance Package
UN	United Nations
UNFCCC	UN Framework Convention on Climate Change
WTO	World Trade Organization

1 Introduction

The results of the Intergovernmental Panel of Climate Change's (IPCC) fourth assessment report (IPCC, 2007) indicate that global greenhouse gas emissions need to be cut by at least fifty percent compared to today's levels until the year 2050, in order to prevent dangerous interactions for natural and social systems. It is commonly understood that strong international cooperation is needed in order to tackle the challenge that is posed by international climate change. Although being basically responsible for anthropogenic climate change, it is obvious that abatement efforts in the necessary magnitude cannot be achieved by developed countries alone, but require participation of developing countries, as well. Some developing countries have already reached absolute emission levels that are considerably higher than those of most developed countries, even though per capita emissions are significantly higher in developed countries. However, including developing countries into international climate mitigation efforts raises an important dilemma in regard to equity concerns, that needs to be solved by the international community.

1.1 Scope and Purpose of the Thesis

Looking at contemporary literature, it is understood that significantly reducing GHG emissions requires a global price on carbon (Stern, 2006, IPCC, 2007). While domestic carbon markets have been established in various developed countries, at present the only instrument to include developing countries in a global carbon market is the Clean Development Mechanism (CDM). The instrument is however facing serious weaknesses and challenges. Most importantly, it has not been able to induce major shifts in emission trends being a project-based baseline and credit mechanism, not mobilizing sufficient capital to induce climate stabilization (2008: pp. 15). This fact emphasizes the debate to up-scale the CDM.

In regard to the establishment of a global carbon market, various scenarios are conceivable. Flachsland et al. (2008) identify four possibilities how a post-2012 carbon market might look like. 1.) A Kyoto-like agreement with binding targets for Annex I countries, allowing trading between each other as well as the import of credits from developing countries. 2.) Linking of existing trading schemes in various Annex I countries and regions, where importing of credits that are generated in developing countries is allowed. 3.) Regional emission trading schemes in developed countries that allow the import of credits generated in developing countries into their schemes. 4.) A Kyoto-like agreement that does not cover all countries initially when being signed but allows for additional countries to be eventually included. Credits that are generated in developing countries are however allowed to enter the scheme.

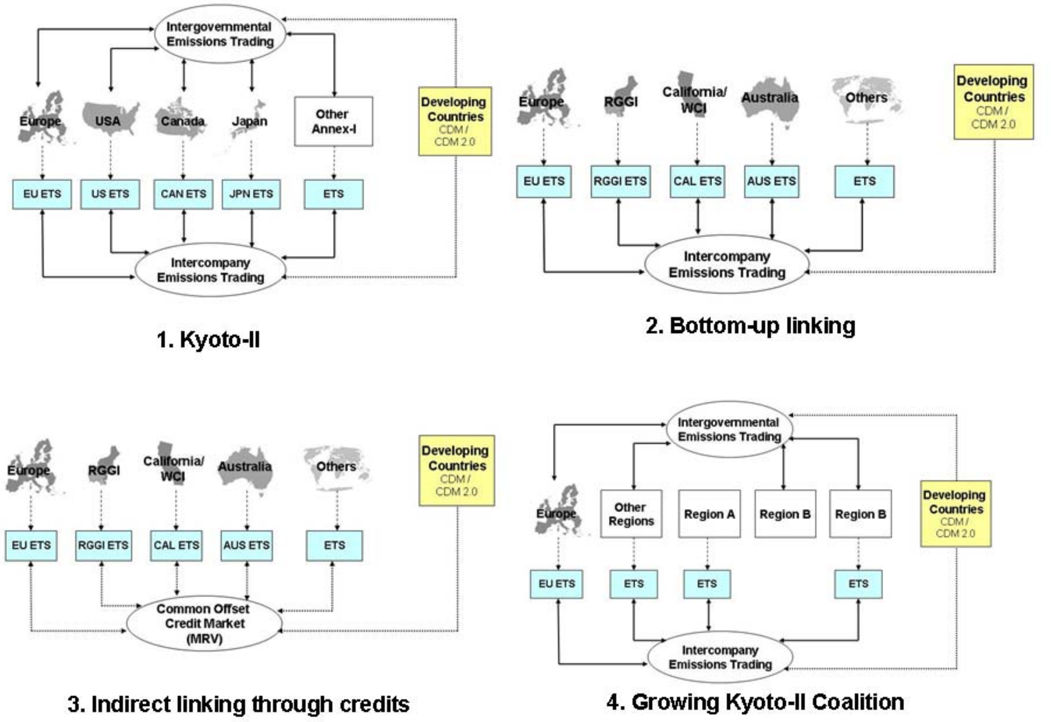

Figure 1-1: Different Scenarios for a Post-2012 Carbon Market Design.

Source: Flachsland et al. (2008: pp. 8)

Not going into too many details, it gets however obvious from Figure 1-1 that outlined possibilities always assume the integration of developing countries. Currently, the only instrument to include newly industrializing and developing countries into a global carbon market is the project-based CDM, being an international offset mechanism that has been established under the Kyoto Protocol. It is a major goal of this thesis to identify possibilities that can overcome its shortcomings as well as to determine proposals that are currently discussed in the international community. Thus, this thesis aims to contribute to the question how developing countries can be included into a global carbon market. As they play a key role in regard to global emission growth, the question how newly industrialized countries, for example China, can be integrated into a post-2012 climate regime is particularly at focus.

1.2 Methodology and Structure

For this thesis, possibilities to include newly industrialized countries, i.e. China, India, Brazil, Mexico etc. into a post-2012 climate treaty are determined. Therefore, the CDM, being the only instrument to include developing countries that exists to date, is firstly determined in chapter 2. Subsection 2.1 introduces the background of the CDM as set in the Kyoto Protocol. The rationale of the CDM is outlined in section 2.2 before the detailed functioning of the instrument is described in section 2.3. Finally, section 2.4 summarizes the current state of the market and discusses current strengths and weaknesses.

Thereafter, possibilities to reform the current mechanism are evaluated in chapter three. Section 3.1 at first determines general design options, while section 3.2 summarizes the proposals for a post-2012 CDM. Sectoral no-lose intensity targets are identified as a promising alternative to the current CDM in section 3.3, as major shortcomings of the current instrument can be addressed on the first sight. Furthermore, it seems to be a good alternative to build capacities in developing countries in regard to global emission trading.

Chapter four focuses on a detailed analysis of the Chinese energy system, including the political environment (section 4.1). An overview of the energy system including actors and the current state is outlined in section 4.2. China is chosen exemplarily for other developing countries, as it is the most important one from an economical, environmental and socio-economic point of view: It is not only the biggest country in terms of population and GDP, but also the most important emitter of greenhouse gas emissions behind the USA and thus importantly contributing to global climate change. In order to understand which factors have driven emission growth in China in the past, a decomposition analysis is applied, using the Kaya identity (Kaya, 1990) (section 4.3). The Kaya identity has been extended for this thesis to get a broader understanding of the influence of different primary energy carriers on emission growth. The Chinese electricity sector (4.4) and mitigation options in the Chinese electricity sector (4.5) have been determined, preparing the discussion of an integration of China into an international post-2012 climate protection agreement, by means of sectoral no-lose intensity targets and other options.

Chapter five then discusses climate policy options for China with special emphasis of sectoral no-lose intensity targets. Section 5.1 firstly identifies general post-2012 climate policy options, discussing them in the Chinese context. Finally, section 5.2 firstly gives an introduction to the nature of intensity targets in contrast to binding targets. Therefore, the approach has been determined analytically. Secondly, the implications of the approach in the Chinese electricity sector are discussed extending the Kaya identity. Moreover, the amount of credits that is possibly generated by sectoral no-lose intensity targets has been calculated, using IEA World Energy Outlook assumptions as a baseline.

Finally, chapter 6 concludes and outlines options how to integrate various climate policy proposals in a post-2012 climate regime.

2 The CDM's Current State

This chapter determines the current state of the Clean Development Mechanism (CDM). In order to understand possibilities of post-2012 possibilities to include developing countries in international efforts to curb greenhouse gas emissions, it is first necessary to understand the scope and the mechanics of the instrument that is currently in place. It is a central question of this chapter, which shortcomings of the current CDM can be identified.

2.1 The CDM in the Kyoto Protocol

The Kyoto Protocol (KP) provides three so called flexible mechanisms, emission trading between countries, Join Implementation (JI) and the Clean Development Mechanism (CDM). As the CDM is a basic part of the KP, it cannot be understood without having a closer look on the background of the KP, in general terms as well as in regard to economic considerations.

2.1.1 Basics of International Climate Policy

As the ultimate goal of international climate policy is already set in the United Nation's Framework Convention on Climate Change (UNFCCC), the role of the Kyoto protocol can thus be seen in defining and substantiating how this goal can be reached (Mittendorf, 2004). In general, the overall objections of international climate policy are laid out in article 2 of the framework convention on climate change (FCCC):

> *"The ultimate objective of this convention […] is to achieve […] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."* (UN, 1992: p.4)

The goal of the convention is thus to stabilize GHG concentrations in the atmosphere at "safe" levels. It does not make any statement, though, how terms like "dangerous anthropogenic interference" or "sufficient time frame" can be interpreted. Nevertheless the preamble and the principles to the convention reflect the common understanding of some agreed facts and guiding principles for international action on climate change (Grubb et al., 1999). Stern (2006: pp.454) outlines three guiding principles underlying the FCCC:

Ability to Pay: Wealthier countries should support poorer countries in their efforts to adjust to climate change.

Polluter Pays: Developed countries are responsible for the largest share of current and historical emissions.

Right for economic development: The share of developing countries' emissions in comparison to those of developed countries is – at least for an intermediate period - required to rise to accommodate developing countries' aspirations for growth and poverty reduction.

These principles are reflected in the commitments accepted by individual parties[1], which e.g. refer to the establishment of GHG inventories. In article 4.2. of the UNFCCC, developed countries listed in Annex I commit the adoption of policies and measures that demonstrate developed countries taking the lead in mitigating anthropogenic climate change. In the Kyoto protocol this fact is reflected by developed countries accepting actual reduction commitments based on a specified base year[2]. These countries and their individual commitments are listed in the Kyoto protocol's Annex B.

Even though some non-Annex I countries meanwhile have considerable shares in absolute emissions, their size of per capita emissions is still notably smaller than in Annex I countries. It is therefore morally difficult to ask for reduction efforts by non-Annex I countries. Considering this background, the Kyoto protocol aims for a GHG reduction of 5.2 % in average by developed countries only. Despite of a common reduction goal it can be found that considerable country to country differences exist[3]. While the EU is obligated to reduce its GHG emissions by 8%, other countries are allowed to keep their emissions on a constant level or may even rise them, as for example in the case of Iceland (+ 10%).

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[1] Commitments are outlined in detail in Article 4, UNFCCC (UN, 1992).

[2] For most countries the base year is 1990. For more details see Table 8-1 in Appendix A.

[3] See also Table 8-1 in Appendix A.

Six greenhouse gases are defined by the protocol, which are outlined in Table 2-1. Not every greenhouse gas has the same contribution to global warming. Therefore the global warming potential (GWP) is defined, comparing the radiative forcing of a given gas relative to CO_2, integrated over a time frame of 100 years. The approach is criticized in academic literature, pointing out that GWPs were uncertain and logically imperfect (Grubb et al., 1999). Nevertheless the approach was accepted in the negotiations by most countries and forms the background of the calculation of emission reductions in the Kyoto process.

Gas	Qualifying Sources	Lifetime (years)	GWP-100	% GHG 1990, Annex I
Carbon Dioxide (CO_2)	Fossil fuel burning, cement	variable, with dominant component ca. 100 years	1	81.2
Methane (CH_4)	Rice, cattle, biomass, burning and decay, fossil fuel production	12.2 ± 3	21	13.7
Nitrous Oxide (N_2O)	Fertilizers, fossil fuel burning, land conversion to agriculture	120	310	4.0
Hydro fluoro-carbons (HFCs)	Industry, refrigerants	1.5 - 264, HFC 134a (most common) is 14.6	140 - 11,700; HFC 134a (most common) is 1,300	0.56
Perfluoro-carbons (PFCs)	Industry, aluminum, electronic and electrical industries, fire fighting, solvents	2,600 - 50,000	average about 6,770; CF_4 is 6,500; C_2F_6 is 9,200	0.29
Sulphur hexafluoride (SF_6)	Electronic and electrical industries, insulation	3,200	23,900	0.30

Table 2-1: Greenhouse Gases in the Kyoto Protocol

Source: Grubb et al. (1999: p.73)

Table 2-1 shows tremendous differences between various greenhouse gases in all categories. It is important to mention that CO_2, being the most important GHG is basically caused by fossil fuel burning, as used to generate electricity or in the transportation sector. Furthermore it is also a by-product in the cement industry. Methane, being the second common GHG is mainly generated by agricultural activities. It is the shortest living GHG, while PFCs and SF_6 have a much longer life expectancy of several thousands of years. They also have an outstanding global warming potential, being considerably higher than of other greenhouse gases.

2.1.2 An Economic Approach to Climate Policy

Economically the fight against climate change can be interpreted in the theory of public goods.

> *"Climate change mitigation raises the classic problem of the provision of a global public good. It shares key characteristics with other environmental challenges that require the international management of common resources to avoid free riding. The UN Framework Convention on Climate Change (UNFCCC), Kyoto Protocol and a range of other informal partnerships and dialogues provide a framework that supports co-operation, and a foundation from which to build further collective action."* (Stern, 2006: p. xxii)

A global public good is provided by a stable state of the Earth's climate, being affected by millions of individual decisions. Looking at mitigation options to climate change in the form of emission reductions, actors (for example countries) are confronted with a prisoner's dilemma. There is an incentive for countries to free-ride on other countries' abatement efforts. The fight against global warming and thus climate change is therefore tremendously complex and difficult (Siebert, 1997). The Kyoto Protocol can be seen as the first political instrument facing this dilemma, including as many international actors as possible in order to provide a platform where decisions can be taken in common and to realize benefits from cooperation (Barett, 1999).

In order to face challenges being induced by global climate change, it is commonly understood that GHG emissions have to be priced in order to reflect the damages they cause. This is reached most efficiently by establishing a global carbon price, common across sectors and countries (Stern, 2006: pp. 309). There are a couple of different price-driven instruments available to reach this goal, of which emission trading is one among others (e.g. taxes or charges)[4]. Even though a detailed discussion of different approaches would go beyond the scope of the thesis, it is however believed that emission trading allows reaching a given environmental objective at lower costs, or to achieve a better environmental performance at a given costs (Philibert, 2000: p.948). Moreover, the establishment of emission trading schemes as for example in the

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[4] Compare e.g. Stern (2006: pp. 312) for a detailed discussion of taxes and tradable quotas.

European Union (EU ETS) or in various regions of the USA (e.g. RGGI) suggests that that cap and trade emission quotas will be at the core of future cooperation on climate change (Stern, 2006: p.488). Emission trading is furthermore already established in the Kyoto protocol between Annex B[5] countries.

The Kyoto Protocol provides three market orientated mechanisms to maximize cost effectiveness of climate change mitigation, by providing opportunities to reduce GHG emissions where it is cheapest. As a core element, emission trading provides each Annex B country with a certain amount of Assigned Amount Units (AAUs), reflecting its emission cap under the Kyoto protocol. This assigned amount can be interpreted as the responsibility a country takes for emission reductions (Stern, 2006: p.471). AAUs can be traded between Annex B countries. Moreover the project based bottom up approaches Join Implementation (JI) and the Clean Development Mechanism (CDM) are in place. While the JI creates emission reduction units (ERUs) by allowing project activities between developed countries, the CDM creating certified emission reductions (CERs) offers the possibility for developing countries to participate in carbon reduction. Credited ERUs as well as CERs are basically equivalent to AAUs.

Economically, these mechanisms reflect the existence of significant differences in marginal abatement costs around the world, which are caused by various reasons[6]. As it is irrelevant where emissions are abated, a reduction in an industrial country is as effective in regard to climate protection as one in a developing country, where the marginal cost of abatement might be lower due to lower environmental standards or less efficient technology use. This fact is illustrated in Figure 2-1, where various reduction possibilities for a given commitment by country I (being an Annex I country) are illustrated. The framework of the Kyoto Protocol allows emissions to be reduced in country II (being e.g. a non-Annex I country) with lower MAC, thus reducing the overall abatement costs.

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[5] Annex B refers to the Kyoto Protocol while Annex I is referring to the UNFCCC. Annex I and Annex B countries are basically congruent with some exception, e.g. the US (being an Annex I country without having ratified the Kyoto Protocol), Turkey and Kazakhstan.

[6] Stern (2006) mentions a couple of reasons for the existence of different marginal abatement costs among countries: Differences in rates of output, differences in emissions growth, differences in the structure of economies and energy sectors, different levels of technical efficiency and differences in income.

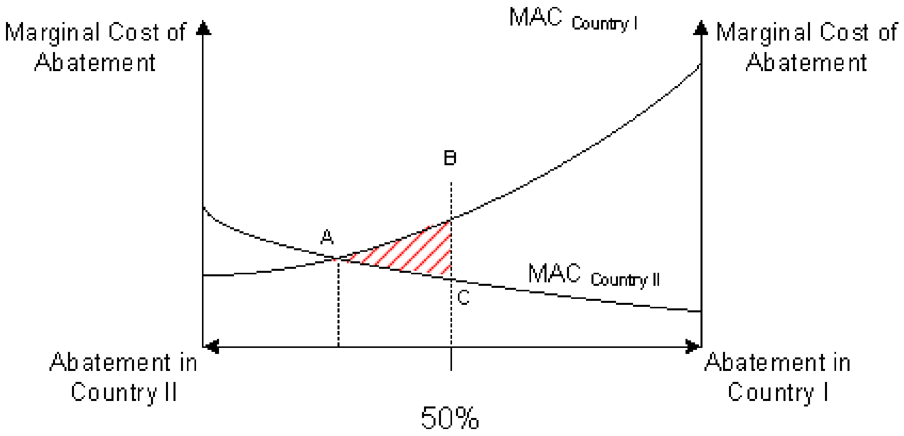

Figure 2-1: Principle of Flexible Mechanisms in the Kyoto Protocol

Source: Own Illustration Based on Mittendorf (2004)

Imagining that due to political or other reasons 50% of the reduction commitment shall be realized in country I, this would lead to efficiency losses, illustrated by the triangle ABC. It would be more efficient to reduce in country II until point A is reached and MAC I equals MAC II. At every point in the triangle ABC abatement would be cheaper in country II. In an emission trading scheme point A reflects the resulting permit price. The same principle holds for the CDM, as MAC curves of non-Annex I countries are usually lower than in Annex I countries.

2.2 Rationale of the CDM

The historic responsibility of developed countries for climate change is out of question. With regard to the principles laid out in the UNFCCC, it is thus reasonable that in the Kyoto Protocol Annex I countries are supposed to take the lead in emission abatement. Nevertheless, future mitigation to climate change has to include non-Annex I countries.

Looking at Figure 2-2 it is obvious that even a 90% cut in 1990 emission levels by Annex I countries would not be sufficient to stabilize GHG emissions at a level that is supposed to limit climate change impacts to an acceptable intensity if non-Annex I countries emit business as usual. In this case this would be a limitation to 450 ppm CO_{2e} in the atmosphere, which is believed to be a sufficient cap to reach the 2°C target as stipulated by the EU with a relatively high probability (IPCC, 2007: pp.40). Even if Annex I countries cut their emissions by 90% until the year 2050, it would still be necessary for non-Annex I countries to reduce their emissions by 50% compared to 1990 levels to achieve the 450 ppm goal.

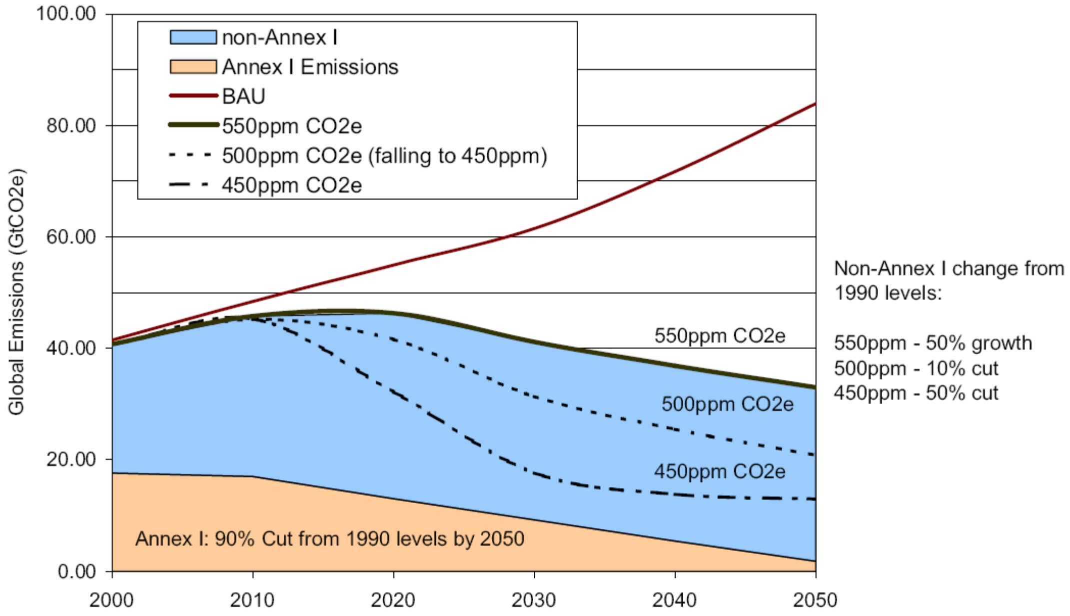

Figure 2-2: Projected Emission Levels in Annex I and Non-Annex I Countries

Source: Stern (2006: p.459)

In form of the CDM the Kyoto Protocol aims to provide a tool reflecting the situation described above, simultaneously referring to the principle of 'polluter pays'. Basically it can be stated that the CDM is a bottom up, project-based instrument, particularly designed to

> *"enable developed countries to meet their commitments, while allowing developing countries to participate in carbon reduction and gain co-benefits in technology transfer"* (Stern 2006: p. 506).

Norway proposed a mechanism for international cooperation in climate protection as early as 1991 for the 1992 Rio de Janeiro negotiations, which was named "Joint Implementation". Developing countries opposed this proposal, as they originally hoped for unconditioned financial transfers by developed countries. The JI was seen as an instrument having a negative impact on their sovereignty. Furthermore there was serious concern of developed countries investing in cheap mitigation possibilities (low hanging fruits) leaving only expensive abatement possibilities for developing countries in the future. Additionally, NGOs expressed their concern that JI might turn out to be a loophole to avoid own commitments as well as mitigation activity in developed countries (Michaelowa, 2005).

Despite heavy caveats by developing countries and the European Union the CDM could be brought on its way in the Kyoto negotiations. It combines two major goals: on the one hand to help developing countries to achieve sustainable development and on the other to assist Annex I parties in achieving compliance with their specific commitments at least costs. The generated emission reductions are certified on the basis of certain criteria. These include voluntary participation, real, measurable, long term benefits related to mitigating climate change and the so called 'emissions additionality'.

As stated in the Marrakesh Accords that specify the CDM provisions

> *"[a] CDM project activity is additional if anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity."* (UNFCCC, 2002: p.43)

When looking at the CDM in general it has to be considered that emission reductions generated by CDM projects (CERs) generate additional certificates to the global carbon market instead of simply reallocating them as it is the case in emission trading. Therefore it is highly important for the credibility and functionality of the CDM that emission reductions actually take place and are truly additional to any business as usual activity. If this is not the case, CDM projects would lead to a net increase in global GHG emissions (Michaelowa and Purohit, 2007). Basically, a project is considered to meet the additionality criterion if the expected project emissions are lower than the calculated baseline emissions (see also section 2.3.2).

While for purely bilateral projects additionality is not a major issue of concern, as CER revenues do not remain in the host country, problems occur when looking at unilateral projects where CER revenues remain with the host country project developer. Michaelowa (2007) argues that host country entities have an incentive to label business as usual activities as CDM projects that would be (financially) attractive without the CDM (as they for example increase an entity's efficiency) because they can gain additional revenues from generated CERs.

In order to prevent that host country entities benefit from business as usual activities labeled as CDM projects, it has been widely debated whether the definition for additionality mentioned above is sufficient, especially in regard to financial additionality[7]. The executive board (EB) defined a tool for the assessment of additionality, including an investment analysis, which is separate from the baseline methodologies (UNFCCC, 2007e)[8], meaning that a project can be not additional, even though its emissions are lower than the baseline emissions (Michaelowa and Purohit, 2007). Even though it has become common practice to use the tool when defining baseline methodologies it is formally not mandatory. However, including the EB tool in the validation process of the CDM project cycle shows that some effort is taken to ensure 'additionality' being granted in order to avoid fictitious emission reduction credits through business as usual activities.

2.3 Functioning of the CDM

In 2001 the international community defined common rules for the CDM as well as for JI. The Marrakesh Accords outline a complex framework for CDM projects. A wide range of various institutions shall guarantee their quality. In the following sections, the CDM process is introduced, firstly identifying and discussing relevant actors and secondly describing the project cycle.

2.3.1 CDM Actors

The COP/MOP

The COP/MOP (Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol) has the ultimate authority of the CDM. Article 12.4 of the Kyoto Protocol outlines that the CDM

> *"shall be subject of the authority and guidance of the COP/MOP and be supervised by the executive board of the CDM (EB)".* (UN, 1998: p.11)

Being the governing body of the CDM the COP/MOP is involved in fundamental procedural matters of political relevance and deals with broader strategic issues relating to the CDM. Therefore, it is not supposed to be involved in the day-to-day

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[7] Finacial additionality refers to the fact that projects leading to emission reductions being economically viable without the CDM should not be validated as CDM projects, as they do not create additional GHG reductions. This aspect is further discussed in Shrestha and Timilsina (2002), Greiner and Michaelowa (2003) and Michaelowa and Purohit (2007)

[8] A schematic overview of the tool can be found in Annex B.

administration of the CDM. It shall provide guidance to the EB, based on recommendations made by the EB to the COP/MOP as well as on the basis of the annual reports submitted by the EB. Additionally, it is involved in the final approval of designated operational entities (DOEs) as well as in the election and surveillance of the Executive Board.

The Executive Board

The EB is composed of ten members plus ten alternate members from parties to the Kyoto protocol including one for each regional group[9] plus one from the small island developing states. Additionally there are two representatives for Annex I Parties and two for non-Annex I Parties. Taking into account that three of the five regional groups are almost exclusively composed of developing countries, it can be assumed that the composition of the board ensures a greater representation of developing countries (Yamin and Depledge, 2004).

The main functions of the EB are to accept validated projects formally as CDM projects and to issue CERs. Moreover, the EB is responsible for the provisional accreditation of operational entities, which are formally designated by the COP/MOP. The EB also decides upon new methodologies and baselines for the calculation of emission reductions.

Due to its position, the EB's operational functions involve close liaison to all stakeholders potentially interested in CDM projects, including not only Parties and Intergovernmental Organizations (IGOs), but also businesses, project developers, non-governmental organizations (NGOs) and other private entities involved in implementing CDM projects. Even though the EB is fully accountable to the COP/MOP, the fact that decisions taken by the EB will affect the environmental integrity of the CDM (and potentially the protocol as a whole) outlines its importance for the CDM process.

Panels

The CDM modalities allow the Executive Board to establish committees, panels or

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[9] The five regional groups are: African States, Asian States, Eastern European States, Latin American and Caribbean States, Western European and Other States. "Other States" include Australia, Canada, Iceland, New Zealand, Norway, Switzerland and the USA. Japan is part of the Asian Group.

working groups "to assist it in the performance of its functions". Therefore, the EB established specific guidelines and specific terms of reference and guidance. Panels can be established on temporary or specific tasks or may also have a standing function. One important panel consulting the EB is the methodology panel supporting the board in all questions related to newly proposed baseline and monitoring methodologies.

Designated National Authority

The CDM modalities state the need for each country to establish a Designated National Authority (DNA) in order to participate in CDM project activities. The main task of the DNA is to give written approval to the project participants after it examined the project according to the presented criteria. In case of the Annex I country DNA, a project participant needs to be authorized to participate in the CDM, hence the Annex I country itself gets involved in the CDM project (IETA, 2006). In the case of the host party's DNA, the responsibility is to confirm that a project activity assists in achieving sustainable development. The host country's DNA is thus in charge for determining what is sustainable and what is not (Netto and Barani, 2005).

Designated Operational Entities

DOEs are primarily responsible for CDM projects to be in conformity with the CDM modalities. A DOE can be either a domestic legal entity or an international organization[10]. It is accredited and designated by the EB on a provisional basis until it is confirmed by the COP/MOP. Basically, DOEs have three important functions. At first, they check project proposals for completeness and forward proposed new methodologies to the EB. Secondly, they validate a project proposal and request its registration, using an approved methodology at the EB. Thirdly, at the end of a CDM project cycle they also verify emission reductions and request the board to issue CERs accordingly. DOEs also call for public comments to the project design document (PDD) and the monitoring report.

Private companies as DOEs are highly engaged in the institutional framework of the CDM. It can be said that private entities in the form of DOEs have a key role,

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[10] A list of DOEs can be found in Annex C.

certifying the actual GHG emission reduction for official bodies of the UN framework. It has been one expressed goal when the CDM was negotiated that private entities play a certain role. It is important for the process that DOEs are neutral, not being involved in the design of the actual project to avoid conflicts of interest.

Project Participants

Project Participants (PP) can either be parties to the Kyoto Protocol or private/or public entities authorized by a party to participate in CDM project activities. The main task of PPs is to propose and to implement CDM activities. PPs also have the possibility to propose new baseline and monitoring methodologies to account for emission reductions. In this respect, the CDM framework provides a bottom-up approach to develop methodologies to account for emission reductions.

Public

All information that is basis to decision making in the CDM process is publicly available. Public comments are accepted in two phases of the project cycle, when designing the project activity and before the DOE starts validating the project. Moreover, the EB has the possibility to ask for public comments on specific documents, such as for example newly proposed methodologies

UNFCCC Secretariat

The main purpose of the secretariat is to "*support and link all actors in providing means for all actors to communicate in interact in a cost effective manner*" (Netto and Barani, 2005: p. 181). Furthermore, it maintains the CDM registry as well as a web-based information system. It provides up-to-date information on implementation and operation of the CDM process. The UNFCCC secretariat is supposed to play a neutral role without giving any recommendations or judgments on the CDM activity.

2.3.2 Project Cycle

A host country as well as a NGO or any other investor (including investors from non-Annex I countries) can come up with a project idea. According to Yamin and Depledge (2004) various approaches to a CDM project can be distinguished. The bilateral approach describes a situation, where entities (PPs) from Annex I countries invest in projects in non-Annex I countries, in order to generate CERs. The generated certificates can be used on their own behalf, i.e. to fulfill their Kyoto commitments (in case the PP is a country), to use it in the EU emissions trading scheme (EU ETS) (in case the PP is a private company subject to the EU ETS) or to sell the generated CERs on the secondary market. The unilateral approach describes the possibility that a non-Annex I party undertakes CDM activity without an Annex I party counterpart in order to sell the generated certificates later on to an Annex I party or actor. The multilateral or portfolio approach describes a situation where an international financial institution such as the World Bank (or other intermediaries) puts a portfolio of CDM activities together on the behalf of others.

However, every project has to run the project cycle described below, which is illustrated in Figure 2-3 and which is described in the following:

Design Phase

The design phase is dominated by the PP, who proposes the CDM project activity. Most importantly, the PP has to ensure that the proposed activity uses an approved methodology for baselines and monitoring. The proposing process is strictly prescribed by the CDM modalities. The Project Design Document (PDD) is the key element in the design process. The UNFCCC provides exact rules, which key information shall be included in the PDD by the PPs.

One important aspect of the PDD is the calculation of expected emission reductions. This is done by comparing the emissions generated by the project to a baseline describing the emissions that would have occurred without the project activity. Therefore, the PP has to choose the crediting period of the project (that is the period for which CERs are issued), basically having two options: A maximum of ten years with no option of renewal or alternatively a period of seven years, which may be renewed at most two times for another seven years per renewed period. The PP has to justify its choice in the PDD (BMU, 2003).

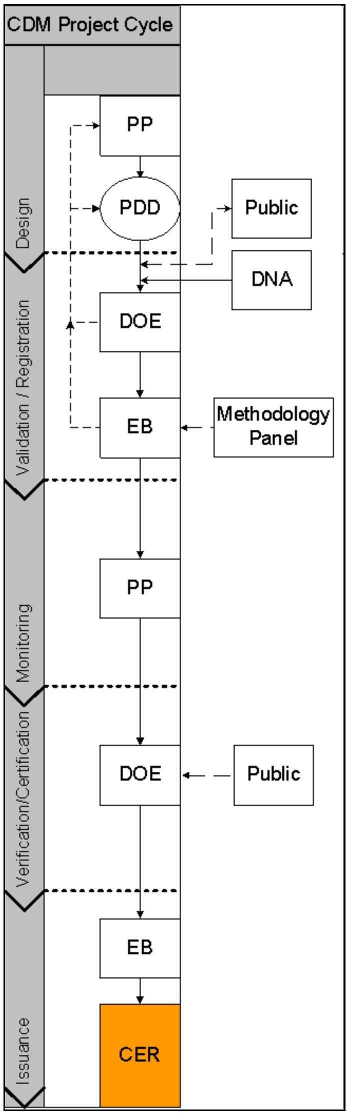

Figure 2-3: CDM Project Cycle

Source: Own Illustration based on UNFCCC (2007)

The PP can choose a baseline methodology out of three possible approaches[11]. An existing methodology can be used, if appropriate. In case the project participant concludes that a new methodology is required in order to get admission for the planned project activity, it may propose a new one to the DOE, which forwards the

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[11] Project participants shall select the approach that seems to be the most appropriate for the project activity, justifying this choice in the PDD. As outlined in UNFCCC (2002: p.37), the three approaches are based on: a) Existing actual or historical emissions, b) Emissions from a technology that represent economically attractive course of action, c) The average emissions of similar projects undertaken in the previous five years in similar social, economic, environmental and technological circumstances, whose performance is among the top 20% of their category. In case the project fulfills the criteria for small scale projects, simplifications are in place, which are not further discussed at this point.

proposal to the EB.

Validation and Registration

After a DOE is contracted by the PP, the DOE checks whether the validation requirements are met. This process includes ensuring that baseline and monitoring methodologies are approved by the EB. The DOE makes the PDD publicly available in order to make it possible for stakeholders, parties and UNFCCC credited NGOs to comment on the planned CDM project activity. After a deadline for public comments has passed, the DOE starts to determine whether the proposed project activity should be validated. The PP is to be informed when the determination process starts. If the suggested project activity is validated, the DOE submits it to the EB, requesting registration. Before requesting registration, the DOE needs to have written approval from the DNAs of the parties involved. The registration by the EB is the formal acceptance of a validated project as a CDM project activity. Unless a party involved or at least three members of the executive board request a review of the proposal, the registration shall be granted eight weeks after the date of receipt of the PDD by the EB.

In case a project is subject to a new methodology it is in a pre-validation stage until the EB has decided about the proposed methodology.

Monitoring

Monitoring refers to the identification, collection and archiving of information necessary to implement a monitoring report. The preparation of a monitoring report by the PP is a precondition for verification of a given project activity by the DOE and thus the certification and issuance of CERs by the EB. The monitoring report is based on the monitoring plan (subject of the PDD), which has to be based on an approved monitoring methodology. If a matching monitoring methodology is not available, a new methodology can be proposed, which has to be approved by the EB. The monitoring report by the PP is a core element in the CDM project cycle. For its creation, PPs collect and archive all relevant data necessary for calculating GHG emission reductions by a CDM project activity (Mizuno, 2007). It forms the basis of decision making in determining how many CERs are finally issued by the EB. Whether the monitoring plan is accepted or not is subject of the decision of the DOE.

Verification and Certification

Verification refers to the review and ex-post determination of monitored reductions in GHG emissions as a result of a registered CDM project activity by the DOE. Consequently certification in this case refers to the written assurance by the DOE certifying that during a given period of time a project activity achieved a certain amount of reductions in anthropogenic GHG emissions. Finally the DOE sends a certification report to the Executive Board (EB).

Issuance

Receiving the certification report from the DOE, the EB instructs the CDM registry administrator to issue a specified number of CERs into the pending account of the PP. The issuance of CERs is considered to be final unless three board members or one of the involved parties to the KP request a review. However, this review is limited to certain issues, such as fraud, malfeasance and incompetence of the DOE. The responsibility for final issuance of the CERs to the registry accounts of the PPs rests with the CDM registry administrator (UNFCCC secretariat), which is also responsible to hold back 2% of the issued CERs for adaptation and administrative expenses as agreed upon under the KP.

2.4 A Brief Review of the Current CDM

The following section is supposed to provide a market overview of the current CDM activities. It concludes with a discussion of the current CDM's performance.

2.4.1 Market Overview

The CDM market experienced steady growth rates since it was implemented. In May 2008, 1058 (as of May 18, 2008) CDM projects have been registered, generating approximately 215 million CERs annually in average. Another 55 projects are requesting registration, being expected to generate more than 10 million CERs in average per annum. Additionally, more than 3000 projects are in the CDM pipeline. All together these projects are expected to create emission reductions of more than 4 Gt CO_{2eq} in the form of CERs until the end of 2012, assuming that crediting periods are not renewed (UNFCCC, 2007b).

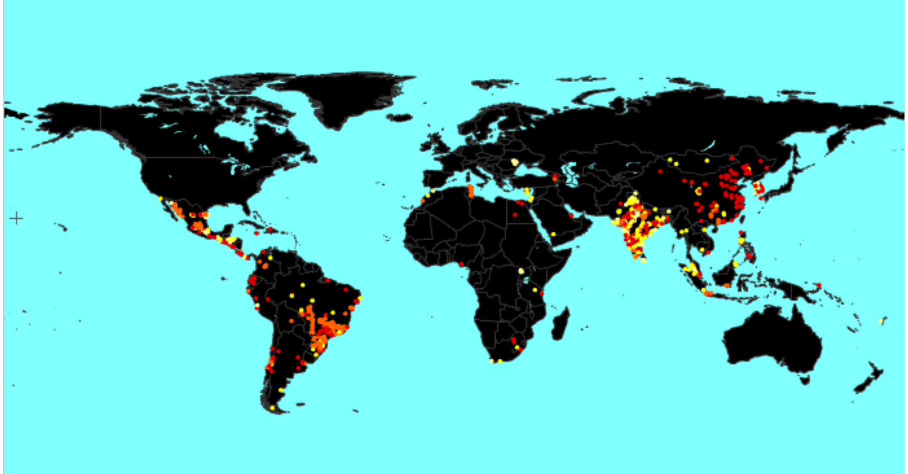

Figure 2-4: Geographical Distribution of Registered CDM projects[12]

Source: UNFCCC (2007a)

Looking at the geographical distribution of CDM projects, Figure 2-4 shows impressively that the majority of registered projects is located in India (36%), China (12%), Brazil (15%) and Central America (mainly Mexico) (16%) (UNFCCC 2007c). Africa is highly underrepresented having a share of only 3% of which 85% are situated in Tunisia, Morocco or South Africa.

The geographical distribution of projects is not equal to the distribution of issued or expected CERs, which is due to different projects sizes and different global warming potentials of the six greenhouse gases (see also Figure 2-1, page 10). Therefore China plays a much bigger role when it comes to the actual reduction in greenhouse gases. As illustrated in Figure 2-5, China accounts for 50% of the CERs expected to be generated until 2012. Generally it can be said that the Asia Pacific Region dominates the market. 77% of the CERs are expected to be generated by projects located in this area until 2012, considering project activities that are currently registered and in the pipeline.

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[12] Differently colored dots stand for various project types (large scale, one location (red), large scale, various locations (orange), small scale, one location (yellow), small scale, various locations (light yellow)

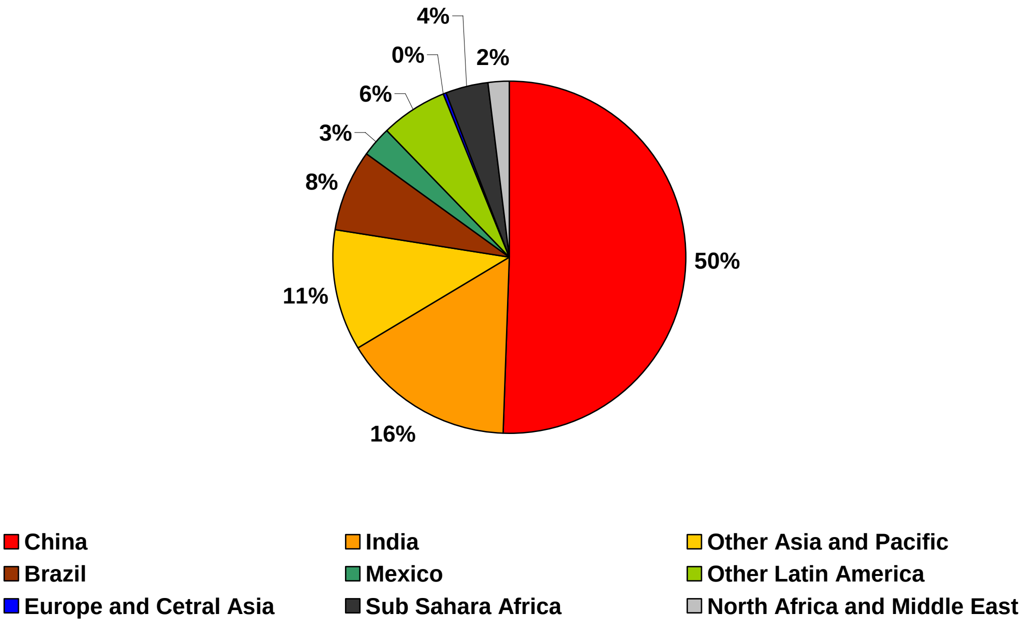

Figure 2-5: Regional Distribution of Expected CERs Cumulated until 2012

Source: UNEP Risø (2007)

Regarding the distribution of various project types, most CDM projects activities (59%) are connected to renewable energy. This trend is not reflected by the volume of CERs, where HFC and NO_2 reduction projects are dominant having a share of 37%. This can again be explained by the high global warming potential of these greenhouse gases. Renewable energy or energy efficiency projects qualify for CO_2 reductions, which has a comparably low GWP.

Looking at the actual projects that generate certified emission reductions, a high share is generated by investment in so called low hanging fruits. Figure 2-6 shows that a reasonable part of emission reductions is due to HFC projects, where emission credits can easily be generated by simply burning HFC. The resulting CO_2 is still a greenhouse gas, though having a much lower global warming potential.

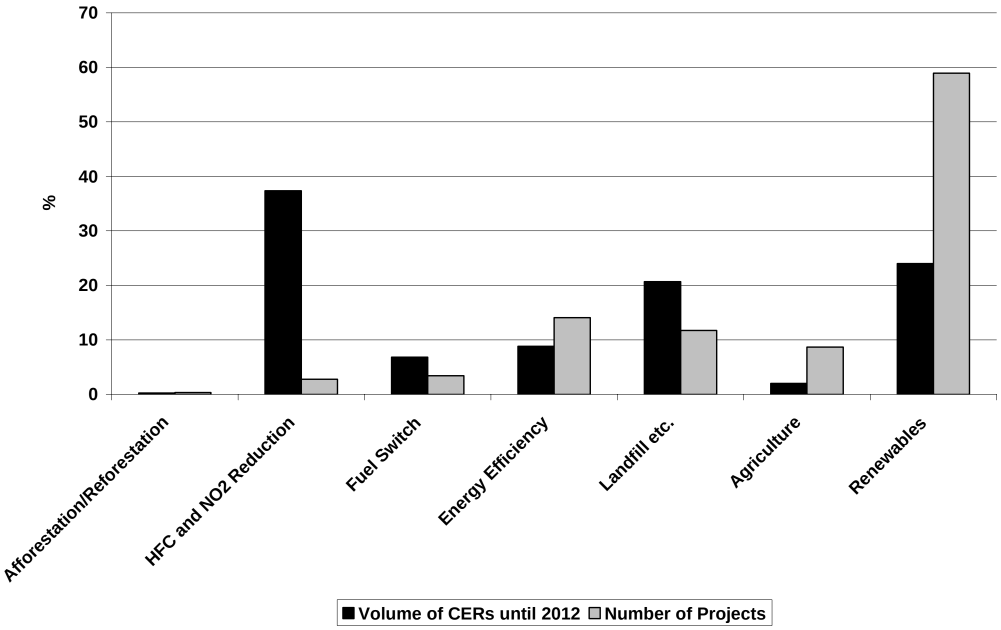

Figure 2-6: Volume of CERs until 2012 compared to Number of Projects in Percent

Source: UNEP Risø (2007)

The prices for CERs depend heavily on the maturity of a project and thus the risk that is connected to the investment in different stages of the project cycle. As illustrated in Figure 2-7 notable differences can be found, in the price ranges as well as in the average prices. Compared to 2005, the discount between pre-CERs and primary CERs even widened in 2006, reflecting concerns for the actual verification of pre-CERs (Ambrosi and Capoor, 2007). The weighted average prices for primary CERs was € 8.40 in 2006 (being in a range of € 5.20 and € 18.90), while secondary CERs were traded in a range between € 8.22 and € 20.65. Being the dominant market player, China has influenced the overall market price by its informal policy of requiring a minimum acceptable price before providing DNA approval, being in the range of € 8 to 9 in 2006. Other countries were able to use China's price floor as a basis, with little discounts for countries that recently entered the market (Ambrosi and Capoor, 2007)

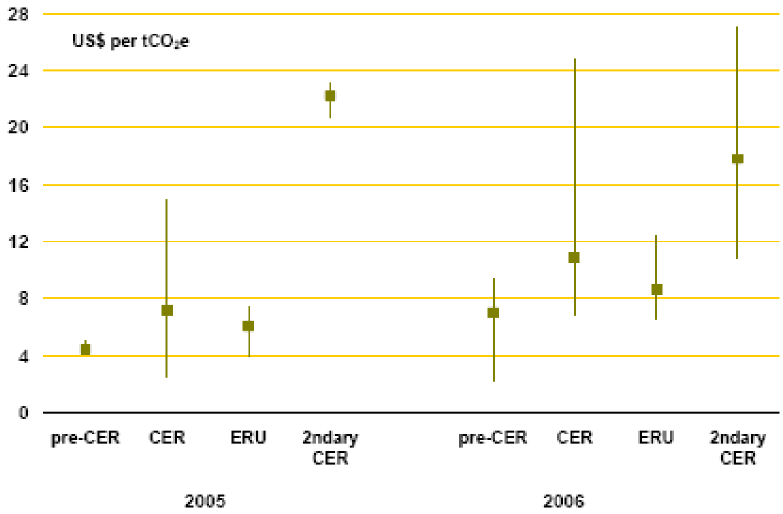

Figure 2-7: Observed Prices for Project Based Assets 2005 and 2006

Source: Ambrosi and Capoor (2007: p. 31)

2.4.2 Discussion of the Current CDM

The simple existence of the CDM, being a political tool trying to support sustainable development in developing countries financed by Annex I countries, implies that developed countries accept their responsibility for climate change. Regarding the UNFCCC criteria, the CDM refers to the 'polluter pays' and the 'ability to pay' principles. The CDM paved the way for a new form of cooperation between developing and developed countries providing a platform for private as well as public entities to invest in projects in developing countries (Stern, 2006: pp.490). The CDM plays an important role in creating a certain interest for the problem of climate change in the private sector leading to the establishment of specialized companies, expertise and networks between Annex I and non-Annex I countries. It allows for private capital flows to developing countries, building an additional financing source for non-Annex I countries to 'regular' developing aid funded by governments.

The CDM furthermore allows developed countries to fulfill their commitments more cheaply. In making developing countries to participate in greenhouse gas mitigation, directing Annex I investment to projects that meet local priorities for sustainable development it can – in an ideal case - create a win-win situation for both, developing and developed countries. Moreover, developing countries benefit from co-effects such as technology transfer. It can be seen as a highly positive aspect of the CDM that it is the only instrument of the Kyoto protocol considering technological transfer. It is still doubtable, though, whether this goal is always achieved. Especially in regard to unilateral projects some argue that it actually reduces the technology transfer from developed to developing countries. Local project developers are likely to use local technology, as *"[...] they may not have sufficient capital or expertise for choosing, adapting and maintaining [foreign] technology*" (Michaelowa, 2007: p.25). At the same time, host country project developers might prefer local technology, as they do not want to depend on foreign investments.

When looking at the distribution of CDM project activities, it is eye-catching that LDCs are highly underrepresented, while big newly industrializing countries (NIC), namely China, India, Brazil and Mexico account for 74% of the projects and the lion's share of the expected CERs (UNFCCC in June 2007). As claimed by Friberg et al. (2006: p.11) the CDM

> *"[...] fails to provide sustainable development benefits and bypasses the poorest countries, which is a market failure the CDM shares with conventional markets."*

Reasons can be found when looking at the project developers being private companies. Even though aspects of the CDM in regard to public private partnerships on a multinational level are considered to be highly innovative (as for example the role of DOEs), Stern (2006: p.506) argues, that profit driven project developers are reluctant to engage in countries being considered as politically difficult. Thus, investment flows are directed to countries that provide relative political and economical security, while high transaction costs, weak institutions and scant industry base lead to investors being rather hesitant to engage in LDCs. On the other hand it should be kept in mind that NICs, such as China, India or Brazil also represent the biggest share of the non-Annex I countries' GDP and also have a reasonable share of the overall population. Cosbey et al. (2006) illustrate a GDP and population deflated distribution of CERs in the CDM pipeline. They show that NICs have a comparatively low share when taking the GDP into account, with India approximately having a share of 4%, Brazil 3%, China around 2.5% of the overall expected CERs in 2012. Rather, countries like Mongolia, Nicaragua and Honduras are relatively seen the most important countries. A similar picture is drawn when having a look at the population deflated distribution of the CER pipeline, where South Korea is outstanding, while China as well as India do not have considerable shares.

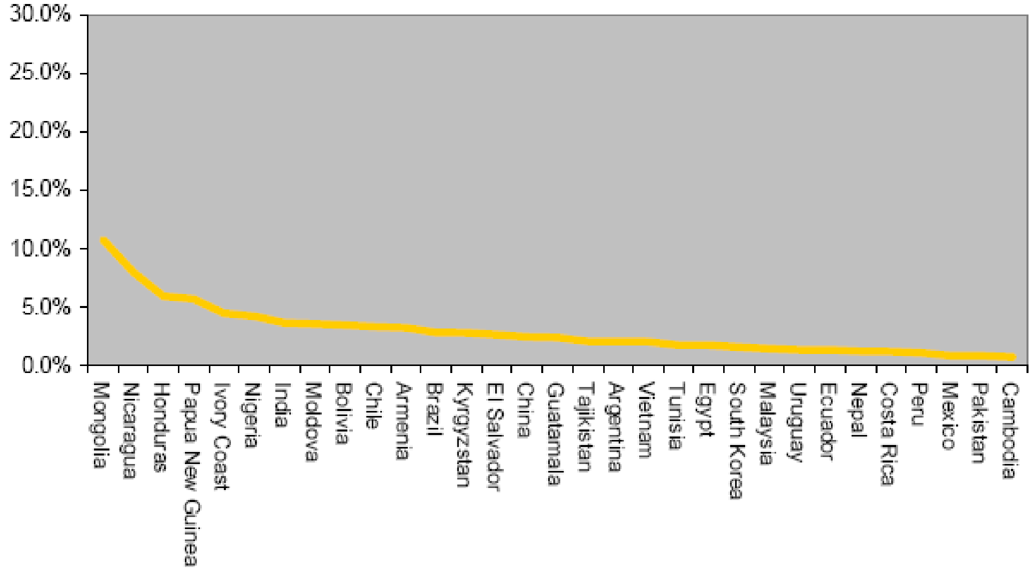

Figure 2-8: GDP Deflated CERs in Pipeline (Total to 2012, as of June 20, 2006)[13].

Source: Coseby et al. (2006, p. 27)

However, when regarding the weighted regional distribution of CERs, it can still be found that Sub-Saharan Africa (where most of the LDCs are situated) is underrepresented, while Latin America and the Caribbean (46%) and the Asia Pacific region (33%) are dominant. An explanation can be found considering that many LDC countries do not participate at the CDM at all, lacking a functioning CDM environment, as for example a working DNA (Cosbey et al., 2006).

In general it is reasonable to say that the CDM has been more successful in allocating cost efficient GHG emission reductions than in delivering sustainable development. As non-Annex I countries can define the sustainability requirements for CDM projects in the form of DNA approval to the project there is no standardized definition for sustainability. At the same time, single individual countries have not enough market power to influence the global price of carbon. Resulting in the competition between non-Annex I countries for CDM investment there is an incentive to set low sustainability standards in order to attract more projects, which can even

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[13] Only the top 31 countries are shown, GDP in 2004, current USD. CER data from UNEP Risø Pipeline June 2006

lead to a race to the bottom (Sutter and Parreño, 2005).

Another weakness of the current CDM is that it fails to provide incentives for developing countries to reduce future emissions. Stern (2006) claims that project based carbon finance acts as a form of subsidy that reduces emissions in a specific project, not affecting the demand for high carbon goods and services across the economy as a whole. As a result, the overall emission level in both host and investing country may stay high or even increases. Stern (2006: pp.478) proposes to offset CDM credits against a reduction baseline rather than against a business as usual (BAU) baseline as it is the case now. It should be mentioned at this point that BAU baselines generally rely on forecasts, which makes them unreliable. Project developers have an incentive to overestimate what would have happened in the absence of a project, in order to maximize the generated credits (Cozijnsen et al., 2007). Furthermore, it shall be mentioned that the CDM does not recognize the implementation of carbon discouraging policies such as taxes, renewable energy and energy efficiency goals etc. as climate mitigation measures, which would set an incentive for countries to implement CDM projects at a larger scale and might lead to a higher consideration of sustainability aspects when agreeing to CDM project activities.

Other critics of the CDM sometimes bring up the concern that the CDM might undermine the environmental integrity of the Kyoto protocol. Greiner and Michaelowa (2003) argue that the CDM – in the difference to international emissions trading or JI – leads to the creation of new emission allowances entering the overall system. If CERs are created for investments that would have happened anyway, for example by investing in energy efficiency projects that would be profitable without selling the credits generated by the CDM, "fake" emissions would undermine the emission targets (Greiner and Michaelowa, 2003). The additionality of a CDM project is thus a tremendously important aspect, which is difficult to control on the one hand and furthermore is responsible for high transaction costs in the CDM cycle. The current CDM framework is equipped with various methodologies to ensure that a CDM project activity is truly additional, as shown in previous sections. If this is the case, the environmental integrity of the KP is not affected. But, Michaelowa and Purohit (2007) find proof that at least some non-additional projects have been accredited by the EB, as "*validators [...] have not been able or willing to thoroughly* *check the additionality argumentation of project developers* ... " (Michaelowa and Purohit, 2007: p. 13). This fact raises the question whether the current methodologies to ensure additionality are sufficient.

3 Reforming the CDM Post 2012

The Kyoto protocol is currently the most important instrument of international climate policy. While it will soon phase out, it is not certain which kind of climate regime will follow. A number of different post-Kyoto climate policy options are widely discussed, some targeting a follow-up mechanism in the rationale of the current protocol, basing on a system of internationally binding targets for Annex I countries, while others push for a completely new mechanism[14]. Integrating developing countries in the fight against global warming is an issue of pivotal importance. Participation could take different forms, ranging from mandatory requirements to qualitative pledges, e.g. to make their development path more sustainable. Although being the most important instrument to enforce the participation of developing countries, the role of the CDM after 2012 is currently not clear. It is however reasonable to believe that at least elements of the current structures will be kept and somehow integrated into a post-Kyoto structure.

> *"The KP can be seen as a first stepping-stone on the path to international co-operation on climate change, given political, economic and scientific realities. The institutions, mechanisms and guidelines developed under Kyoto represent enormous investment of negotiating capital"* (Stern, 2006: p.479).

However, it is conceivable that another market based mechanism could supplement the current flexible mechanisms, even though some basic elements and institutions remain. In this section the future role and design of the CDM shall be discussed, while further principal modification possibilities of the Kyoto Protocol are not regarded. In any case it is clear that a post-2012 CDM will require a demand for generated credits, most likely induced by international emission trading schemes.

First, principal requirements options for a post-2012 CDM are introduced, before discussing actual proposals. Finally, post-2012 CDM proposals are presented and analyzed.

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[14] For an overview and categorization of post-2012 approaches see e.g. Cosbey et al. (2007, pp. 36)

3.1 Options for Designing a Post-2012 CDM

Looking at various possibilities how to include developing countries to a post-2012 climate regime, a couple of options can be distinguished. At present, the CDM is the only instrument that takes developing countries into account for international climate change mitigation. It is however far from providing a sufficient incentive for developing countries to reduce GHG emissions; furthermore sustainable development aspects are only limitedly encouraged. On the other hand, an institutionalized CDM process has been established, widely accepted by developing and developed countries. As shown in the previous chapter, the establishment of the CDM led to the implementation of a complicated and institutionalized framework, but also to a vital market with a broad number of different stakeholders. Therefore, it is highly doubtable that countries that are currently profiting from the CDM agree to a post-Kyoto regime where the idea of the CDM would be completely abolished. For some developing countries the CDM goes along with increased investment flows, technology transfer and access to leading-edge clean technologies (Cosbey et al., 2007), while for developed countries generated CER help them to fulfill their binding Kyoto commitments at lower costs. It is however obvious that the CDM also faces weaknesses as outlined in section 2.4.2. Furthermore, it cannot be neglected that non-Annex I countries are a strongly heterogeneous group covering countries with different states of development and interests. Least developed countries (LDCs) suffering from a limited economic and political stability and weak legal structures highly differentiate from newly industrialized countries (NICs) like the Republic of Korea, Brazil or China, which have – at least in parts – a high economic and political standard that is comparable to Annex I countries. It is reasonable to doubt whether one single instrument can sufficiently cover the needs and expectations in regard to international climate policy of all these countries. A post Kyoto CDM should guarantee that LDCs are sufficiently supported in sustainable development issues, while a process demanding more active participation of NICs in international emission trading, possibly including binding targets, should be brought on its way.

In the following, basic design options of a post-Kyoto CDM are discussed in principle. Equipped with this terminology, specific proposals that are currently under discussion for the design of a post-Kyoto CDM are introduced (section 3.2) and analyzed (section 3.3).

3.1.1 Absolute vs. Relative Targets

Absolute targets are often linked to absolute emission caps, as for example the commitments taken by Annex B countries in the Kyoto protocol. Extending these to developing countries could be defined as the incorporation of developing countries into the Annex I/Annex B (Philibert and Pershing, 2001). Developing countries would thus be fully integrated to a global carbon market, having the possibility to sell and buy credits, but also being faced to possible penalties if targets are not met.

In general, developing countries strongly oppose absolute emission targets as they fear possible restrictions on their economic development (see e.g. Philibert, 2000: p.948). In order to address developing countries' concerns it would be possible to fix targets at such a high level that they would not have any effect on developing countries' growth projections. It is doubtable, though, whether this would be an effective and acceptable alternative. In combining fixed targets with a trading scheme the over-allocation of permits to developing countries could create an huge amount of tradable permits, often referred in literature as "hot air" (Philibert and Pershing, 2001).

In contrast to absolute emission caps for developing countries, relative emission targets are flexible and linked to a pre-agreed variable. Various variables are conceivable, e.g. 'population growth rate', 'development of exports' or 'GDP growth rate' of which economic growth represents a variable of major concern for developing country planners and is therefore probably the most important one (Philibert and Pershing, 2001). Relative targets are supposed to be more politically feasible in regard to developing countries than absolute targets (Gielen et al., 2002). In comparison to absolute targets relative targets do not cap absolute emissions. Capping absolute emissions is often understood as a simultaneous cap for economic development. Relative targets rather set a certain level of efficiency. Therefore, they might be easier to accept for developing countries, as in case of strong economic development this would not be prohibited by an emission cap.

Many different possibilities for implementing relative targets are conceivable. Baumert and Goldberg (2006) propose a dynamic target based on actual emissions they call "Action Target". In this case the required reductions are expressed as a percentage of a country's actual emissions during a predefined compliance period.

Reductions would for example always be a certain percentage compared to a business as usual scenario. Emission expectations leading to the BAU scenario would be determined ex-ante and corrected ex-post.

However, compared to absolute targets, relative targets do not have the same level of certainty in regard to emission reductions as the economic growth rate (or any other variable a reduction target would be linked to) is not perfectly foreseeable. Theoretically, even an absolute increase in emissions would be conceivable. Thus, when the goal is to achieve a certain level of emissions, relative targets are inefficient (Fischer, 2003: p.2). Gielen et al. (2002) find that an absolute cap is not only more efficient but also more predictable in terms of future emission levels. Nevertheless, in regard to an international emission trading system, flexible targets can reduce ‘hot air’ as over-allocations are avoided (Philibert and Pershing, 2001).

3.1.2 Binding vs. Non-Binding Targets

Binding targets generally imply penalties for non-compliance to a pre-defined target. On the other hand it is crucial for the idea of non-binding targets that participating countries (e.g. developing countries) would not have to fear any penalty in case the target is not met. Instead, countries would only earn benefits if they met a pre-defined threshold, for example by having the possibility to sell emission credits. A non-binding target can therefore be seen as an incentive to reach a pre-defined goal, as their emission reduction efforts are rewarded by the revenues they earn by selling the credits.

It is likely that non-binding targets can be more stringent than binding targets, as developing countries are not necessarily obliged to fulfill them and therefore have a ‘pull-out option’. Negotiations about targets would likely not be about potential losses, but about potential gains for countries, in other words about the size of the incentive (Philibert and Pershing, 2001).

Non-binding targets respond to the strong economic development concerns often mentioned by developing countries in regard to binding targets offering a greater certainty that their economic growth is not negatively affected. Binding targets often go hand in hand with penalties in case a target is not met. Even though this methodology ensures that emission targets are met, it might lead to decelerating economic growth, especially when economic growth is not decoupled from emission growth. Different forms of non-binding targets are conceivable (see also Philibert and Pershing, 2001). One possibility would be to formulate a non-binding target in the form of a general statement, e.g. in the form of a generalized goal to reduce GHG emissions. Another possibility would be to allocate emission allowances to developing countries who could sell credits on a global carbon market as long as the allocated budget is not exceeded. Analogously, emission reductions below a baseline could be sold. Other countries (for example Annex I countries) having fixed targets would be a precondition in order to stimulate the demand for such permits.

It is also conceivable to combine binding and non-binding targets (Philibert, 2000: p.949). The non-binding target would therefore be established at a lower level than the binding target with the non-binding target being a ‘selling target’ and the binding target being a ‘buying target’. A country would then be obliged to buy credits if its emissions exceed the binding target, while it may sell credits when its emissions are lower than the non-binding target. If a country’s emissions were in the corridor between non-binding and binding target it would not take part in any trading activities.

3.1.3 Economy-wide vs. Sectoral Targets

Emission reduction targets could be applied to sectors (e.g. electricity, steel, cement etc.) rather than the whole economy. In principle, every policy instrument that is applicable for the whole economy can also be applied on the sectoral level. Sectoral targets can thus have different forms, binding or non-binding as well as relative or absolute. They can be established nationwide or across countries, although cross-country standards might face implementation problems.

For sectoral targets some disadvantages compared to inter-sectoral alternatives are conceivable. They might be less cost effective than economy-wide approaches as they do not cover the same quantity of emissions and thus abatement opportunities. Furthermore the definition of participating sectors might be rather arbitrary. Additionally, inter-sectoral emission leakage might occur, which is fully accounted for in only economy-wide approaches (Philibert and Pershing, 2001). Emission intensive activities could be shifted to sectors that are not covered by an emission target. On the other hand sectoral targets might be easier to accept for countries that do not have taken emission commitments yet, as only selected sectors would be included in an international climate regime. Emission projections and monitoring are easier to handle on the sectoral level as they are for the whole economy, which makes it easier to value the dimension of potential emission reduction commitments. Moreover, developing countries would have the possibility to exclude sectors that are either difficult to control (for example LULUCF) or not desired to be part of any kind of international treaty (for example industry branches that are major drivers of the country's economy).

From an Annex B[15] country's point of view, sectoral approaches could help to solve leakage concerns and confront international competitiveness risks (Baron and Ellis, 2006). Currently, Annex B countries face a situation where emissions caused by the production of internationally traded goods create costs that would not occur if the same good was produced in a non-Annex B country. Over time, this can lead to the relocation of emission sources to non-Annex B countries (leakage). Even though this would lead to an emission reduction in Annex B countries (having fixed and binding targets) the relocation would not lead to a global reduction of emissions. In case of an international sector-wide approach, leakage and competitiveness issues could be addressed to some extent by applying emission reduction targets for the whole sector in non-Annex I countries (Claussen and Diringer, 2007). It is interesting to mention at this point that in each of the most important GHG intensive industry sectors worldwide, ten or less countries account for over 80% of the global emissions[16] (Schmidt et al., 2006: pp.8).

In developing countries sectoral approaches could focus climate change mitigation efforts to some rapidly growing sectors, which are characterized by large capital stocks with high GHG intensity (Baron, 2006). A good example would be the electricity sector, where the broad investment in carbon-intensive but relatively cheap coal or gas power plants can be observed, having a life expectancy of several decades. Sector-based approaches could bring mitigation incentives for developing countries in relevant sectors, without requiring economy-wide emission reduction targets (Baron,

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[15] Annex B refers to the Kyoto Protocol while Annex I is referring to the UNFCCC. Annex I and Annex B countries are basically congruent with some exceptions, e.g. the US (being an Annex I country without having ratified the Kyoto Protocol) and Kazakhstan.

[16] The following sectors are considered (number of countries accounting for 80% of the sector's global emissions in brackets): Electricity (10), Iron and Steel (3), Chemicals and Petrochemicals (9), Aluminum (4), Cement and Limestone (7), Paper, Pulp and Printing (4). See also Annex G.

2006).

Additionally, sectoral approaches could possibly address uncertainties regarding the monitoring of emissions in certain sectors as for example methane and nitrous oxide from agriculture and livestock or CO_2 removal from forestry. Furthermore, they are a possibility to address the inability to control emissions in other sectors such as the transportation sector (Philibert and Pershing, 2001). As sectors that cannot be monitored precisely are possibly excluded from a sector based GHG commitment, countries might have fewer constraints against any form of an emission reduction commitment. In addition to that, sectoral approaches offer the possibility to differ between producing and consuming sectors, which might be interesting from a political point of view (Philibert and Pershing, 2001).

3.1.4 Project-based vs. Policies and Measures

The current CDM can be interpreted as a project-based baseline and credits trading scheme. CERs are generated by individual projects, while policies and measures leading to emission reduction efforts are not regarded. As all parties are obliged by the UNFCCC to undertake policies and measures that help to mitigate climate change (UN, 1992) it would be a logical extension to identify and define specific policy requirements. This option would not necessarily be linked to emission targets in any form, but builds upon agreements to implement specific mitigation options (Philibert and Pershing, 2001). These options vary widely. Developing countries adopting specific policies could be one option. Possible policy options include energy subsidy removal, fiscal reforms and carbon taxes, as well as domestic energy consumption limits or research and development and education policies that are designed to affect long term GHG emissions (Philibert and Pershing, 2001).

Policies and measures can be integrated into the current CDM structure, even though some modifications would have to be implemented. Credits could be generated by a policy or standard that leads to reduced GHG emissions. The policy or standard does not automatically have to be an obvious climate change objective, but could also be designed in the form of a fuel efficiency standard for cars with the aim to reduce air pollution (Cosbey et al., 2007). In terms of additionality it can be argued that policies and measures automatically fulfill the criterion as they would not have been implemented without the incentive given by the CDM. However, baseline setting could turn out to be difficult as it would be challenging to predict emission trends in absence of such a policy. Thus, the monitoring of effects that are caused by policies and measures is challenging.

3.2 Proposals for a Post-Kyoto CDM

In the following sections, three approaches to a post-Kyoto CDM are discussed, especially in regard to sectoral crediting. Analogously to the current CDM, post Kyoto approaches are supposed to generate certified emission reductions that can be sold on an international carbon market (see also section 2.1). Therefore it is especially interesting how current proposals deal with the question how credits are generated.

First of all, the idea of Sustainable Development, Policies and Measures (SD-PAM) is discussed. Second, an introduction to the ideas of a sectoral clean development mechanism is pictured, being firstly developed by Samaniego and Figueres (2002). Finally, the idea of sectoral no-lose intensity targets developed by Schmidt et al. (2006) is discussed.

3.2.1 Sustainable Development, Policies and Measures

The concept of sustainable development, policies and measures (SD-PAM) describes an approach to respond climate change, introduced by Winkler et al. (2002). It is based on the observation that climate change concerns are marginal for developing countries, while economic and development policies have higher priorities. SD-PAMs build fundamentally on the principle of “common, but differentiated responsibilities” being outlined in Article 3 of the UNFCCC (UN, 1992: p.4) to define the differentiated roles of developed and developing countries in fighting climate change. Instead of setting emission targets, the approach focuses on implementing policies for sustainable development. Sustainability is therefore understood as contributing to basic human needs, in a way that *“can continue over time, result in less damage for the environment and provide more social benefits and long-term economic development“* (Winkler et al., 2002: p. 63). This approach can hence be seen as a pledge by developing countries to implement sustainable development policies and measures. Therefore, they first need to examine their development priorities. In a second step, policies and measures that will help developing countries to reach their sustainable development goals need to be identified. Thereafter, it would be necessary to identify policies and measures that lead to reductions in GHG emissions as well as those that will lead to an emission increase. The former could be rewarded by international climate policy instruments, as exemplarily discussed below.

SD-PAMs define a desired future state of development before working backwards how this state can be reached. Mitigation of climate change is not a major intention. It is however estimated that a more sustainable development path will be less GHG intensive than any business as usual development path not focusing on sustainable development. This assumption is graphically illustrated in Figure 3-1.

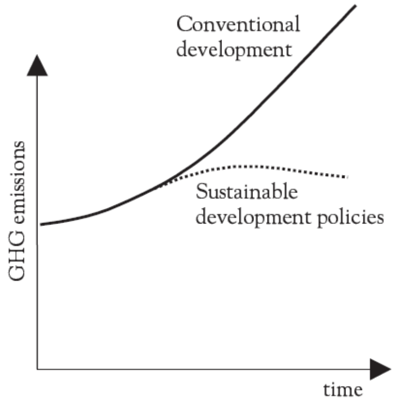

Figure 3-1: Theoretical Impact of SD-PAMs on GHG emissions

Source: Winkler et al. (2002: p.64)

Even though the SD-PAM approach focuses on sustainable development rather than on mitigation of climate change, it is still conceivable that specific SD-PAMs leading to GHG emissions reductions qualify for crediting in a project-based baseline and credits trading scheme. The current CDM requires projects to reduce emissions and contribute to sustainable development, which is a strong analogy to SD-PAMs (Winkler et al., 2005). However, it would be necessary to open the CDM modalities for SD-PAMs, especially in regard to additionality. As SD-PAMs ‘stand for themselves’, the CDM would not be the pivotal incentive to implement the project. Thus, SD-PAMs would per definition not qualify for CDM projects. SD-PAMs can be interpreted as an instrument in development policy in order to mainstreaming carbon finance and climate change issues into development.

3.2.2 Sectoral Clean Development Mechanism

The ‘sectoral clean development mechanism’ is often cited in the post-Kyoto CDM debate as an instrument that could substitute the current CDM. It is however not always clear what exactly is meant by a sectoral approach, as different people have used the terminology, describing different approaches.

Samaniego and Figueres (2002) firstly proposed a sectoral clean development mechanism (SCDM) as a complementary to the existing mechanism. The SCDM enhances the current CDM by the possibility to include specific sustainable development policies. They would not necessarily cover a whole sector (as for example the cement sector), but could also be applied on a sub-sectoral, cross-sectoral or regional level. As SCDMs would fit in the current CDM structure, the amount of generated emission reduction credits would be a matter of baseline definition. The setting of the baseline would thus remain a vital and also critical issue of the project cycle, which would not be modified itself. In comparison to the current CDM, the SCDM baseline goes beyond the idea of a single project baseline. The GHG emission reductions by a SCDM are verified against a baseline scenario describing the emission level without the implementation of the policy or measure, be that regional, sectoral or both. As far as additionality is concerned, it might be easier to prove in a SCDM than in the project-based CDM. In the SCDM the policy itself is the project, an additionality test would therefore need to be performed at the policy level instead evaluating additionality individually from case to case. It is however problematic how the effect of the implemented policy or measure can be quantified. It is considered to be highly controversial to set a business as usual baseline, as it is difficult to state what would have happened without the policy or measure. In regard to the 'additionality' criterion, it would be possible for the EB to define a list of policies that would qualify for being additional, for example incentives/subsidies for the dissemination of renewable energy generation, appliance and/or motor efficiency standards, building efficiency standards etc. (Figueres, 2006: pp.15). This would be an alternative to the current practice, where the EB defines what additionality is not. As governments or government agencies would be the project participants in the rationale of the current CDM, CERs would be issued to them. Whether governments keep the revenues or distribute them to actors being affected by the implemented policies is left to them.

Various other sectoral approaches to the CDM have been proposed, which build on the idea of the SCDM, but do not fundamentally differ. Cosbey et al. (2005) name the approach described above ‘policy based’. A sectoral CDM in their understanding is described as a bundling of different projects along the lines of a sector. Therefore they consider sectors promising the highest potential for implementing sustainable development policies.

Figueres et al. (2005) define a programmatic CDM, which is based on the bundling of different single project-based CDM projects. In contrast to the SCDM approach defined by Samaniego and Figueres (2002), the programmatic CDM includes private sector activities more explicitly. Therefore, private actor initiatives could include the voluntary adoption or advocacy of technology standards, private promotion of improved wood stoves or the sponsoring of a more efficient alternative to burn clay bricks (Figueres et al., 2005: pp.7). Putting aside this clarification, the approach basically resembles the SCDM approach. Thus, the programmatic CDM would be included in the current CDM structure, meaning that one acting agent would be responsible for the selected policy to be proposed in a single PDD, gaining CERs for the GHG reducing actions being a result of the implemented program or policy.

Another variation of a sector-based approach is proposed by Bosi and Ellis (2005). Going beyond the current project-based CDM structure, various sectoral crediting mechanisms (SCM) are introduced, namely policy, rate-based and fixed-baseline approaches (Bosi and Ellis, 2005: p.6). Therefore, they point out two different options. A trans-national SCM being based on an international standard and applied on facilities world-wide, while national SCMs would be applied on facilities in a national sector only. In case of a fixed-baseline, credits would be allocated to governments or entities that are engaged in the sector if the emissions drop below the baselines. In case emissions exceed the baseline, governments (or entities) would face penalties for non-compliance.

3.2.3 No-lose Emission Intensity Targets

The idea of no-lose emission intensity targets as presented in the following has been developed by the Center for Clean Air Policy (CCAP) (Schmidt et al., 2006). It combines different approaches to a post-2012 climate regime, namely national, sectoral, non-binding and relative. The CCAP approach is based on the idea of developing countries pledging to achieve voluntary no-lose emissions intensity targets in major energy and heavy industry sectors, e.g. electricity, steel, pulp and paper, oil refining and metals. When actual emission intensities are below a no-lose baseline, the corresponding emission reductions are certified and can be sold on an international carbon market. Thus, there is no penalty for not meeting the target, but a positive incentive to over-comply.

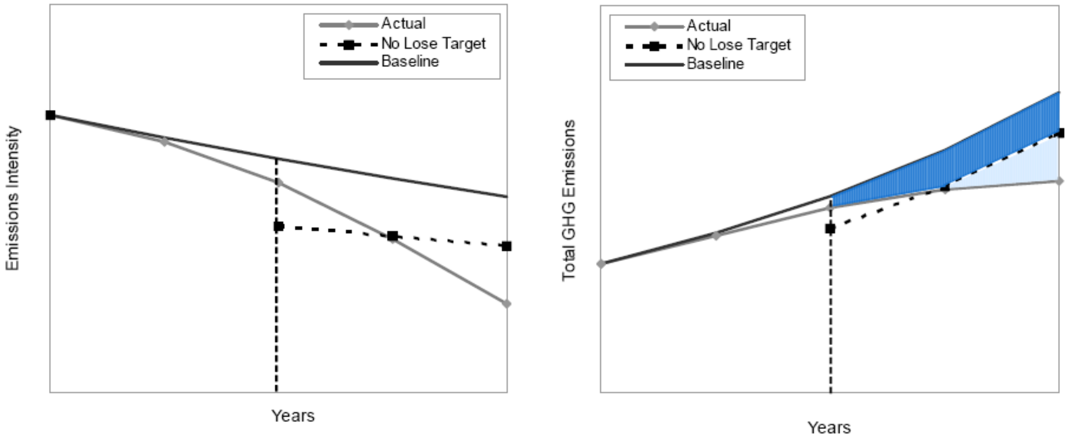

Figure 3-2: Schematic Development of GHG emissions intensity levels (left) and absolute emissions (right). The amount of emissions saved compared to the BAU case is illustrated by the blue area, of which the light blue area describes credits that are available for sale.

Source: Schmidt et al. (2006: p.4)

Figure 3-2 schematically shows how a no-lose intensity target is supposed to function. For both panels the bold black line represents the business as usual case. On the left hand side the development of intensity targets is shown. The dotted horizontal line represents the no-lose target, while the actual decline of the emissions intensity is shown by the grey line. On the right hand side the development of annual absolute emissions is qualitatively pictured. The amount of emissions saved is shown by the blue area, of which the light blue area pictures the emission savings qualifying for crediting. However, as intensity targets are the determining parameters, a decline in absolute emission growth rates (as assumed in Figure 3-2) is not guaranteed, as increasing production will enable additional emissions without affecting the intensity level.

Formalized, credits C generated at any given time i can be calculated by

$$C_i = (\bar{\gamma} - \gamma_i) \cdot X_i ,$$

with $\bar{\gamma}$ being the no lose emission intensity target and γ_i being the actual emission intensity at time i (emission intensities are measured in t CO_{2e}/production unit). X_i

represents the overall sectoral production in i, for example in tons of cement or kilowatt-hours electricity. As credits are only generated when the actual sectoral emission intensity is lower than the no lose intensity target, $\bar{\gamma} > \gamma_i$ is a necessary side condition.

A feasible option could be to calculate emissions and output on a yearly basis (ex-post or ex-ante) so entities would be enabled to participate in the global carbon market during the same compliance period in which emission reductions occur. Alternatively emissions and output could be calculated ex-post over the whole target demonstration period.

The country selling credits has to decide whether and how credits are distributed internally. Schmidt et al. (2006) show two alternatives: First, to allocate the certificates or the revenues from the sale to individual entities that actually have made efforts to reach the target while free-riders are spared out. Second, it would also be possible to award possible credits directly to all covered companies. Schmidt et al. (2006) do not clarify the modalities of rewarding companies. However, various possibilities can be imagined, inter alia tax relieves for participating companies or an ex-post rewarding based on the production output or the emission intensity. It is however doubtable whether the incentive for private entities to invest in efficiency improvements while the rewarding is not certain is sufficient. In particular since the achievement of the selling point of overall intensity is a collective outcome, incentives need to be granted by the state for individual facilities. Therefore, a country might need to implement regulatory policy instruments to ensure climate action. At the same time it is probable that derivate markets for certificates from the scheme will emerge, describing the value of credits by the uncertainty whether no-lose targets will be achieved.

The exact setting of the intensity pledge is an important question. In the CCAP approach, Schmidt et al. (2006) propose that intensity targets are to be negotiated. Negotiations with individual countries shall be based on a global benchmark for energy intensity levels for major processes within each sector[17]. The benchmarks are supposed to be determined by international experts. Alternatively, experiences from

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[17] Schmidt et al. (2006) argue that possibilities other than energy intensity levels could raise difficulties in regard to country to country (sector to sector) variations in the fuel mix.

the EU ETS might be used. A variety of possibilities is conceivable when evaluating different benchmarks, which are pictured in the following. However, it can be argued that a single sectoral benchmark sets stronger incentives to structurally turn to low carbon technologies. Applying different benchmarks for different technologies, higher emitting technologies, as for example coal fired power plants in the electricity sector are subsidized.

Exemplarily looking at the electricity sector, it is obvious that a single sector can be determined by several benchmarks. In the electricity sector a couple of different benchmarks could be chosen for various technologies, such as gas fired power plants, coal fired power plants etc. Schmidt et al. (2006) point out that in order not to inhibit the international negotiation process a limited number of benchmarks should be defined[18], however still reflecting the major range of engineering differences between facilities.

The technology type that underlies the benchmark can also be discussed. While Schmidt el al. (2006) propose to base benchmarks on commercially available technologies, various other options are possible. These include the best available technology and technologies under development. However, as technology development is continually progressing, it would be necessary to update benchmarks from time to time. As the speed of technological development varies from sector to sector, specified and sector based reviews are necessary. In analogy to the current CDM, Schmidt et al. (2006) propose the benchmark to be updated at least every seven years.

If only one benchmark is in place covering existing as well as newly built facilities, already existing facilities face disadvantages. Reasons can be found in the different technical availability of emission reduction technologies and the cost for retrofit old technologies versus new facilities. Schmidt et al. (2006) therefore propose to set different benchmarks for new and old facilities. Alternatively it is also conceivable to give old facilities more time to reach the common benchmark.

The energy intensity benchmarks described above would build the base for defining a domestic GHG intensity target for the covered sectors. Countries would

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[18] Schmidt et al. (2006) propose a maximum of five benchmarks.

apply the benchmarks to their national facilities using the corresponding fuel mix to determine the analogous GHG intensity level for each participating sector. But, the national GHG intensity target a country would finally propose also depends on other, rather unilateral factors next to the globally standardized benchmarks. In evaluating its individual pledge, a country inter alia will consider the following aspects. First, Schmidt et al. (2006) argue that a country will evaluate which effects an intensity pledge could have on the competitiveness of the sector. Second, the country also regards how a GHG intensity pledge matches with general development objectives, e.g. improving the air quality. The resulting pledge would have to be negotiated with the international community, which can try to give incentives for developing countries to accept more aggressive no-lose targets.

Such incentives are given in the form of technology finance and assistance packages (TFAP) to assist developing countries in their climate mitigation efforts (Schmidt et al., 2006: pp. 13). It can be claimed in general, that the more ambitious the no lose target is, the higher is the absolute amount of emissions being actually saved from the atmosphere, compared to a business-as-usual level, assuming that the actual intensity is lower than the intensity pledge. Financing is supposed to be provided by developed countries, international financial institutions and export credit agencies. TFAPs could support the deployment of advanced technologies, the development of small and medium sized enterprises to assist in technology implementation, capacity building activities and pilot and demonstration projects. Therefore, TFAPs contribute to decreasing costs for new, climate friendly technologies, which might lead to developing countries accepting more aggressive no-lose intensity targets. However, it depends on other factors, whether developing countries have an incentive to make an effort reaching the no-lose target, especially on the expected price for emission certificates. A high expected price would logically be a stronger incentive than a low expected price. In any case, the price level depends on the demand for credits in developed countries, thus on the stringency of climate mitigation policy in Annex I countries.

3.3 Discussing Post-2012 CDM Approaches

A post-2012 CDM needs to balance the demands and expectations of developed and developing countries. Generally, it therefore needs to improve the quality (e.g. sustainable development) as well as the quantity (e.g. accessibility and cost-effectiveness) dimensions of the current CDM (Cosbey et al., 2007: p.3). It is presumed that developing countries are more likely to agree to any post-2012 approach if developed countries bear the costs of mitigation efforts. In the past, non-Annex I countries often based their argumentation on equity issues, stating that Annex I countries are responsible for climate change and therefore are also accountable for occurring costs. In general, it is reasonable to assume that a post-2012 CDM agreement will be judged by its ability to reflect the basic principles underlying the UNFCCC as outlined by Stern (2006) (see section 2.1.1), namely the ability to pay, polluter pays and the right for economic development. Annex I countries on the other hand will take into consideration how well a post-2012 CDM can contribute to international climate change mitigation efforts. Furthermore, it will be regarded how cost effective GHG reductions can be achieved. This fact is especially important when assuming that Annex I countries continue to have binding emission targets, having the possibility to use tradable certified emission reductions to fulfill their commitments. Moreover, Annex I countries will probably not accept a post-2012 CDM that significantly could diminish the competitiveness of their domestic industries, especially in regard to large NICs such as China, India or Brazil. At the same time, non-Annex I countries stress the fact that they will not accept any constraints on their economic development.

3.3.1 Quality of a post-2012 CDM

The main aspect that needs to be discussed in regard to the quality of a post-2012 CDM is the aspect of ‘sustainability’, which can be derived from Article 2, UNFCCC (UN, 1992: p.5). Sustainable development is a major goal of the Convention and the CDM in particular. However, it remains a difficult question how to define sustainability and sustainable development. The Brundtland commission defined sustainable development to be

> *“[...] the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”* (WCED, 1987)

It goes beyond the scope of this thesis to discuss all conceivable aspects and dimensions of sustainability and sustainable development[19]. However, the criterion 'sustainability' has more dimensions than 'environmental effectiveness' even though environmental aspects are regarded as well. But, in addition to measuring how effective GHG emissions can be avoided, 'sustainability' also takes local environmental effects into account, as for example water- and air quality or land use. Furthermore sustainable development also has a social component, considering for example health, employment and equity issues. Equity at this point can be understood on the intra-national level (as for example in the form of income differences) as well as on the international level (in regard to more developed countries). Moreover, in regard to the Brundtland definition, intergenerational equity should be kept in mind as for example in regard to the exploitation of natural resources. Thirdly, an economic factor can be considered. Therefore, aspects as for example energy efficiency, energy costs and security of supply play an important role. It can be assumed that the principles of the UNFCCC will underline a post-2012 CDM as well as they define the current CDM. A post-2012 CDM thus has to ensure the enforcement of sustainable development, especially in developing countries. This will build trust for considering other forms of commitments in the future (Winkler et al., 2002: p.83).

3.3.2 Upscaling the CDM

In general, the discussion of sectoral proposals can be seen as a reaction to weaknesses in the current instrument, also in regard to environmental effectiveness and additionality. As the project-based CDM is linked to high transaction costs in order to guarantee the environmental effectiveness in form of a complex project cycle, scaling up the CDM to the programmatic, policy or sectoral level is believed to ease major shortcomings of the current instrument (Höhne, 2007). At the same time, modifying the instrument from its current project-based character is considered to address the 'quantity dimension' of the CDM that has been discussed at the beginning of this section.

Generally, it is extremely difficult to make a statement on the quantity of generated certificates as it depends on many variables. But, it is also tremendously important to have an idea of the magnitude of generated emission certificates, as the amount of

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[19] For a discussion of indicators for sustainable development see for example International Atomic Energy Agency et al. (2005)

certificates being generated in developing countries has impacts on the design of climate policy instruments in Annex I countries. In this context, it is interesting to determine whether trading approaches other than fixed and binding targets can be integrated in an absolute cap and trade scheme, as it would be the case when linking Annex I countries to an up-scaled CDM. Various alternatives are conceivable, as shown earlier in this chapter. Philibert (2000) shows that it is basically possible to include trading schemes based on non-binding targets to cap and trade emissions trading based on fixed and binding targets. However, efficiency losses are likely, for example in the case of relative emission targets (Gielen et al., 2002).

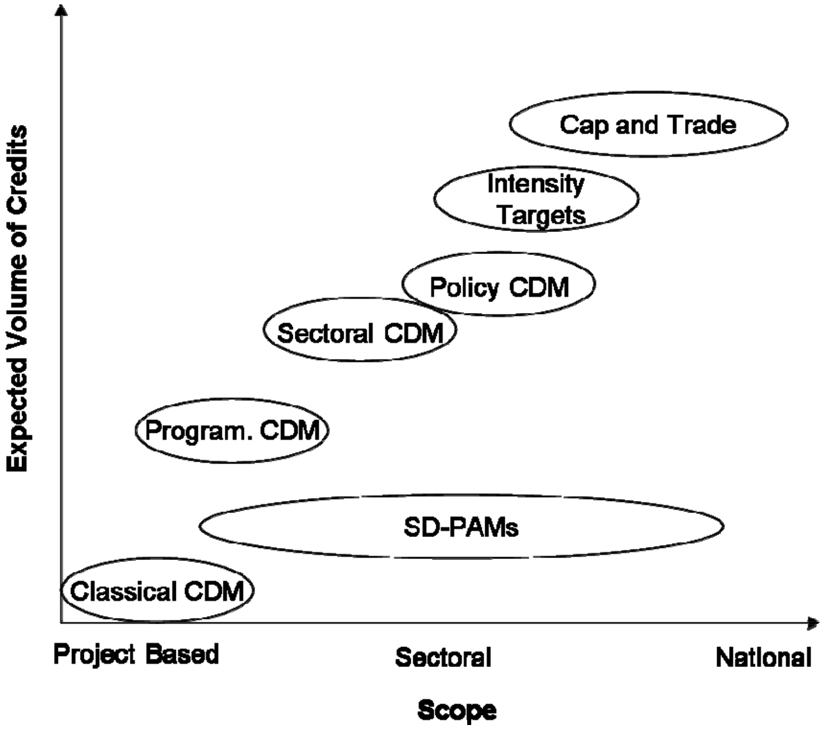

Figure 3-3: Options for Scaling up the CDM

Source: Own Illustration, Expected Volume of Credits Inspired by Höhne (2007: p.4)

Regarding emission trading, various possibilities can be differed. Next to including a particular country into a global cap-and trade regime, several alternatives are conceivable as shown in section 3.1. Having a look at Figure 3-3, various options of baseline and credit schemes for scaling up the project-based CDM are shown. While the x-axis points out the implication level, the y-axis indicates how close a particular approach comes to the idea of economy-wide binding caps, as they are applied for Annex I countries in the Kyoto protocol, thus also on the quantity of generated certificates.

Most proposals can be implemented on more than one level, e.g. sectoral or national, as their detailed design is still a matter of international discussion. While the classic CDM is a purely project-based mechanism, all post-2012 CDM proposals aim to scale up the instrument. The programmatic CDM is very closely linked to a project-based approach, while the sectoral CDM and the policy CDM basically aim to be implemented on the sectoral level. As SD-PAMs describe a broad package of policies and measures, they can be project-based, sectoral or national. Intensity targets and binding caps can be applied both on the sectoral as well as on the national level, even though cap and trade is mostly discussed for the whole economy.

Figure 3-3 does not consider the possibility of binding and non-binding targets, which could in principle be applied to all outlined approaches. However, in general trading approaches raise import questions in regard to baseline setting and additionality concerns that need to be discussed on an international level. It is uncertain whether an international emissions trading scheme with binding emission commitments will be introduced in the next commitment period. It is very likely that it will not include developing countries. Nevertheless, a post-2012 CDM can benefit the stimulation of the necessary capacity and infrastructure for international emissions trading to be implemented in the future, such as detailed emission inventories and projections (Sterk and Wittneben, 2006: pp. 280). However, even in applying a sectoral or policy CDM, governments gain experience with large-scale climate protection policies. This cannot necessarily be claimed for the current CDM, as it does not include climate policy options, but is limited to single projects.

Any post-2012 CDM will be judged by its general availability to address shortcomings of the current mechanism. Next to constraints in regard to the environmental integrity, thus its availability to contribute to global GHG reductions, its availability to support structural changes of sectors or economies will also be an issue. Being a project-based instrument, the CDM as it is in place now, does not support sectors or economies to be generally less carbon-intensive. Furthermore, it is an important issue how and if environmental effectiveness is guaranteed, measured in regard to how successful GHG emissions can be avoided. The current CDM faces this problem by defining the ‘additionality’ criterion (see section 2.2). In general, environmental effectiveness is difficult to measure in regard to any policy instrument as uncertainties occur in a number of relevant aspects such as predicting, quantifying and monetizing the impacts of global climate change (Aldy et al., 2003). On the other hand, proving that a particular measure leads to emission reductions is highly complex and bureaucratic – thus causing high transaction costs – and is still not guaranteeing environmental effectiveness, as it can be observed for the current CDM.

In the following, post-2012 CDM possibilities are shortly discussed in regard to their particular impact on discussed shortcomings, namely high transaction costs, no incentives for changing the structure of the economy towards low carbon technologies and guaranteeing environmental effectiveness. The latter refers majorly to the additionality criterion as well as the baseline setting. Furthermore, it is also regarded whether a specific post-2012 proposal can contribute to an upcoming and growing global carbon market.

Programmatic CDM

The programmatic CDM will basically bundle different CDM projects, thus lowering transaction costs and increasing the generation of certificates in comparison to the CDM. However, the programmatic CDM does not offer a solution to problems like additionality and baseline setting. Comparing all discussed possibilities, the programmatic CDM demands the least changes from the current CDM structure, being able to lower transaction costs of a single CDM project, without fundamentally addressing major shortcomings.

Sectoral

Various definitions of a sectoral CDM have been discussed. At this point it shall be focused on multi-project baselines along the lines of a sector and entire sectors being integrated into the CDM under a sectoral baseline. In both cases transaction costs are presumed to be low once a detailed baseline is set, as the current project cycle could be spared. However, additionality could be difficult to determine when thinking in today's categories. In applying a multi-project or sectoral baseline, it could not be guaranteed that all reductions leading to GHG reductions are truly additional. Financial additionality might raise problems in particular, as it will probably be impossible to prove whether a measure to lower GHG emissions is motivated by the sectoral CDM or due to economic or operational considerations. If an entire sector is covered, a sectoral CDM will be more demanding in regard to government capacity than the current or programmatic CDM, as credits are issued to the government and not to the project developer (Höhne, 2007: p.5). Thus, the government needs to set domestic incentives to the industry and has to develop policy instruments to pass the credits to the particular sector. Depending on the level of the baseline, the capability of a sectoral CDM to give incentives for structural changes in regard to GHG emissions is higher than in today's CDM, as it overcomes the limited project-to-project perspective.

Policy CDM

Allowing policies to be credited under the current scheme broadens the limited project to project perspective. Therefore, it can be assumed that a policy CDM has more potential to provide incentives for a general transformation of the economy towards lower GHG emissions. In addition to that, additionality could be defined more precisely, in identifying environmental policies that would be additional per definition for example introducing feed-in tariffs for renewable energy. If not, defining additionality would be highly complicated and difficult to determine, as it is impossible to say which policy would be motivated by the CDM. As in the case of the sectoral CDM, a high governmental capacity is needed, in terms of allocating the credits as well as in enforcing the particular policy. It is therefore hardly imaginable that the instrument would qualify for least developed countries. In general, one can argue that it is very difficult to determine which GHG reductions are actually triggered by the credited policy instrument.

Sectoral No-Lose Intensity Targets

In comparison to foregoing approaches, sectoral no-lose intensity targets go far beyond the structure of the current CDM. In fact, additionality and baseline setting can be avoided, once it is agreed upon a sectoral intensity target. In addition to that, lower transaction costs can be presumed, as the current project cycle is not needed. Institutionally, a sectoral no-lose intensity target could rather be compared to the EU ETS than to the CDM. In regard to building a global carbon market one day, this fact is certainly an advantage, as institutional capacity would be built in developing countries. In comparison to the current CDM the CCAP approach offers a higher probability for real emission reductions, as countries pledge to reach a certain intensity level. Compared to that, the CDM as well as most post-2012 CDM proposals would only lead to a stagnation of GHG emissions in the best case. An improving efficiency level decelerates emission growth compared to the BAU case, even though it can be objected that it does automatically lead to decreasing overall emissions. In case the production increases dramatically, overall emissions can rise with decreasing efficiency levels. The non-binding character of the approach can be interpreted as an uncertainty in regard to the approach's environmental effectiveness. It cannot be guaranteed that entities are willing to invest in efficiency improvements as they cannot necessarily expect rewarding. Whether countries are willing to make efforts to reach the no-lose target probably depends on the international carbon price. The higher an international carbon price is, the higher is the incentive to invest in abatement technologies. As it is the case for the sectoral and policy CDM, sectoral no-lose targets would require a high amount of governmental capacity, as credits would be issued to the participating governments and not to the project proponent. How to set incentives for companies to participate in the scheme is therefore a pivotal question.

Scaling up the CDM also implies that additional credits in comparison to the current project-based instrument will likely be generated, even though it depends highly on the exact baseline setting. However, certified emission reductions that will be generated by an up-scaled CDM also need to be demanded by an international carbon market. Various approaches to a post-Kyoto CDM that are currently under discussion could be linked to international emission trading. As shown in the foregoing section, the flexible mechanisms under the Kyoto protocol are a well established part of today's global carbon market. It is an interesting question, which effect a potential post-2012 CDM could have in regard to the design of emission trading schemes in the developed world (compare e.g. Runge-Metzger, 2006). Therefore, it is in particular interesting how many certificates could be generated by a specific approach. It is further interesting to evaluate, whether a post-2012 CDM can be used as an intermediate step towards developing countries fully participating in international emissions trading with fixed and binding emission baselines in the future.

In this regard, the development of sectoral no-lose targets seems to be particularly appealing. On the first sight it can be assumed that major shortcomings of the current CDM could be resolved with the instrument, even though some questions remain, especially when comparing no-lose intensity targets to a global cap and trade regime. However, it is assumed that a sectoral no-lose intensity target could help building capacities for future implementation of a global emission trading scheme.

4 Analyzing the Chinese Energy System

After having identified possibilities for reforming the current CDM in the foregoing sections, chapter 4 steps back from the theoretical discussion of post-2012 approaches. Rather, the Chinese energy system is analyzed in order to get an idea of the magnitude and possible real world implications of a post-2012 CDM.

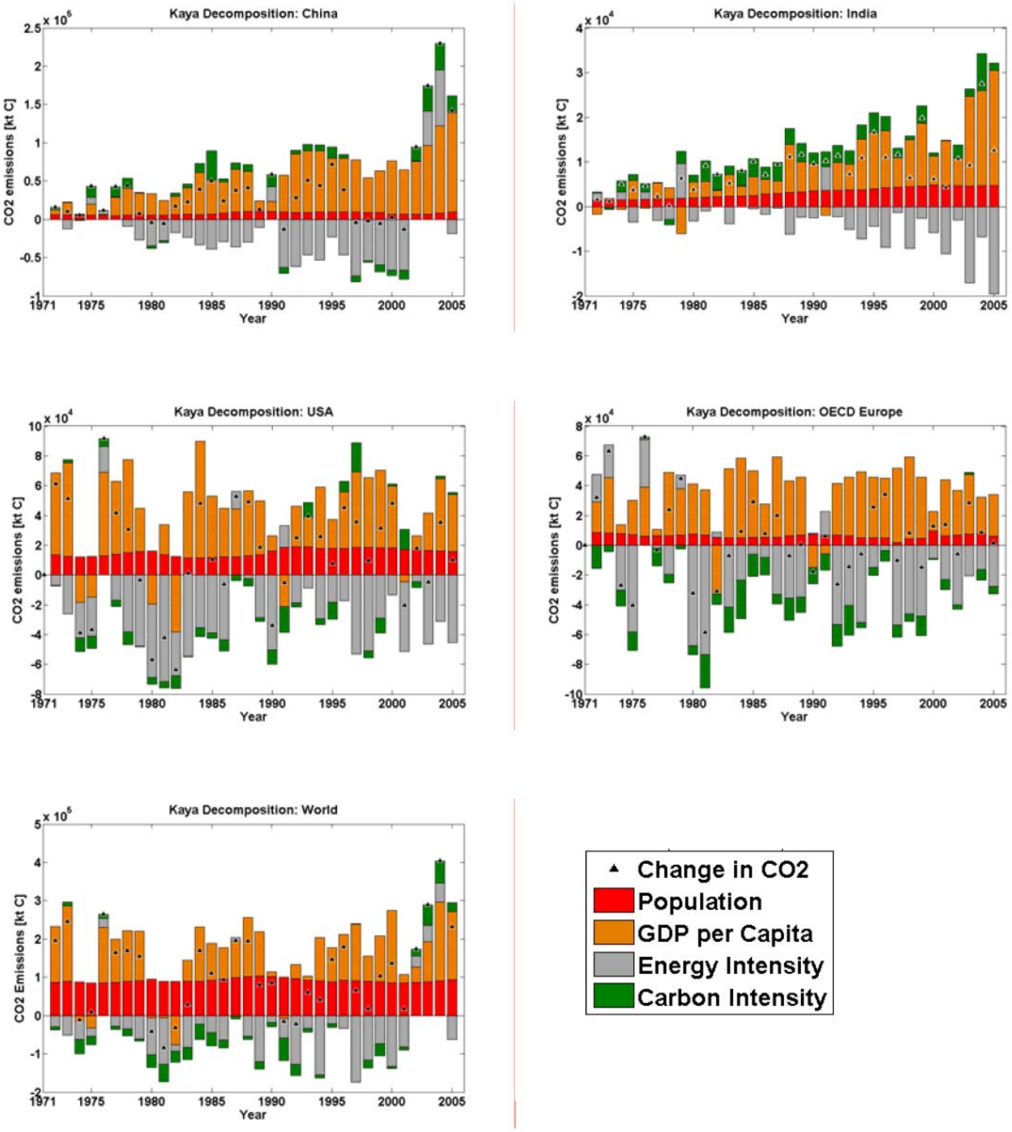

Figure 4-1: Kaya Decomposition of Different World Regions. The Annual Change in CO2 Emissions from one year to the following year is illustrated that can be attributed to the components Population, GDP per Capita, Energy Intensity and Carbon Intensity.

Source: Edenhofer et al. (2008: p.6)

The Chinese energy system has been chosen exemplarily for different reasons. On the one hand, China is the biggest country in the world, having experienced tremendous economic growth in the last decades. Economic growth has gone hand in hand with the growth of emissions. Figure 4-1 illustrates the development of energy related carbon emissions in various world regions from 1971 until today. It can be shown that at least since the year 2000, China has been a main driver of global carbon emissions, while India – representing another big developing country – plays a comparably minor role.

Therefore, the goal of this chapter is to get a deeper understanding of the Chinese energy system in order to make a statement on how suitable post-2012 CDM options are for one of the most important emerging economies in the world. As the focus shall be set on sectoral non-binding targets in chapter 5, the electricity sector will be exemplarily analyzed in this chapter. Therefore, it is firstly necessary to get a broader understanding of the political environment (section 4.1). It then needs to be clarified, how energy has been used in China in the past and how various scenarios for the future look like. In this context it is particularly important to understand which factors drive the Chinese GHG emissions (section 4.3). Finally, the electricity market structure shall be analyzed in order to be able to make a statement on the importance of the electricity sector and its accountability for international policy instruments after 2012 (section 4.4) including the sector’s abatement possibilities in section 4.5.

After having identified and understood the regional conditions, the discussion of post-2012 CDM approaches will be resumed in chapter 5, based on a broader knowledge basis about the Chinese energy system.

4.1 Political Environment

4.1.1 General Issues

The People’s Republic of China (PRC; in the following just ‘China’ if not specified otherwise) is one of few countries in the world that officially is a socialist state and for sure it is the most powerful of these, in economic as well as in demographic terms. Since the socialist People’s Republic was proclaimed in 1949 by Mao Zedong, fundamental changes have taken place, deeply affecting the economic and social realities in China. Deng Xiaoping (1979-1990s) opened the Chinese socialist system towards social market economy, establishing reforms that basically allow private actors to take part in economic activity. In fact, the current society shows only limited features of a socialist system. Heilmann (2002: p.188) shows that only three of 13 criteria for a socialist political system are fulfilled in China. Especially economic and social criteria are not or only partly realized[20]. In order to explain differences between pure socialist theory and every day life in China, the Chinese Communist Party (CCP) speaks of ‘socialism with Chinese characteristics’. The Chinese philosophy is dominated by the belief that a certain (e.g. western) level of affluence has to be reached before a socialist society can be established. Therefore, the Chinese society is seen as being at the beginning of a long way leading to socialism, where capitalistic tendencies are a temporary necessity to guarantee and accelerate economic growth (Heilmann, 2002: pp. 70).

Politically, the PRC is divided in provinces (22), autonomous regions (5), municipalities directly under the central government (4) and special administrative regions (2). In addition to that, the PRC claims the Republic of China (Taiwan) to be a part of the PRC, which is treated as a (defected) province for example in the National People’s Congress (see below). Each province is subdivided in prefectures, counties and townships.

In the Deng Xiaoping era, the Chinese government started to change from absolute centralized control of the economy towards a more liberal approach, guaranteeing more autonomy to selected regions and opening selected branches of the economy to external investment. Therefore, special economic zones (SEZ) have been established, equipped with economic and administrative privileges, as for example local congresses and governments having legislative authority. Focusing on attracting foreign investment, tax relieves for foreign companies are granted in SEZ among other incentives. In contrast to the official Chinese philosophy, private foreign ownership as well as Sino-foreign joint ventures are allowed in SEZ and the economic activities are driven by market forces, not planned by the central or provincial government.

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[20] Heilmann (2002) divides five political, four economic and four social criteria.

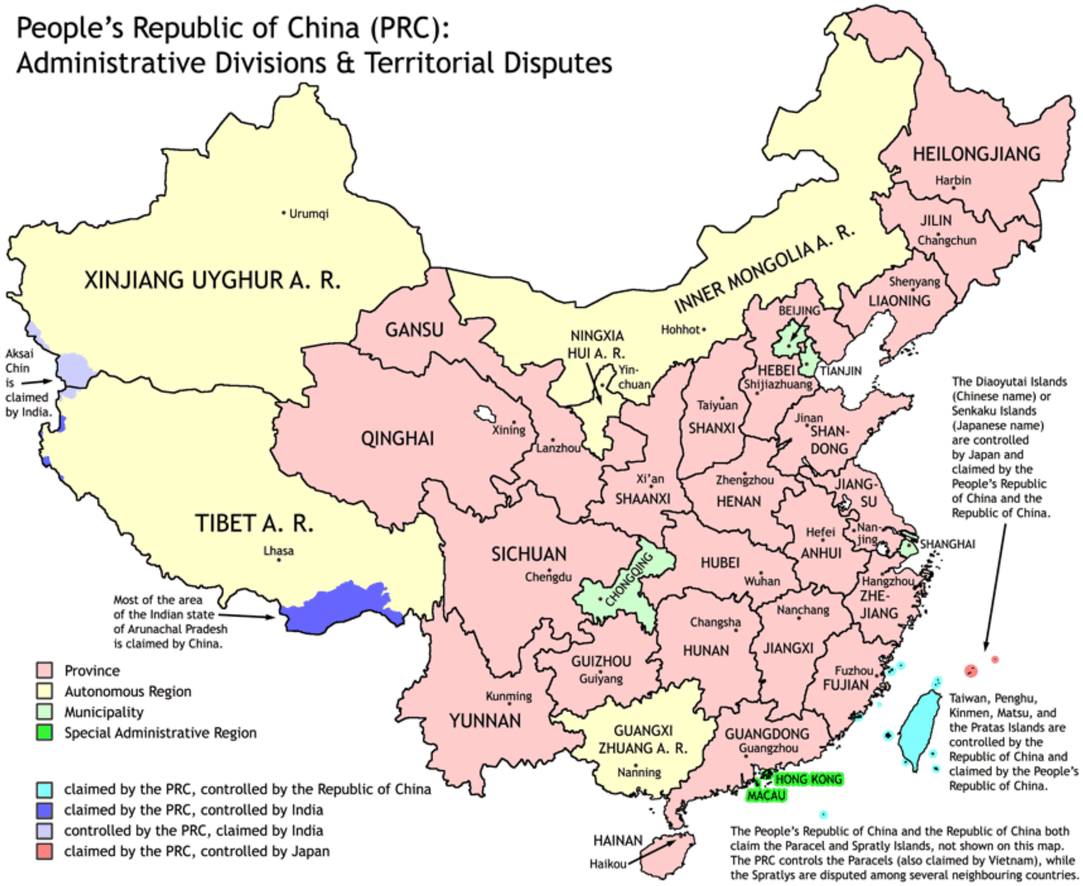

Figure 4-2: Administrative Map of the PRC

Source: http://upload.wikimedia.org/wikipedia/commons/9/99/China_administrative.gif

Since the early 1980s, SEZ have been established, focused on the coast and cities along the Yangtze valley[21]. The provincial and autonomous regions' capitals as well as the special administrative areas (Hong Kong, Macau) also have the status of a SEZ. In addition to that, free trade zones (15), state-level economic and technological development zones (32), and new- and high-tech industrial development zones (53) have been created in large and medium-sized cities, also offering special conditions to attract (foreign) investment, often illegally by the local authorities without the approval of the central government (Heilmann, 2002: p.101). By entering the World Trade Organization (WTO) in 2001 it is probable that the influence and importance of the SEZ will decline as the principle of a partly closed market contradicts the WTO statues.

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[21] The first four SEZ were Shenzhen, Zhuhai, Shantou and Xiamen.

In allowing changes from the centralized totalitarian system established in China during the Mao Zedong era (1949 – 1976) the country has doubtlessly changed fundamentally. China has faced an unprecedented economic growth, with the GDP per capita rising by factor 6.5 since 1980 (see also section 4.3.4 at pp. 73). On the other hand, this growth goes along with negative impacts on the environment; on the global level Chinese GHG emissions have increased significantly, leading to the fact that China is one of the biggest emitters of GHG today[22] and on the local level by acid rain, air pollution and other local environment impacts. According to the World Bank (2007a), 20 of the world's 30 most polluted cities are located in China, while 650,000 people die annually from air pollution (Wörtz and Hanig, 2007). Moreover, the boom only reaches a minority of the society, while broad parts do not benefit from the economic growth (Kurlantzick, 2007: p.2). Therefore, solving economic inequalities and environmental problems will be a crucial issue for the leading Communist Party in the future, which is also manifested by recent official statements (compare e.g. Hu Jintao's speech at the 17th Party Congress (Hu, 2007)).

4.1.2 A Brief Review of the Chinese Political System

The CCP plays a tremendously important role in the political system of China. Its leading cadres control all important areas in Chinese politics ranging from administration and justice to unions and corporations. Moreover, the CCP politically controls the police as well as the military. Due to missing separation of powers and unlimited influence on economical decisions the party practically exerts direct influence on all important decisions in the country. Reforms in the past have not touched its political power and those of its cadres (Heilmann, 2002: pp. 78). Accounting for the CCP's power position in all important bodies of the state, the country's constitution plays only a minor role.

Ideologically the CCP officially governs based on four basic principles:

- Leadership of the CCP
- Democratic dictatorship of the people
- Socialist development

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[22] Some sources (Netherlands Environmental Assessment Agency, 2007) claim that China is already the world's number one emitter of carbon dioxide.

- Marxism/Leninism as defined by Mao-Zedong[23]

However, for most of its members those principles have only a symbolic character (Heilmann, 2002: p.71). It is questionable whether the basic principles and the absolute centralized power of the communist party are contemporary valid, regarding the economic and political facts in China. In 2000 Jian Zemin introduced the 'three represents' as an approach to renew the CCP becoming a guiding principle of the Communist party at its 16th Party congress in 2002. Thereafter, the CCP is dedicated to the "interests of the overwhelming part of the Chinese people" as well as the needs of all progressive, economic and cultural forces (Jian, 2002). The concept can be seen as a step towards opening the CCP to other (all) classes of the society in spite of being a revolutionary party representing the "working class". Facing a rising gap between rich and poor and increasing environmental problems, Hu Jintao (2007) presented the 'scientific development concept'[24] at the 17th Party Congress in 2007, aiming to shift the governmental agenda from 'economic growth' to 'social harmony'. In this context he outlines the need for democratic reforms as well as sustainable development. Regarding its official agenda, the CCP seems to aim for more sustainable growth, guaranteeing wealth for broader parts of the society and facing environmental problems. It is however uncertain how much regional cadres as well as conservative parts of the CCP are willing to follow Hu Jintao's concept.

In principle the state's administration is mirrored by the party structure. Figure 4-3 illustrates well how every state agency is basically controlled by its CCP counterpart. On the national level, the Politburo standing committee is the most influential body. It is appointed by the Central Committee and has guiding authority over most party and state institutions as well as over the central military committee. Its nine members are elected by the National Congress of the CCP, which gathers in Beijing every five years. It is lead by Hu Jintao, who is the President of the People's Republic, the General Secretary of the CCP and the chairman of the Military Commission at the same time.

In the following the most important institutions of state and party shall be briefly

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[23] Chinese official translations refer to 'Mao-Zedong-thoughts' at this point (Jinshan Zhu, personal communication 15.4.2008).

[24] Chinese official translations also refer to 'scientific thinking of development' (Jinshan Zhu, personal communication, 15.4.2008)

described.

Central Committee

The Central Committee is the highest authority of the CCP. Its members (around 300) discuss the party policy and are elected by the National Congress of the CCP. The most influential and powerful people in the party, state and military are gathered in the Central Committee. It also nominally appoints the members of the Politburo.

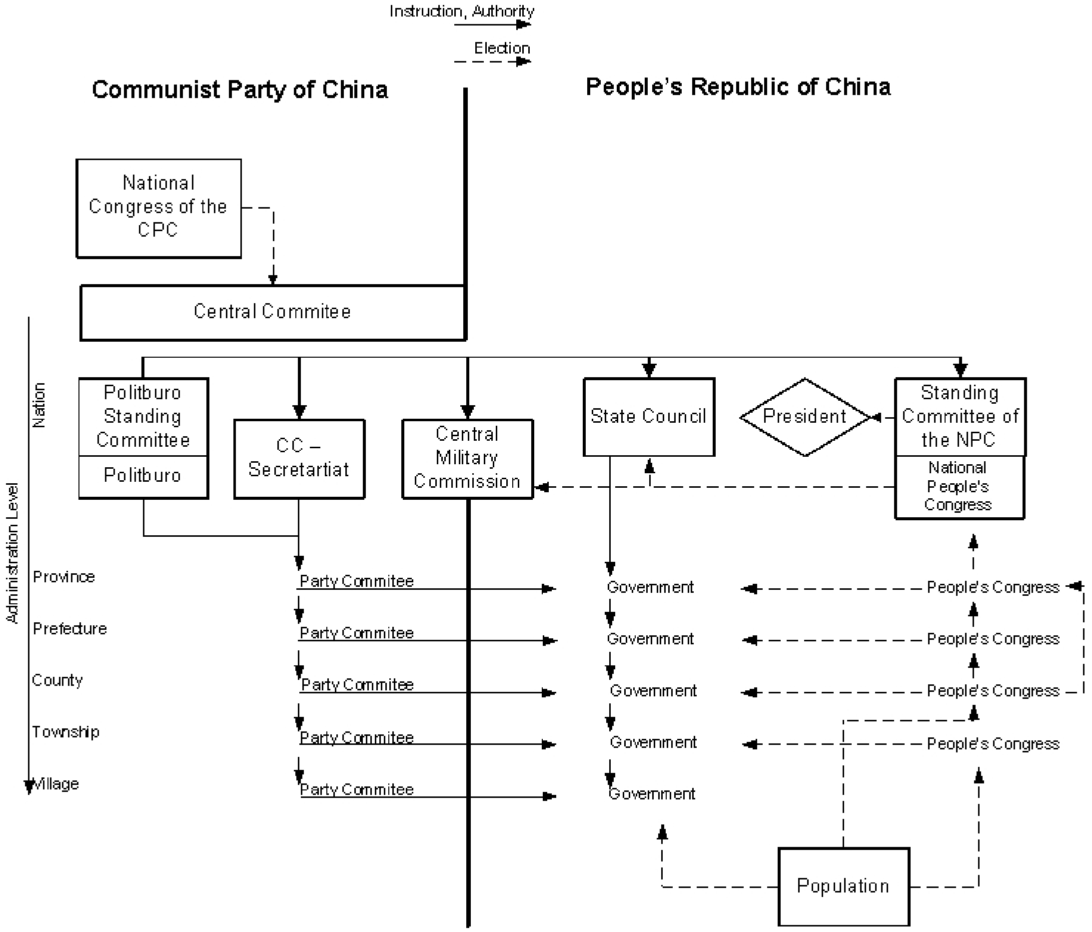

Figure 4-3: China's Administrative Structure

Source: Own Illustration, modified from Heilmann (2002: p. 89)

Central Military Commission

The Central Military Commission refers simultaneously to a party as well as a state institution. In fact, both institutions are staffed with identical personnel. Thus, the party ensures that the control over the armed forces is kept in the hands of the CCP. It is considered to be the supreme military policy-making body. Its leader is the commander-in-chief of the Chinese armed forces, being officially elected by the

National People's Congress.

State Council

The State Council functions as the national government of the People's Republic. It is lead by the Premier of the PRC (currently Wen Jiabao) who is also a member of the Politburo Standing Committee. Important decisions are taken by the State Council's standing committee meeting twice a week, including the premier, four vice-premiers (of which each oversees a specific area of the administration) and five state councilors including the party's secretary general. In addition to the standing committee, the State Council is composed of organs on the ministerial level. Most important actors are the state administration for industry and commerce and the national development and reform commission. However, the power of the state council is limited, even though it gained some influence in the general attempts to decouple party and state activities (Hongwei, 2002: pp. 60). The CCP is very aligned to decisions and personnel decisions of the government. Candidates for government positions are chosen by the leading circle of the CCP and have to be confirmed by the National People's Congress.

National People's Congress

According to the Chinese constitution, the National People's Congress (NPC) is the highest state body in China. Its delegates are elected for five years and gather once a year for discussing and approving legislative initiatives from the government (State Council) as well as taking various personnel decisions[25]. Deputies to the NPC are elected by the provinces, autonomous regions and municipalities directly under the central government as well as the military. Deputies are conflated in 34 regional delegations (including Hong Kong, Macau, Taiwan and Chinese citizens living abroad) plus one additional delegation for the military.

Not having much influence in the past as the NPC was basically seen as an institution to ratify decisions that were taken by the CCP beforehand, the role of the people's congresses on all levels has changed. Even though the NPC (and other people's congresses on a lower administration level) is far away from having genuine

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[25] The NPC votes/confirms by vote the following positions: President and Vice President, Prime Minister, Vice Prime Ministers (4), State Councilors (5), Ministers (29), Members of the Central Military Commission, President of the Supreme Court, Attorney General (Heilmann 2002: p. 130)

parliamentary rights (legislative control, budget control, appointing and discharging of the government) some tendencies of political controversies have been shown in the last years (Heilmann, 2002: p.133).

4.1.3 Decision Making in China

Neither the constitution of the PRC nor the statutes of the CCP leave any doubt at China's centralized character. Strategic decisions are taken by an exclusive part of the CCP, namely the Politburo standing committee, the Politburo and to a lower extent the Central Committee of the CCP. On lower administrative levels, CCP institutions and cadres are responsible for enforcing the CCP's official political position, so regional party and state organs have to follow the orders from Beijing. Main political decisions and economic targets are laid out in the Five-Year Plan for National Economic and Social Development (short: Five-Year Plan). Being the major planning instrument, it outlines national key construction projects; further, it aims to manage the distribution of productive forces and individual sector's contributions to the national economy and map the direction of future development (Pan, 2008). However, coming along with broadened economic freedom, vital regional market structures push back the influence of the central power (Heilmann, 2002: pp.97). Since the economic reforms have been launched, leading functionaries of the provinces including autonomous regions and municipalities directly under the government have gained enormous influence in decision making. Especially those cadres representing the prospering cities and regions in the East of China are overrepresented in the most important institutions of the party as well as the state, even though their influence has obviously been reduced in the last years (Heilmann, 2002: p.98).

In recent years, Chinese leaders seem to realize that their country has become complex in many ways. As ruling it centrally from Beijing has become nearly impossible, voices are getting louder to enforce democratic reforms including a competent legal system enjoying the public's confidence (Thornton, 2008). Currently it can be stated that corruption is a major problem and decisions are often based on a web of personal relationships known as "guanxi", a system of exchanged favors and assistance established over a long period in time. This fact enhances the lack of confidence of the population in the ruling CCP, which in turn enhances the loss of legitimation the party is facing.

Summing it up, the Communist Party has lost influence, also because its legitimation is not exclusively based on being the revolutionary avant-garde party any more. Rather, the economic prosperity supports the ruling system as many people profit from the system, but protests are getting louder and more visible. At the same time, it gets more difficult for the CCP and its leaders to enforce their political will as many different regional authorities and private actors, which they cannot necessarily control, have gained political power and influence on the regional level. This fact gets tremendously obvious in environmental policy where environmental law is considered to slow down economic development on the regional level by decision makers on the lower administrative levels (Wörtz and Hanig, 2007), creating incentives for regional and local governments to avoid the implementation of national laws and directives.

In case the central power generally loses control, severe consequences could also be found for the energy sector, which will be evaluated in the following section.

4.2 The Chinese Energy System

4.2.1 Administration and Policy

As other markets and sectors of the Chinese economy, the Chinese energy market is not a completely free market. It is heavily influenced by the decisions taken by the central government even though some competition has been allowed at various parts of the value chain, as for example coal extraction and power generation (Rosen and Houser, 2007: p.17). Some big energy companies have a high influence on the government (IEA, 2007b: p.267). Politically, the National Development and Research Commission (NDRC) is the most important state agency for the energy sector, having policy, regulatory and administrative functions. Bigger energy projects need approval from the NDRC’s Energy Bureau, which has the leading role in formulating energy policy. Other NDRC departments are responsible for energy efficiency, regulation of industrial sector or pricing; the NDRC Price Bureau controls how much firms can charge for gasoline, diesel, natural gas and electricity. Various other state and province authorities take responsibility for different aspects related to energy, as for example the state administration for coal mine safety, the ministry of land and resources, the ministry of water resources and so on[26]. The Ministry of Energy was

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[26] A more detailed description of the organization of energy policy making and administration can be

abolished in 1993, but might be reestablished in the near future as presumed by the IEA (2007b: p.270). Bundling the administrative competences that are currently established at many different state institutions might lead to a higher efficiency in the energy administration in general.

The 11th five year plan covering the period from 2006 – 2010 highlights the priorities of Chinese energy policy. Next to key infrastructure projects, the plan sets goals for energy efficiency, environmental protection and research and development (IEA, 2007b: p.270). The importance of improving the energy efficiency and focusing on environmental issues was emphasized by Hu Jintao's speech at the 17th party congress in 2007 and allows the conclusion that environmental aspects get into the main focus of Chinese top level politicians (see Hu, 2007).

4.2.2 The Energy Sector – An Overview

In recent years, China faced an massive energy growth going hand in hand with an enormous increase in the use of coal. Especially, after the year 2001 energy demand accelerated significantly. This fact can be explained by multiple reasons, but it is certainly more than a coincidence that China joined the World Trade Organization (WTO) exactly this year. In China, energy is mainly provided by coal. While in 1971 coal had a share of 49% of the total energy supply, representing less than 200 Mt OE, its share has risen to 64% in 2005 being approximately 1100 Mt OE. Basically, this fact can be explained by China having significant coal reserves and therefore not being dependent on energy imports. However, in regard to supply security it has to be regarded that major coal fields are prevalently located in the central and Western provinces, far away from the industry centers in the East, where the coal is demanded. Supply disturbances are preprogrammed, as for example during winter 2008, when due to heavy snow falls coal supply was short, leading to cuts in electricity supply. Generally, the IEA (2007b: pp. 283) estimates that coal imports will play a bigger role in the future for coastal provinces, as inland transportation capacities are not sufficient. Currently, rail capacities in particular are scarce, being able to handle only 40% of the demand (Without Author, 2008). Coal plays a major role in the electricity generation demanding 55% of the overall coal supply in China. At the same time 26% of coal consumption was demanded by the industry, 4% by the residential sector and

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found in Annex D.

15% was distributed to other sources (IEA, 2007b: p.262).

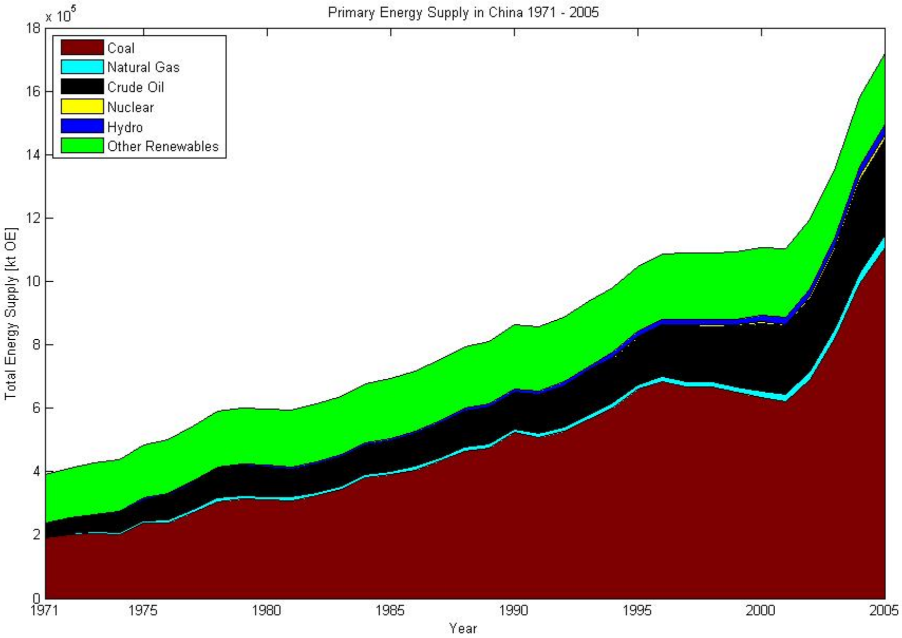

Figure 4-4: Composition of Primary Energy Carriers in China 1971 – 2005

Source: Own Illustration based on IEA (2007a) Data

In regard to renewable energy (primarily composed of solid biomass), Figure 4-4 illustrates that its overall share in the energy mix has decreased significantly since 1971, to 12.8% in 2005. In absolute terms the energy supplied by solid biomass and other renewable energy stayed relatively constant, increasing from 154 Mt OE in 1971 to 221 Mt OE in 2005[27]. This trend can partly be explained by rural-urban migration, which has been accompanied by a switch from solid fuel (solid biomass and coal) to coal based district heating in the household sector (IEA, 2007b: p.265). Generally, the high share of biomass can be explained by increased electrification especially in rural areas as it is mainly used for energy purposes in non-electrified regions (Rosen and House, 2007: p.23).

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[27] Solid Biomass plays by far the most important role; other renewables (mainly wind) had only a share of 0.2% of the overall primary energy supply in 2005 (IEA 2007: p.262).

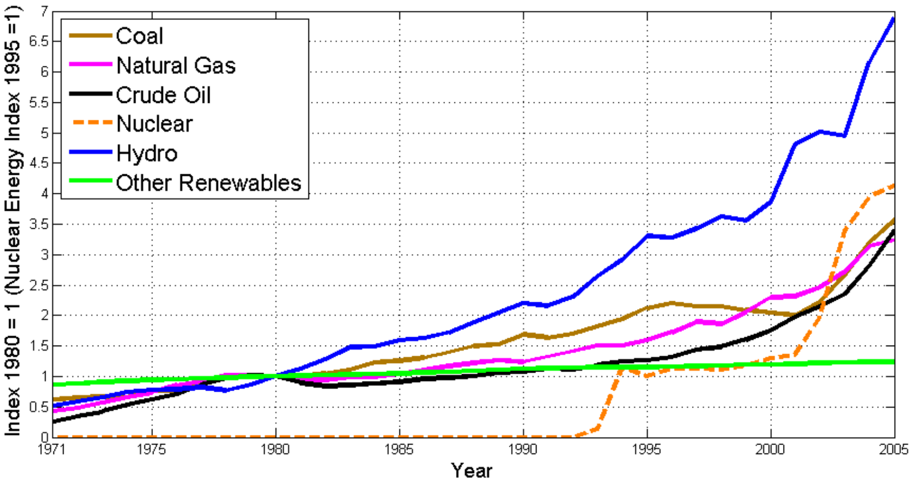

Figure 4-5: Development of Primary Energy Carriers in China

Source: Based on IEA Data (IEA, 2007a)

Oil supply has risen constantly during the last 35 years, having a share of 301 Mt OE or 17.5% of the overall primary energy supplied in China in 2005. The biggest share is demanded by the industry sector, even though the growth in oil consumption is heavily driven by increased demand in the transportation sector (Rosen and Houser, 2007: p. 19). To some extent, rising oil demand is driven by an increased demand in coal. As coal mines are generally not located in the energy demanding eastern parts of the country and rail transportation capacities are not sufficient, a major part of the coal transportation is handled by oil consuming trucks and ships (IEA, 2007b: p. 266).

China has a well developed oil supply structure, being the fourth largest petroleum producing country in the world outside the Middle East. However, China is a net importer of crude oil since 1993. The oil market is basically dominated by three state owned oil companies that emerged from the Ministry of Petroleum Industry, of which two, the China National Petroleum Corporation (CNPC) and the China Petroleum and Chemical Corporation (Sinopec) operate on the ministry level. CNPC is the world fifth's largest oil producing company, while Sinopec has a much larger downstream portfolio, being highly engaged in the refining business. The China National Offshore Oil Corporation (CNOOC) is the country's third biggest oil company, which was founded mainly to develop China's offshore resources; it is mainly an upstream company, partly in cooperation with international oil companies (Rosen and Houser 2007: p. 20).

In contrast to oil, natural gas plays a minor role for the Chinese primary energy supply. In 2005, 40 Mt OE were supplied by natural gas, which equals 2.3% of the overall share. Natural Gas supply is basically covered by inland production, with huge gas fields being located in the Sichuan province. The Chinese current five-year plan foresees to increase the share of natural gas in the country's energy mix until 2010 (EIA, 2006: p.12).

From all energy forms, hydro energy experienced the highest increase over the last decades. Its share grew by nearly factor 7 compared to 1980; however, its overall significance is rather low, having a share of 2% of the energy supply in 2005, equaling 34 Mt OE. However, large scale hydro projects are impelled, as for example the Three Gorges Dam (expected to be finished in 2009 with a capacity of 18.2 GW) and the Yellow River dam with an expected capacity of 15.8 GW (see also section 4.4.4).

Nuclear energy plays only a minor role in China, even though its importance has risen significantly since the first nuclear power plant was connected to the grid in 1993. In 2005, 0.8% of China's energy supply was covered by nuclear energy, being 14 Mt OE in total.

It can be concluded that the Chinese energy system is highly dependent on coal, which is caused by its domestic availability. However, the burning of coal does not only have negative influences on climate change leading to higher carbon emissions in comparison to other fossil fuels, but is also responsible for SO_2 and NO_x emissions causing acid rain as well as heavy metal emissions, for example mercury. Moreover dust emissions from coal fired power plants leads to respiratory system diseases (Liu et al., 2008).

4.3 Emissions in the Chinese Energy System

Having in mind that the goal of the thesis is to analyze various post-2012 mitigation policy options regarding China, it is crucial to analyze the Chinese emissions in more detail and to understand the driving forces behind the emissions growth.

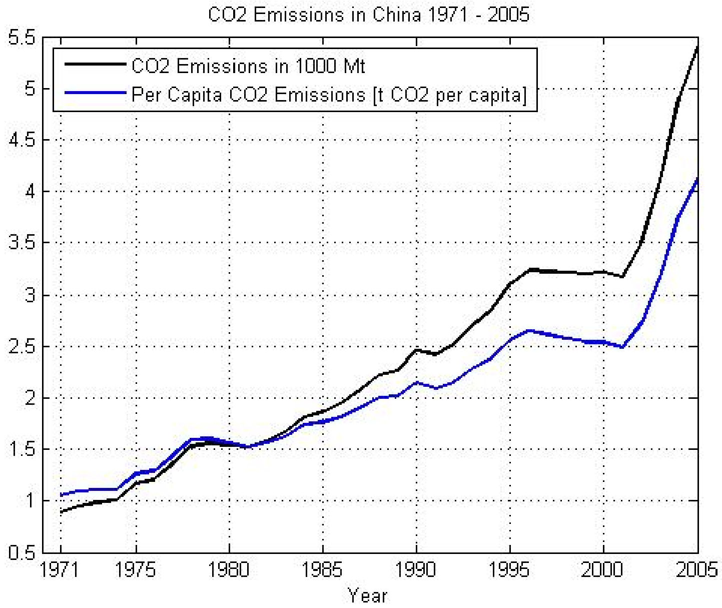

Figure 4-6: Development of Chinese CO_2 Emissions and Chinese CO_2 per Capita Emissions between 1971 and 2005.

Source: Own Illustration based on IEA (2007a) and World Bank (2007a)

Figure 4-6 shows the development of Chinese CO_2 emissions between 1971 and 2005. It gets obvious that the total emissions as well as the per capita emissions have increased dramatically. In 2005, China emitted over 5 Gt of CO_2, while the per capita emissions rose up to over 4 tonnes of CO_2 per capita. Emissions as well as per capita emissions more than doubled since 1990.

In regard to post-2012 policy options this information is however not sufficient. Rather, it is necessary to understand the driving factors behind the increase. Therefore, a detailed decomposition analysis based on the Kaya identity is outlined in this section.

4.3.1 Methodology - The Kaya Identity

In general, an impact (I) to the environment as caused by CO_2 emissions is composed of a population (P), affluence (A) and technology (T) component. This terminology was firstly described by Ehrlich and Holdern (1972) formulating the IPAT equation, being thus

$$I = P \times A \times T\,.$$

Equation 1: IPAT Equation

In regard to greenhouse gas emissions, CO_2 emissions are accepted as impact, while the GDP per capita is the determining factor for ‘affluence’ (Gerlinger, 2004: p.24). The relation was extended by Kaya (1990) who divided the technology component in ‘energy intensity’ (EI; how much energy the economy uses per unit GDP) and ‘carbon intensity’ (CI; how much CO_2 is produced by each unit of primary energy). Hence, the Kaya identity can be written as

$$I = P \times A \times EI \times CI$$

Equation 2: The Kaya Identity

Today, the Kaya identity is a well established tool to analyze anthropogenic CO_2 emissions; among others the IPCC’s working group III uses the tool in the 4th assessment report (Rogner et al., 2007: pp.107) in order to describe trends in CO_2 emissions.

Quantification and mathematical implementation of the Kaya identity is not based on a model, but on the decomposition of identities. Identities can be easily expanded, following the principle:

$$A = \frac{A}{B} \cdot B = C \cdot B$$

Equation 3: Principle of Identity Expansion

The expansion is useful, if the newly generated variable C gives independent information and is an interpretable expression for its own.

In general, decomposition analysis is a possibility to analyze identities, with the objective to “*subdivide the change of aggregate into contributions associated with factors of interests*” (Sun and Ang, 2000: p.1178). Therefore it refers to the change of a given factor between a starting point t_0 and a point t_1. In regard to Equation 3, the decomposition can be expressed as follows:

$$\Delta A = A_{t_1} - A_{t_0} = C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0}$$

which can also be written as

$$\Delta A = \Delta C \cdot B_{t_0} + \Delta B \cdot C_{t_0} + \Delta B \cdot \Delta C$$

Equation 4: Decomposition of Identities

The exact derivation is shown in Annex E.

In Equation 4 the term $\Delta C \cdot B_{t_0}$ refers to the change of variable *C* weighted by variable *B* and is understood as the direct effect variable *C* exerts on *A*. Analogously, $\Delta B \cdot C_{t_0}$ describes the effect of variable *B* on *A*. In weighting one variable by the other, this form of decomposition analysis is called *Laspeyres index method* (Gehrlinger, 2004: pp. 87).

A broad variety of decomposition methodologies and studies have been developed, which are reviewed e.g. by Ang and Zhang (2000). Basically, the decomposition analysis is based on the index method as used for example for calculating price indices. De Bruyn (2000) shows that among various index methods, the *refined Laspeyres index method* is superior[28]. Therefore, other methods are not regarded at this point.

The remaining term $\Delta B \cdot \Delta C$ in Equation 4 is called residual term. In the past, its treatment has not been without controversies, with some arguing to leave it out of the calculations (Gerlinger, 2004: pp.90). In contemporary literature the term has been equally distributed to the effects of the various variables (e.g. Sun and Ang 2000), leading to the following effects:

$$C_{eff} = \Delta C \cdot B_{t_0} + \frac{1}{2} \Delta B \cdot \Delta C$$

$$B_{eff} = \Delta B \cdot C_{t_0} + \frac{1}{2} \Delta B \cdot \Delta C$$

with

$$\Delta A = C_{eff} + B_{eff}$$

Equation 5: General Treatment of Residual Terms in Decomposition Analyses

In principle it is possible to extend the expressed identity unlimitedly.

This basic rationale can now be applied to the Kaya identity. Thus, the change in CO_2 emissions (F) can be composed from the factors population (P), affluence (A), energy intensity (e) and carbon intensity (c). Affluence is given in the GDP per capita, being derived by dividing the GDP by population. As described above, energy

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[28] Other index methods are for example the Paasche index method and the Marshall-Edgeworth method. See also Annex E for more details.

intensity is defined as primary energy supply (PE) divided by GDP. Carbon intensity is then defined as CO_2 emissions divided by primary energy. Thus, the CO_2 emissions can formally be expressed as follows:

$$\Delta CO_2 = POP_{t_1} \cdot \left(\frac{GDP}{POP}\right)_{t_1} \cdot \left(\frac{PE}{GDP}\right)_{t_1} \cdot \left(\frac{CO_2}{PE}\right)_{t_1} - POP_{t_0} \cdot \left(\frac{GDP}{POP}\right)_{t_0} \cdot \left(\frac{PE}{GDP}\right)_{t_0} \cdot \left(\frac{CO_2}{PE}\right)_{t_0}$$

simplified

$$\Delta F = P_{t_1} \cdot A_{t_1} \cdot e_{t_1} \cdot c_{t_1} - P_{t_0} \cdot A_{t_0} \cdot e_{t_0} \cdot c_{t_0}$$

Equation 6: Decomposition of the Kaya Identity

The single effects can be generated by multiplication, as done for the population variable exemplarily:

$$\begin{aligned}
Peff &= \Delta P \cdot A_{t_0} \cdot e_{t_0} \cdot c_{t_0} \\
&+ \frac{1}{2} \cdot (\Delta P) \cdot \left[(\Delta A) \cdot e_{t_0} \cdot c_{t_0} + A_{t_0} \cdot (\Delta e) \cdot c_{t_0} + A_{t_0} \cdot e_{t_0} \cdot (\Delta c)\right] \\
&+ \frac{1}{3} \cdot (\Delta P) \cdot \left[(\Delta A) \cdot (\Delta e) \cdot c_{t_0} + (\Delta A) \cdot e_{t_0} \cdot (\Delta c) + A_{t_0} \cdot (\Delta e) \cdot (\Delta c)\right] \\
&+ \frac{1}{4} \cdot (\Delta P) \cdot (\Delta A) \cdot (\Delta e) \cdot (\Delta c)
\end{aligned}$$

Equation 7: Effects on the Population Variable in the Kaya Identity

The first part of the equation ($\Delta P \cdot A_{t_0} \cdot e_{t_0} \cdot c_{t_0}$) can be interpreted as the effect of the population component on the change of CO_2 emissions, analogously to the effect explained generally in Equation 5. Following parts describe interactions between the remaining variables and form the residual term. The other effects A_{eff}, e_{eff} and c_{eff} can be derived analogously. Finally, the change of CO_2 emissions ΔF can be expressed as the sum of the single effects:

$$\Delta \mathrm{F} = \mathrm{P}_{\mathrm{eff}} + \mathrm{A}_{\mathrm{eff}} + \mathrm{e}_{\mathrm{eff}} + \mathrm{c}_{\mathrm{eff}}$$

Equation 8: Change of the CO_2 Emissions Decomposing the Kaya Identity

4.3.2 Expansion of the Kaya Identity

In regard to the Kaya identity, Sun and Ang (2000) illustrate how the Laspeyres index method can be used for decomposing the factors of the Kaya identity. In order to get more detailed information about the influence of single primary energy carriers as well as the importance of the electricity sector the Kaya identity can be expanded. This can generally be done by adding a so called structural component to the decomposition equation (Gerlinger, 2004: pp.92), which is principally shown in Equation 9:

$$A = \frac{A}{B} \cdot B = \sum_i \frac{A_i}{B_i} \cdot \frac{B_i}{B} \cdot B$$

Equation 9: Sum Expansion of Identities

In regard to the Kaya identity, i can be for example sectors of the economy, with $\sum_i A_i = A$ and $\sum_i B_i = B$.

In order to get a broader understanding of the drivers of CO_2 emissions, the carbon intensity c shall be analyzed more closely. The Kaya identity shown in

Equation 6 can therefore be extended by a factor *q* being the relation of a specific primary energy carrier PE_i to the overall supplied primary energy *PE*. Thus, the CO_2 emissions can be expressed as:

$$\begin{aligned}
&CO_2 = POP_{t_1} \cdot \left(\frac{GDP}{POP}\right)_{t_1} \cdot \left(\frac{PE}{GDP}\right)_{t_1} \cdot \sum_i \left(\left(\frac{CO_{2i}}{PE_i}\right)_{t_1} \cdot \left(\frac{PE_i}{PE}\right)_{t_1} \right) \\
&\textit{simplified}: \\
&F = P_{t_1} \cdot A_{t_1} \cdot e_{t_1} \cdot \sum_i c_{i,t_1} \cdot q_{i,t_1} \\
&\textit{with}: \\
&c_t = \sum_i c_{i,t} \cdot q_{i,t}
\end{aligned}$$

Equation 10: Decomposition of the Kaya Identity Extended by *q*

Looking at Equation 10 it gets obvious that only emission-intensive primary energy carriers can be covered. Trends for emission-free primary energy carriers, such as nuclear energy, hydro or renewable energy cannot be pictured as in this case $\frac{CO_{2i}}{PE_i} = 0$. Therefore c_i needs to be weighted by a constant value, for example the average carbon intensity $\overline{c_t}$. The change in CO_2 emissions (ΔF) being the sum of the effects can thus be expressed as pictured in Equation 11. For simplicity reasons it shows only the direct influence of the variables on ΔF; in the '*matlab*' calculations (compare Annex E) the residual terms are regarded, though. Their calculation follows the principle outlined in Equation 7.

$$\begin{aligned}
&\Delta F = \Delta P \cdot A \cdot e \cdot c \\
&+ \Delta A \cdot P \cdot e \cdot c \\
&+ \Delta e \cdot P \cdot A \cdot c \\
&+ \sum_i P \cdot A \cdot e \cdot (c_i - \bar{c}) \cdot \Delta q_i \\
&\textit{with} \\
&\sum_i (c_i - \bar{c}) \cdot \Delta q_i = \sum_i c_i \cdot \Delta q_i
\end{aligned}$$

Equation 11: Sectoral Kaya Decomposition of the Carbon Intensity

The term $\sum_i c_i \cdot \Delta q_i$ describes the influence of the fuel switch from one primary energy carrier to the other on the overall change of CO_2 emissions; it does not describe the direct influence of the carbon intensity as it would be the case in Equation 8, but the relative change of primary energy carriers and their influence of the periodical change of CO_2 emissions that then can be attributed to the carbon intensity *c*. The mathematical proof for the correctness of Equation 11 is given in Annex E.

4.3.3 Data and Influencing Factors

For the decomposition analysis various data need to be known. Next to population and Gross Domestic Product (GDP) data, it is also important to get reliable data on primary energy supply and CO_2 emissions. A high resolution analysis of the carbon intensity furthermore requires detailed data of primary energy. Various limitations are set by the data availability. Some data are not covered before 1971, others report only until 2003, which is no sufficient especially when regarding recent trends. For this thesis, mainly three sources of data are used, namely IEA (2007a), World Bank (2007b) and the Oak Ridge Laboratory's Carbon Dioxide Information Analysis Center (CDIAC, 2008). Depending on the quality, different data sources were used with data availability over a possibly long time frame being the main criteria. Generally, the differences between data from different sources (besides the limitations mentioned above) are rather minor.

World Bank data for population and GDP has been used due to the fact that the former offer more recent data than the IEA data sets, including the year 2005. The primary energy supply in the sufficient resolution could only be provided by the IEA (2007a).

	IEA	World Bank	Oak Ridge
Population	🟩	🟩 X	🟥
GDP	🟨	🟩 X	🟥
Primary Energy Supply	🟩 X	🟨	🟥
Emissions	🟥 O	🟨	🟨

Table 4-1: Data Sources Used for the Decomposition Analysis.
Data being used is marked by X; the colors refer on the data quality (Green = Good, Yellow = Some limitations; Red = Poor). Emissions have been calculated from IEA data using IPCC (1996) conversion factors (marked by O), taking Oak Ridge (CDIAC) and World Bank data as reference value.

Emission data are provided both by Oak Ridge and the World Bank. But, World Bank data are not broken down by energy carriers, while CDIAC (2007) provides data for solid, liquid and gaseous fuels, not broken down in energy carriers. Next to the possibility of taking emission data directly from a third source, emissions can also be calculated from primary energy data using conversion factors. In order to get consistent results, emission data are calculated out of conversion factors provided by IPCC (1996: pp. 1.24).

PE Carrier	Source	Carbon Emission Factor [ktC/TJ]
Bit Coal	Marland and Rotty (1984)	25.5
Bit Coal	Marland and Pippin (1990)	25.4
Bit Coal	Grubb (1989), OECD (1991)	25.8
Lignite	Grubb (1989)	27.6
Anthracite	Grubb (1989)	26.8
Peat	Grubb (1989)	28.9
Crude Oil a	Marland and Rotty (1984)	21
Crude Oil b	Grubb (1989), OECD (1991)	20
Natural Gas	Marland and Pippin (1990), Grubb (1989), OECD (1991)	15.3

Table 4-2: Carbon Emission Factors as outlined by IPCC (1996: p. 1.24) and studies backing the numbers. Factors used in the calculation are highlighted in grey.

Table 4-2 shows the carbon emission factors for various primary energy carriers. As the IEA groups Chinese coal generally as sub bituminous coal (abbreviated 'bit'), carbon emission factors for bituminous coal have been used to calculate the resulting CO_2 emissions. As different studies find different values for coal and crude oil, numbers were taken for the calculation when confirmed by more than one study. In order to get an idea how accurate the calculated emissions are, the results are compared to other data bases as described above. The results show only little variance compared to the Oak Ridge data as illustrated in Figure 4-7.

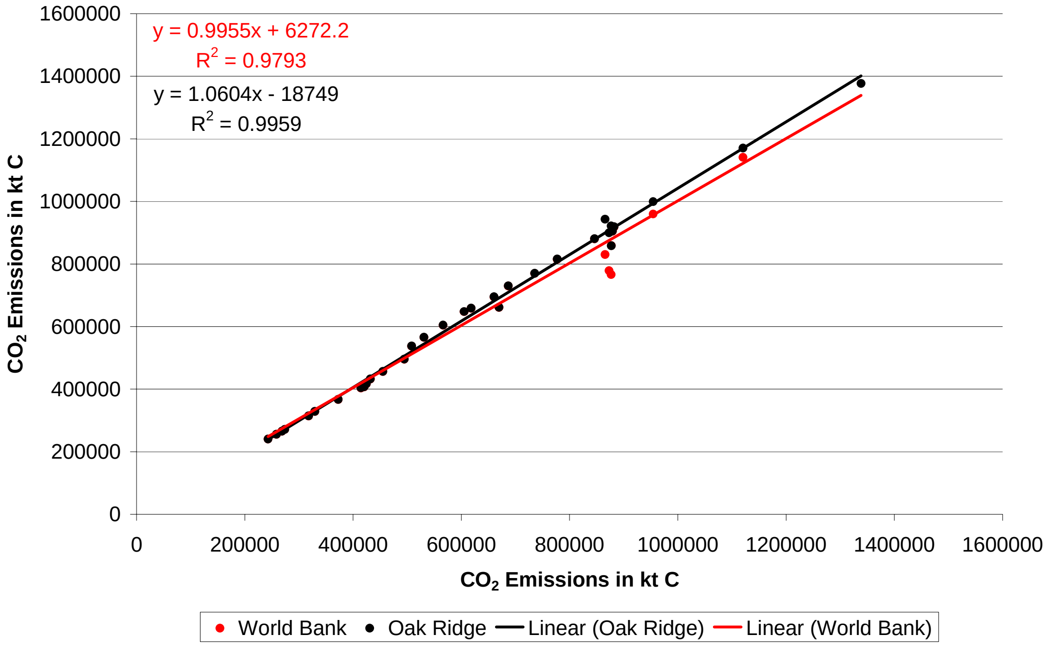

Figure 4-7: Linear Regression Analysis of Calculated CO_2 Emission Data from IEA (2007a) Primary Energy Data using IPCC (1996) conversion factors over World Bank (2007b) and CDIAC (2007) Emission Data. The x-axis represents calculated values, while correlating data from other sources are shown on the y-axis.

As the linear regression analysis shows a high correlation between the calculated sectoral emission data and Oak ridge data sets (R^2=0.9959) as well as World Bank data (R^2=0.9793) the calculated emission data are used for the decomposition analysis being well comparable to those given by World Bank and Oak Ridge.

In general it can be claimed that data in regard to China are not always reliable. Heilmann (2002: p. 165) points out that systematical distortions could be found in official Chinese GDP and growth calculations as for example the influence of inflation on net value added has not been regarded sufficiently. Therefore, the results shall be understood as general trends rather than exact results.

4.3.4 Results

Applying the methodology and data described in the foregoing chapters, it is possible to analyze the Chinese CO_2 emissions in detail. Figure 4-8 shows the general development of the input factors of the Kaya identity, illustrating that the ‘affluence’ variable, GDP/capita, has grown most significantly by factor 6.5 since 1980.

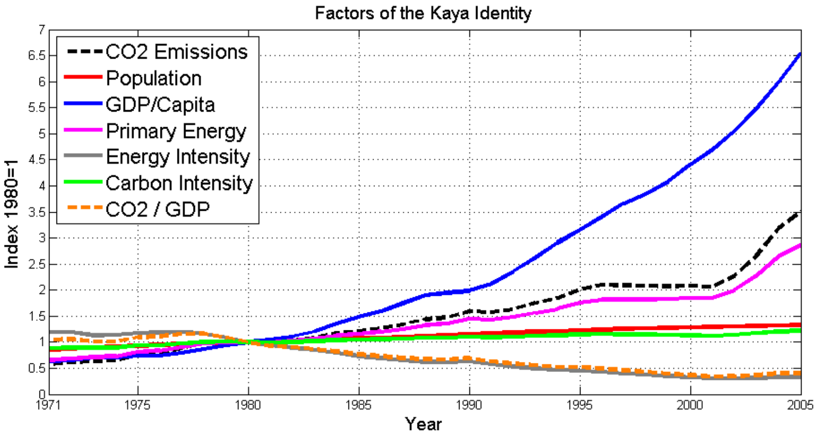

Figure 4-8: Factors of the Kaya Identity[29]

It is further obvious that emissions grow parallel to the growth of primary energy supply, implying that the growing energy demand is mainly covered by emission intensive fossil fuels. This fact can be confirmed, having the findings of section 4.2.2 (pp. 62) in mind. While population and carbon intensity (defined as CO_2 emissions per unit primary energy) have increased slightly, emission intensity has experienced a tremendous decrease from the 1980s until 2000. The trend has however bended in recent years. It is eye-catching that emissions stabilized in the period from 1995 to 2000 while the economy continued to rise. This phenomenon can be explained by increases in carbon – and energy efficiency.

Figure 4-9 illustrates the decomposition results showing yearly changes of factors influencing the CO_2 emissions. Generally, emissions have continually increased from year to year, even though some negative trends can be found, especially in the late 1970s and early 1980s, which might be explained by the oil crisis and a general global depression. The economic growth is the major driver of Chinese CO_2 emissions, while population increase does not play a significant role. Energy efficiency had constantly increased until 2002 (with one exception in 1989), lowering emissions significantly. However, the trend has completely bended in 2003. Carbon intensity has contributed positively to carbon emissions most of the time, even though a negative trend can be found from 1997 to 2001, when overall emissions decreased, as well.

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[29] CO_2 per unit GDP has been included in Figure 4-8 even though it is not an element of the Kaya identity. It is mainly congruent to the emission intensity.

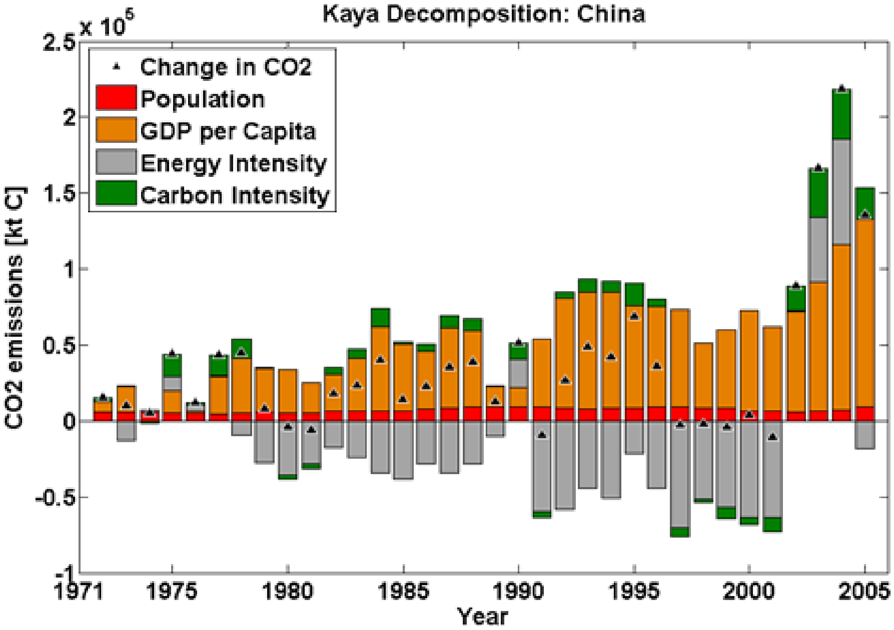

Figure 4-9: Kaya Decomposition of the Chinese CO_2 Emissions

Source: Own Illustration based on IEA 2007a and World Bank 2007b Data

Determining the reasons why carbon emissions decreased in the end of the 1990s until 2001 and have started to increase again thereafter is an interesting issue. In this context one important aspect that has to be regarded is the coal supply. Next to the fact that coal supply decreased in the period of interest (compare also section 4.2.2), the decreasing influence of carbon intensity on the overall CO_2 emissions was majorly driven by coal, as shown in Figure 4-10.

As mentioned in foregoing sections, coal demand is basically driven by the electricity and industry sector. For the industry sector, Wu et al. (2005) see the main reason for decreasing CO_2 emissions during 1999 and 2001 in the speed of the sector's energy efficiency improvements. In 1996, the electric power law came into force mandating – among other things – the prohibition of small-scale, relatively inefficient power plants and the closure of existing ones. According to Wu et al. (2005: p.329), 2.84 GW of plants smaller than 100 MW were closed down between 1997 and 1998 and an additional 1.8 GW of generation capacity was shut down in 1999. The closure came along with the construction of new, more efficient thermal power plants and the introduction of several reforms aiming to ensure a better management of the electric power industry (Wu et al. 2005). The amount however does not seem to be significant regarding an increase in capacity of 105 GW in 2006

(IEAb, 2007: p. 261). In addition to that, socio-economic reasons for the contribution of energy intensity to the decrease of CO_2 emissions can be found. Some (Fisher-Vanden et al., 2004) argue that the reform in ownership structure of industrial enterprises (beginning in the early 1990s) towards more privately owned companies away from state-owned enterprises has driven the increase in energy efficiency. As generally privately owned companies are more efficient (Matsumoto and Imura, 1998), the increase of privately owned facilities in China can be one reason for decreasing CO_2 emissions. Moreover, the deregulation of energy prices between 1985 and 2004 very likely also plays a considerable role (Hang and Tu, 2007). In general, energy prices have been set by the Chinese government, even though liberalization processes have been enforced since the late 1970s. Hang and Tu (2006: pp. 2978) show that coal and natural gas prices are set too low in comparison to other markets, which in turn leads to an indirect incentive for coal (and natural gas). Energy price reforms were accelerated in 1996 and by 1999 plan allocations of energy had been largely eliminated (Hang and Tu, 2006: p.2979). It can be estimated that the decrease in CO_2 emissions starting in 1997 is at least partly caused by rising energy prices. This estimate is supported by Fisher-Vanden et al. (2004) finding that price effects accounted for 54.4% of the decline in measured aggregate energy intensity.

However, energy consumption as well as energy- and carbon intensity have experienced a sharp increase since 2002, going along with a significant rise of overall CO_2 emissions. It could be assumed that the efficiency gains from closing down inefficient small scale power plants and efficiency gains in the industry sector had been realized at this point in time. But, reasons for increasing energy- and carbon intensity after 2002 can primarily be found in the rapid expansion of energy intensive sub-sectors and products, leading to energy consumption growing faster than the economic output (Liao et al., 2007). This fact can be illustrated by China facing a huge construction boom since 2003 as well as an enormous growth of steel, aluminum and cement production (Liao et al., 2007: p.4644). Moreover, it should be kept in mind that China entered the WTO in 2001, leading to increasing investment as well as export possibilities and thus a rising demand in Chinese production facilities in general.

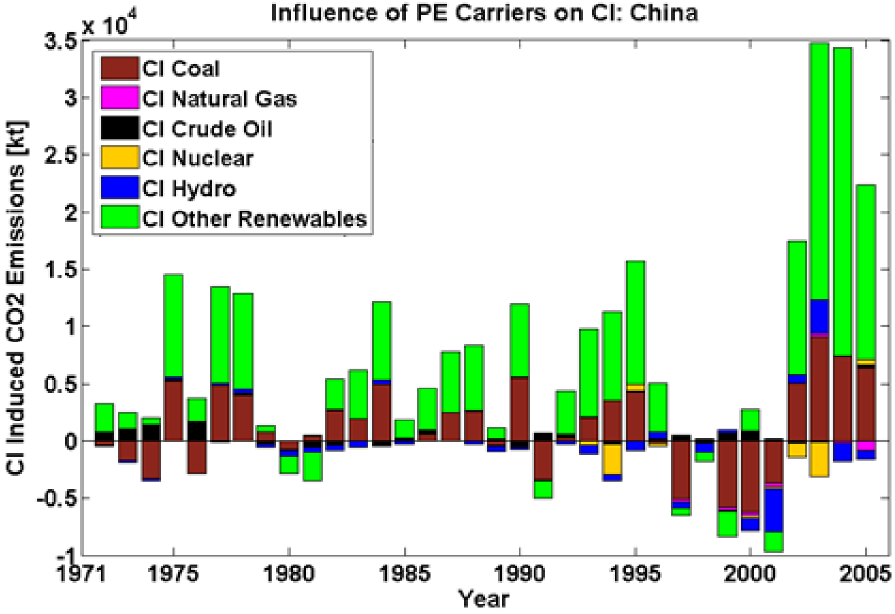

Figure 4-10: Kaya Decomposition of the Chinese CO_2 Emissions Broken Down by Carbon Intensity.

Source: Own Illustration based on IEA (2007a) and World Bank (2007b) Data

In addition to that, Figure 4-10 illustrates another interesting aspect in regard to the energy mix. Even though the Chinese government promotes the use of renewable energy, its share of total primary energy supply continues to decrease and is thus contributing to rising carbon intensity. Nuclear and hydro energy can only limitedly influence the carbon intensity as their capacity is increased irregularly in form of capital intensive large scale projects. In the period from 1997 to 2001 when net CO_2 emissions decreased and carbon intensity also had a continuous negative effect on the emissions, a detailed analysis of the carbon intensity can show that the main driver of decreasing emissions was coal, meaning that coal grew slower than the average energy consumption. At the same time hydro and renewable energy grew significantly faster than other primary energy carriers.

4.3.5 Outlook – IEA Scenarios

In regard to post-2012 climate policy options, it is important to have an idea of future developments of the Chinese energy sector. Therefore, the IEA World Energy Outlook is regarded, providing three scenarios for the Chinese Energy sector until 2030: a reference scenario, an alternative policy scenario and a high growth scenario. Generally spoken, the ‘reference scenario’ pictures a BAU development path, based on current economic trends and political decisions. In contrast to that, the ‘alternative policy scenario' assumes a generally more sustainable economic and environmental path, while the high growth scenario presumes an even higher economic growth than outlined in the 'reference scenario'. The IEA estimates growth rates for all factors that are relevant for the Kaya decomposition until 2030 in two stages. In a first step the IEA assumes growth rates for 2005 – 2015, a second step points out the time span from 2015 to 2030. As the influence on the CO_2 emission change shall be illustrated in five-year intervals, the intermediate steps are generated by linear interpolation. The results being used in the analysis are illustrated in Annex F.

Figure 4-11 shows the assumed growth rate of various primary energy carriers for the described three IEA scenarios. It can be seen that the order of growing primary energy carriers remains stable for different scenarios, even though the magnitude varies significantly. Nuclear energy experiences the highest growth rate in all scenarios, followed by oil and hydro. Coal and natural gas are believed to grow at comparable rates in the reference and alternative policy scenario, while coal grows significantly faster than natural gas in the high growth scenario. The alternative policy scenario is basically driven by the expansion of nuclear energy and a faster growth rate for hydro power. At the same time especially coal grows slower than in the reference scenario.

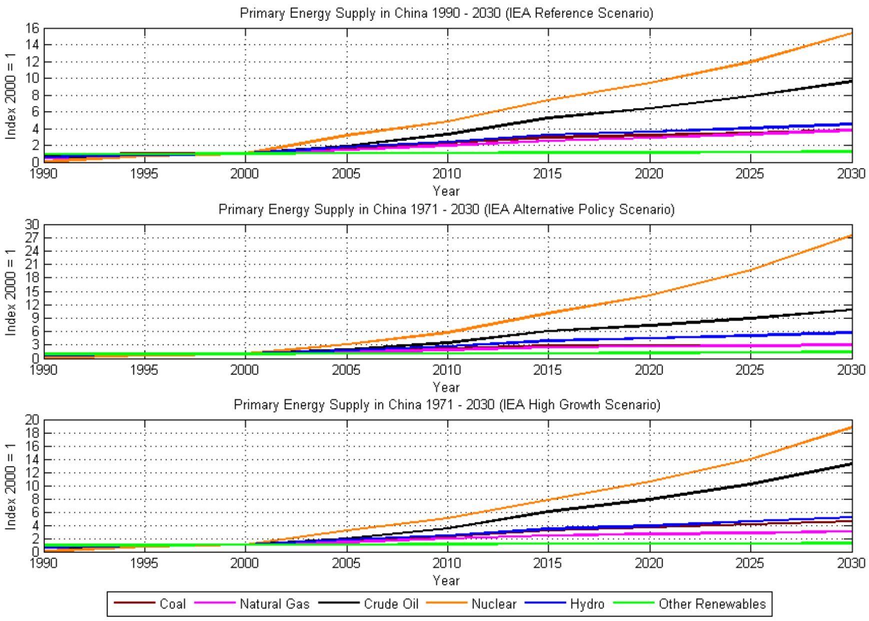

Figure 4-11: Growth of Primary Energy in IEA Scenarios

In general, coal and natural gas are presumed to rise in a comparable magnitude in all three scenarios, varying between factor three and factor four. Surprisingly, (other) renewables do not play a major role in any scenario. It can be presumed that growth rates in renewable energies are opposed by decreases in traditional biomass due to increasing electrification in rural areas.

In regard to factors of the Kaya identity it is especially interesting how economic growth is related to the growth in CO_2 emissions. As shown in Figure 4-12, all scenarios show a tendency for decoupling emissions from economic growth in different magnitudes after 2015. The alternative policy scenario assumes that emissions will be stabilized on a constant level after 2015, still being grown by factor three in 2030 compared to the year 2000 compared to factor four in the reference case and factor five in the high growth scenario. However, general trends are congruent in all three scenarios. Energy intensity continues to decrease considerably, while carbon intensity stays constant in all scenarios. As major changes in the Chinese one-child policy are not expected, population is expected to grow continuously on a very low level.

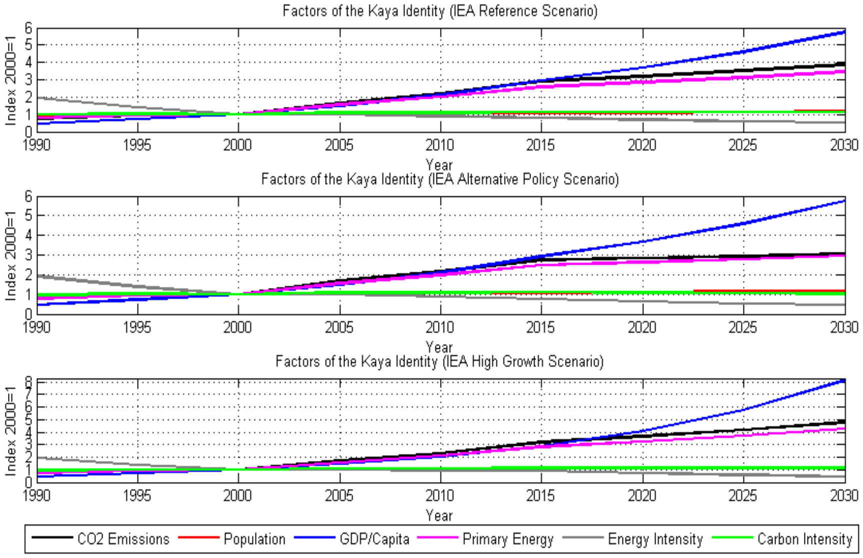

Figure 4-12: Development of Kaya Factors in IEA Scenarios

Figure 4-13 shows the decomposition of IEA scenarios. Compared to the high growth scenario, economic growth slows down after 2015 in the reference as well as in the alternative policy scenario; hence its importance to the overall growth of CO_2 emissions is diminished. Despite of assuming continuing economic growth in the high growth scenario, the growth of emissions slows down after 2015, mainly driven by increasing energy efficiency. Even though emission growth remains relatively constant on a low level after 2015 in the alternative policy scenario, it is obvious that the impact of energy efficiency is stabilized as well. However, while carbon intensity does not have any significant positive or negative effect on CO_2 emissions in the reference and the high growth scenario, it contributes to a slow decrease of CO_2 emissions in the alternative policy scenario.

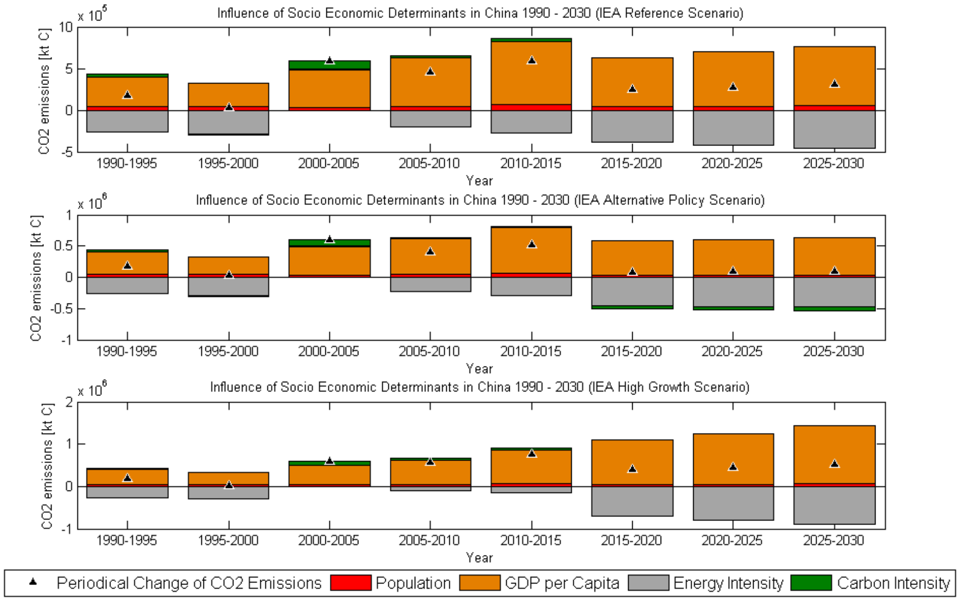

Figure 4-13: Kaya Decomposition of IEA WEO 2007 Scenarios

Regarding the IEA projections, it is obvious that the current scenarios would not lead to decreasing emissions. Generally, scenarios need to be handled with care, as projections are uncertain. Moreover, one can argue that bottom-up scenarios as presented by the IEA based on real world implications, are "mentally locked-in" in the current business as usual realities and cannot picture fundamental changes that might happen in the future[30]. However, regarding IEA scenarios, it gets obvious that (international) climate policy needs to focus on the reduction of carbon intensity in the future.

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[30] Personal Converstaion with Michael Lueken, Potsdam Institute for Climate Impact Research (April 9, 2008).

4.4 The Chinese Electricity Sector

As a major part of the Chinese coal consumption is used in the electricity sector, it is one of the major drivers of CO_2 emissions in China. In fact, the IEA (2006: p.13) assumes that the power sector is responsible for 44% of the SO_2 emissions, 80% of the NO_X emissions and 26% of the CO_2 emissions and is thus the sector that is singularly most responsible for anthropogenic GHG emissions. Therefore it is investigated in more detail in this section.

4.4.1 General Issues

Generally, Figure 4-14 shows the development of the Chinese electricity sector from 1971 to 2005. The output has risen dramatically, reaching approximately 2500 TWh in 2005. The major fuel used for electricity generation is coal, having a share of 79%, followed by hydro providing 16% of Chinese electricity. Other forms of electricity generation play only a minor role: oil has a share of 2.4%, nuclear energy 2%, natural gas 0.5% and renewables 0.1%.

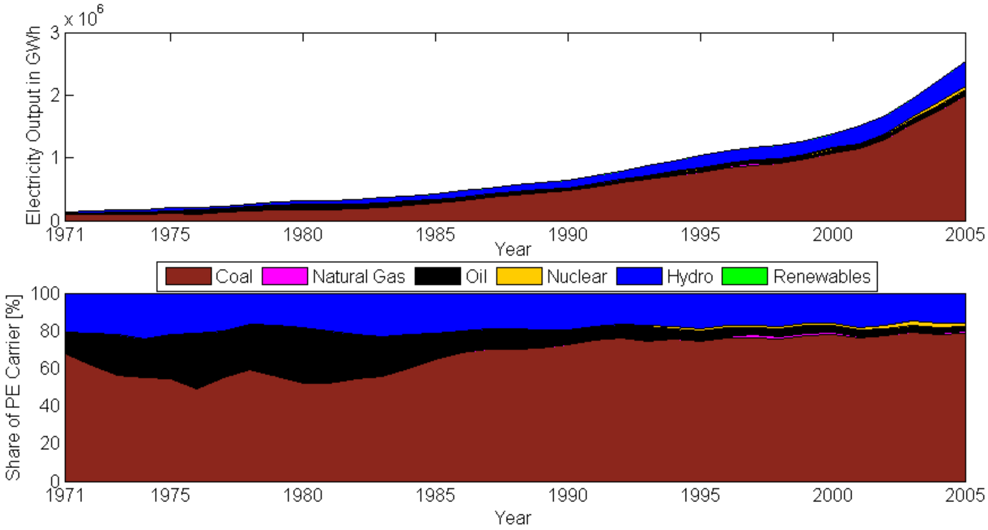

Figure 4-14: Relevance of Different Primary Energy Carriers for the Chinese Electricity Generation (incl. Hong Kong)

Data Source: IEA (2007a)

While the growth in electricity output was fairly linear between 1980 and 2000, it accelerated significantly after 2002. The increase was particularly driven by electricity generation from coal. Various explanations can be found for the acceleration in growth. On the one hand, it seems likely that a couple of reforms leading to a more liberalized electricity market after 2002 (see below) correlate positively with the increase in generation capacity, even though it is still widely discussed in literature whether competition induced by the reforms was sufficient to stimulate generation increases (see for example Ma and He (in press)). On the other hand, Ma and He (in press: p.8) argue that the surge in generation was rather a "knee jerk reaction" to the ban on the construction of power plants from 1999 to 2002.

In 2005, the installed capacity reached 517 GW, being predominantly coal fired (IEA, 2007b: p. 343). Even though other generation forms such as natural gas and nuclear power are pushed, coal is still dominant also regarding the power plants under construction. By the end of 2005, over 120 GW of generating capacity were under construction (EIA, 2006: p.11), of which the lion's share is covered by coal. In addition to that, it should be kept in mind that approximately 20% of coal power plants existing in China are illegal (110 GW in comparison to 440 GW 'legal' capacity in 2005(MIT, 2007)) and thus not covered by official statistics. They are not necessarily lacking governmental control or to put in the words of MIT (2007: p. 68) are hidden in the closet, but "*[it means that] they are not part of a coherent national policy, that they frequently operate outside national standards, and that they often evade control even by their ostensible owner at the national corporate level*". Therefore, national policy instruments are difficult to implement on them. Reasons for the discrepancy can be found in divergent interests of state and regional or local authorities. As the latter focus on a fast prosperity of their local or regional economy, they tend to avoid waiting for long lasting central approval processes or even ignore rejections by upper authorities.

4.4.2 Structure

A gradual process of reforms in the electricity sector began in the mid-1980s, when parties outside the central government were allowed to invest in electricity generation. Back then the sector was organized centrally and controlled by the Ministry of Power. In 1997, the ministry's assets were transferred to the newly formed State Power Corporation (SPC). Until 2002, the SPC was the dominant actor in the sector, owning 46% of the nation-wide generation capacity and 90% of the transmission assets. In the end of 2002, the Chinese government decided to dismantle the SPC into two grid operators, five electricity companies and four consulting and construction companies as illustrated in Figure 4-15.

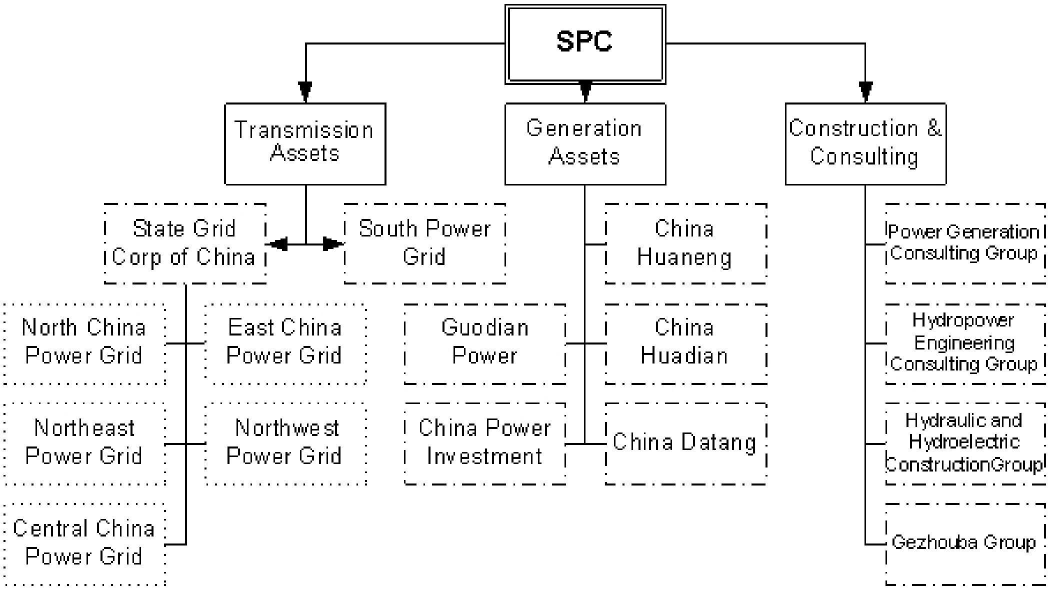

Figure 4-15: Actors on the Chinese Electricity Market after the 2002 Reform

Source: Own Illustration

In the context of the power market reform, the State Electricity Regulatory Commission (SERC)[31] was funded on the ministerial level, having the regulating authority over the sector (Xu and Chen, 2006). The goals of the reform can be summarized as follows:

- to break the SPC's monopoly and introduce competition
- to improve efficiency and lower costs
- to rationalize the tariff system and optimize resource allocation
- to promote the development of the power industry and push forward the nation-wide interconnection
- to set up an open, orderly and well-developed power market system based upon the principles of separation of administration and enterprise and equal competition under the regulator of government[32]

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[31] Some sources also refer to the China Electricity and Regulatory Commission

[32] Translated from the "Scheme of the Reform for Power Industry" by Xu and Chen (2006: p. 2461)

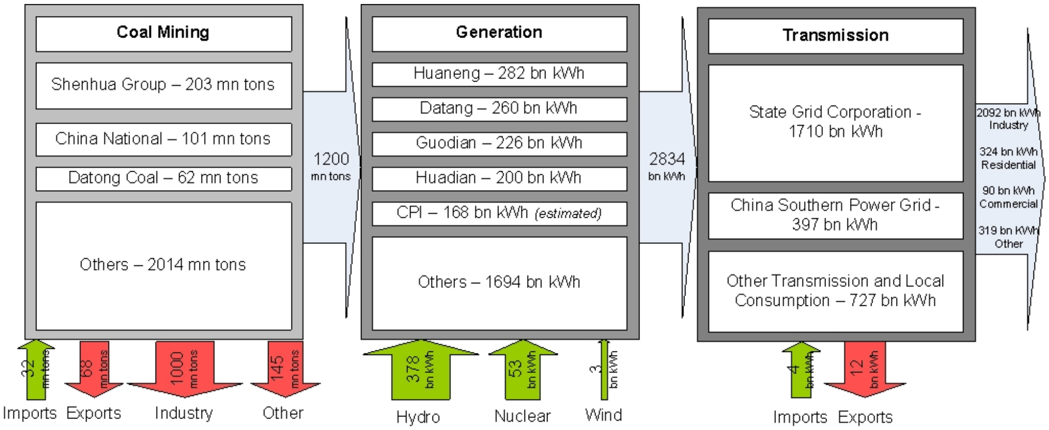

Figure 4-16: The Chinese Electricity Market

Source: Adapted from Rosen and Houser (2007: p. 24) using 2006 figures given by Rosen and Houser (2007)

Figure 4-16 summarizes the Chinese electricity market after the reform. In regard to electricity generation, the role of the five successor companies of the SPC is outstanding, even though their share has been diminished compared to 2002 when the SPC was split up, ranging at approximately 40%. Local, provincial and privately owned generation companies (summarized in 'Others') have a comparably large share of the market, where some competition has emerged (Rosen and Houser, 2007: pp. 24). According to Ma and He (in press) a majority of power generators (45%) are administered by local governments, while 6.21% of the generation capacity goes back on foreign or private investment. As private power generators emerge, incentives are set for state owned players to invest in efficiency improvements.

In regard to transmission and distribution, the better interconnection of several grids is envisaged in the 2002 power sector reform. In 2004, five of six big power grids were interconnected tying together a generation capacity of nearly 200 GW[33]. However, some provinces as for example Fujian are not well interconnected and others such as Tibet or Xinjiang remain completely isolated until today (IEA, 2006: p. 41). Power transmission is highly dominated by the two companies that were founded following the former SPC. They created six regional wholesale markets, of which five are controlled by the state power grid cooperation (see also Figure 4-15) (Xu and Chen, 2006).

In contrast to generation and transmission, (coal) mining was already liberalized in

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[33] In 2004, 200 GW was equivalent to more than 50% of the total generation capacity of 391 GW. More recent data in regard to the power grids were not available for this thesis.

the early 1990s. A relatively small number of large, state owned mines are responsible for over 50% of the output, but on the other side most mines are small and belong to towns and villages. The consolidation and closure of small mines as envisaged by the government is not necessarily in the interest of local governments, fearing the loss of local jobs and is therefore processing relatively slowly (IEA, 2007b: p. 267). The share of village, town and privately-owned mines, considered to be small scale mines, has increased substantially after it was significantly reduced between 1999 and 2002, when government programs called for the closure of small mines (Wang, 2007). In 2005, more than 20,000 small mines were responsible for approximately 40% of the Chinese domestic coal output. At the same time, the biggest actor (Shenhua Group) had a market share of 8.5%. Given a market with a high number of actors of which none can reach a dominant market position, it can be claimed that in contrast to generation and transmission, the mining sector is fairly competitive.

4.4.3 Pricing

The Chinese price system for electricity on the wholesale level is based on a catalogue system defining prices for selected categories. Provincial/regional catalogue prices are set for eight main categories of consumers with three voltage classifications. Next to a sectoral diversification, tariffs are also dependent on the time of day energy is demanded[34]. In addition to that, a range of fees and charges is added to the final price, which can differ locally as well as from sector to sector[35] (IEA, 2006: pp. 51).

Price policies for generating facilities have experienced a steady liberalization process since 1986. At this time, power plants were exclusively state owned and regulating price mechanisms were from lower importance. Prices for electricity reflected the operational, but not the capital costs, which were covered by state facilities anyways. With independent power producers (IPP) entering the market it became necessary for Chinese authorities to change the existing price policies. At first, power plants using investment from external sources (non-state) were allowed to charge higher prices, eventually leading to a more diversified price setting on basis of age, efficiency, fuel, location and type of the generated power. This program, called

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[34] This form of time of day tariffs does not apply for the residential sector and irrigation

[35] Extra charges are for example levied for the Three Gorges Dam construction in neighboring regions.

“new price for new power program”, was launched in 1992, allowing all newly constructed power plants to charge higher prices for electricity and thus to price-in capital costs. The program is considered of being successful in encouraging investment in new generating capacity especially by private investors; however, it could not give sufficient incentives for investors to invest in more efficient power plants, to reduce their costs or to seek more favorable financing terms (IEA, 2006: p.52). Currently, the Chinese price system is output based (i.e. per kWh) including annual energy as well as capital costs. The latter are calculated assuming a specified annual operation time. For equity reasons the Chinese regulators assume that all comparable power plants run roughly the same amount of hours per year, regardless of operating costs or fuel efficiency (Wang, 2007). In addition to that, a form of standard-offer pricing was established in 2004, paying all new generators a premium for using energy efficient and environment friendly technologies, e.g. flue gas desulphurization.

Regarding transmission and distribution, electricity generators are not allowed to sell electricity directly to end users, but have to sell it to grid operators at regulated prices. In turn, grid operators sell it to end users. Prices for grid operation are not separately outlined, but included in the regulated electricity prices. However, it can be presumed that transmission and distribution will be liberalized in the near future. Pilot projects have been brought on its way, allowing large-volume consumers to purchase electricity directly from generators (Ma and He, in press). Additionally, it is envisaged that power generators are allowed to bid in regional wholesale markets in order to gain prioritized grid-access. This part of the 2002 power reform was however postponed due to 2002 electricity shortages and has not become effective, yet (Wang, 2007).

In regard to electricity pricing, one major problem of the Chinese electricity market is the fact that coal prices are more market orientated than electricity prices. As coal is the dominant fuel used for electricity generation in China, coal prices as well as coal availability have a tremendous impact on the electricity sector. In contrast to electricity prices, coal prices were deregulated in 1993. In order to promote electricity generation and fast power capacity increase, coal for the electricity sector was however sold to electricity generators at prices being significantly lower than market levels, called “within-plan coal” (Ma and He, in press). This form of a double-track pricing scheme supported the electricity industry but harmed the coal industry, being forced to sell coal below (domestic) market prices[36]. The double-track pricing scheme can be seen as an in-fact subsidy for state owned power producers. Ma and He (in press: p. 8) argue that many independent power producers (IPPs) lacked the political influence to get on hold within-plan coal and thus had to purchase coal at significant higher domestic market prices. Accelerated economic growth and the closure of many small-scale coal mines led to a notably increasing domestic coal price between 2001 and 2004 enhancing the effect of coal producers suffering from the system. As a consequence of increasing conflicts between the coal and the electricity industry, the "coal and electricity price co-move" pricing policy was launched in 2004. Hence, electricity generation prices co-move with coal prices and electricity retail prices co-move with generation prices (Ma and He, in press). However, the co-movement is not a free-market adjustment. The NDRC continues to regulate the coal and electricity market stipulated to a complicated formula: if the average coal price fluctuates by more than 5% in a period of six months, the electricity tariff shall be adjusted in the same direction (Wang, 2007). Thus, approximately 70% of a rise in coal price can be passed through to the end user (IEA, 2006: p. 55). This fact should remove current constraints and uncertainties for coal miners as well as for electricity companies, providing incentives to invest in new mining and generating capacity. However, bottlenecks in the transportation sector (basically rail) are currently the main reason to prevent coal mining companies from investment in new production capacity (IEA, 2006: p.55). To a certain extent the same is true for electricity generators in regard to the power grid, whose expansion is in the main focus of the government. Especially the west-east power grid expansions are a priority issue on the political agenda (Xu and Chen, 2006). Generally, coal and hydro resources being the main resources for the power sector are located far away from the centers of demand in the eastern and southern parts of the country. Transportation capacities thus play a pivotal role. As transportation capacities remain scarce, imported coal or natural gas will get more competitive, gaining more importance in the electricity sector, especially in the economically prospering eastern provinces (IEA, 2007b: pp. 417). Increased

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[36] As a consequence, the coal mining industry used to be heavily subsidized and highly unprofitable over decades. Therefore necessary investment was held back, leading to obsolete mining technology as well as poor working conditions (Wang, 2007).

dependency on world market prices would probably accelerate further liberalization in the Chinese electricity sector.

4.4.4 Short Term Investment

In regard to climate policy options, it is especially interesting to have a closer look at the short-term investment decisions in the electricity sector.

Technologies	Technological Availability	Cost ($ per kW)	Efficiency	Market share in China
Subcritical	Now	500 - 600	30% - 36%	Main base of China's current generating fleet
Supercritical	Now	600 - 900	41%	About half of current new orders
Ultra-Supercritical	Now, needs further R&D to increase efficiency	600 - 900	43%	Two 1000 MW in operation
IGCC	Now, faces high costs and needs more R&D	1100 - 1400	45%-55%	Twelve units waiting for approval by NDRC

Table 4-3: Coal Based Power Generation in China

Source: IEA (2007b: p. 345)

Table 4-3 shows the technological status, investment cost and efficiency of various coal-based power plant technologies. Existing Chinese coal power plants are mainly subcritical plants having a rather low efficiency. However, technological improvement in the near future is likely when looking at envisaged short term investment. Currently, 30 GW of the overall generation capacity of 517 GW (in 2006) is covered with supercritical power plants, whose efficiency is significantly higher than the average of coal based electricity generation in China, being 32%. In addition to that, supercritical power plants account for half of the newly ordered power plants in China, corresponding to a capacity of 100 GW. Therefore, it is reasonable to assume that the overall efficiency will rise; the IEA (2007b: pp. 345) assumes that it will be 39% in 2030. In general, the majority of newly constructed power plants in China are technically state of the art. Additionally, China makes some effort to invest in high-tech power plant technology such as Integrated Gasification Combined Cycle (IGCC) (People's Republic of China, 2007). In regard to climate policy, IGCC is thought to be a key technology in regard to Carbon Capture and Storage (CCS) as CO_2 can easily be separated in the process (Liu, 2008).

The importance of natural gas in the power sector is likely to increase, especially in fast growing coastal regions. Supply disturbances in domestic coal due to lacking transportation capacities are already a major problem. At the same time, an import structure for liquefied natural gas (LNG) is established as China generally aims for a more diversified electricity mix (IEA, 2007b: p. 346). Whether the significance of natural gas increases in the future will basically depend on the development of the gas infrastructure and the price of imported LNG (IEA, 2007b: p. 346). The development of rail capacities will moreover also play a certain role.

In 2008, 11 nuclear power plants with a total capacity of 8.6 GW are connected to the grid. Nuclear energy is planned to be extended significantly, even though the IEA (2007b: p.346) expects bottlenecks for nuclear technology on the world market and long construction times to delay ambitious Chinese targets to have 40 GW installed until 2020. According to the World Nuclear Association (2008), another six reactors with a capacity of 5.6 GW are currently under construction and are expected to be completed in the period from 2010 to 2012. For another 16 reactors construction is envisaged to begin soon.

China has the highest hydropower potential in the world especially on the rivers Yangtze, Lancang (Mekong), Hongshui (Tributary to the Pearl River) and Wujiang (Tributary to the Yangtze River). The installed large hydro capacity was 100 GW in 2006 adding up to 50 GW small hydro power (REN 21, 2007: p. 38). Some large scale hydro power projects are currently under construction including the Three Gorges Dam (18.2 GW of which 14.7 GW are in operation (2007), envisaged to be finished in 2009), the Xiluodu projects (12.6 GW, to be completed in 2015) and the Xiangjiba project (6 GW, envisaged to be completed in 2015). The Chinese government aims to have 300 GW of installed hydro power capacity in 2020.

Even though renewable energy plays a certain role on the primary energy level (especially due to traditional biomass) its share in electricity generation is small. In regard to biomass, only 1.5% is used for electricity generation, the biggest share is traditional biomass. The Chinese government plans to increase its use in the electricity sector (as well as for heat generation and transportation fuels) significantly, aiming to reach 5.5 GW of biomass-fired generating capacity in 2010 and 30 GW in 2020 (IEA, 2007b: p. 354).

Wind energy experiences significant growth rates, even though its overall importance in the electricity generation is still small. Having installed 1.3 GW wind energy in 2005, the capacity doubled by the end of 2006 (IEA, 2007b: p. 355). According to the Global Wind Energy Council, China installed an additional capacity of 3.45 GW in 2007 reaching more than 6 GW of installed wind capacity (GWEC, 2008). China thus reaches its goal set in the 11th five year plan to have 5 GW in 2010 early and is likely to meet its target to install 30 GW by 2020. In 2006, domestic manufacturers and joint-ventures accounted for 45% of the production, even though Chinese design and manufacturing capacity for large wind turbines is below international standards (IEA, 2007b: p. 355).

In 2005, China's solar photovoltaic capacity amounted to 70 MW, of which approximately 50% are installed off-grid. A vital domestic industry has been built, achieving an annual PV module production capacity of 300 MW at the end of 2006. China plans to build 300 MW until 2010 and 1.8 GW until 2020 (IEA, 2007b: p. 355).

Table 4-4 summarizes the installed capacity in China and the 2010 and 2020 goals of the Chinese government as far as they are available. Especially in regard to fossil fuels, projections are difficult to make as described before. Current capacity for natural gas and oil power plants are taken from IEA (2007b: p. 597).

	2007	2010 (Plan)	2020 (Plan)
Coal	517**	N/A	N/A
Natural Gas	10*	N/A	N/A
Oil	12*	N/A	N/A
Nuclear	8.6	14.2 ***	40
Hydro	150**	180	300
Wind	6	5	30
Solar PV	0.07	0.3	1.8
Biomass	~ 4	5.5	30
* 2005			
** 2006			
*** refers to plants that are currently under construction			

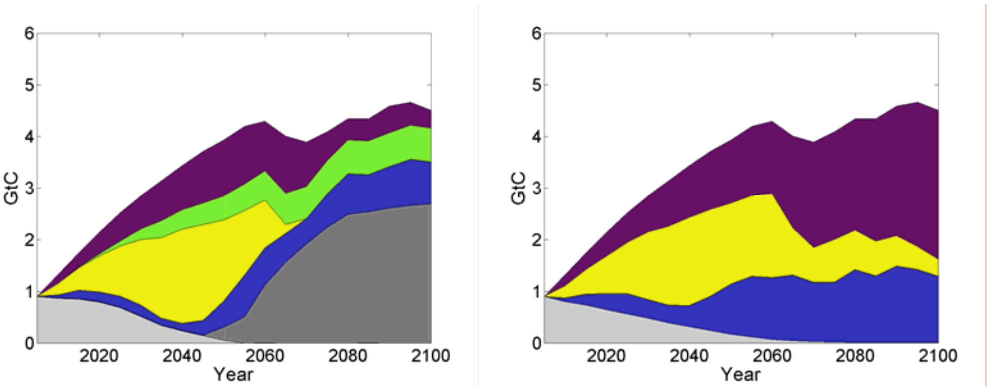
Table 4-4: Installed Electricity Capacity [in GW] in China and Short and Medium Term Capacity Goals

Source: GWEC (2008), IEA (2007b), Li (2006), MIT (2007), REN21 (2007), WNA (2008)

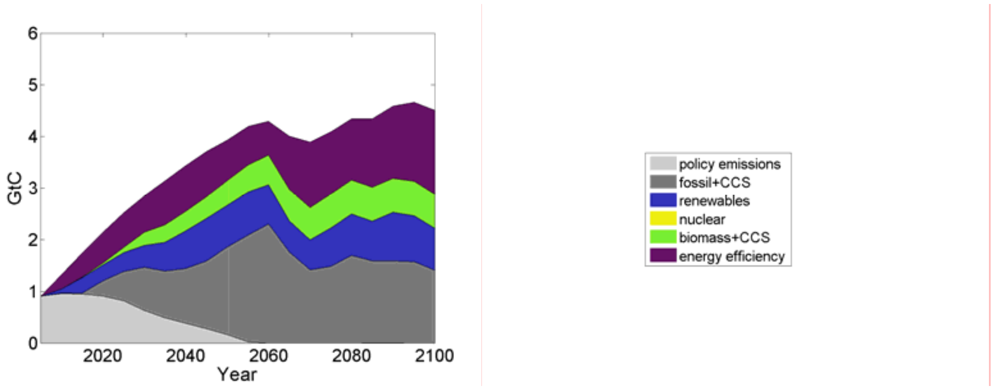
Generally, the Chinese government has gained some experience in supporting the development of renewable energies in the past. Research and Development subsidies have been provided since the early 1990s as well as favorable accounting rules for renewable energy. Next to the central government, some local governments have also supported renewable energy using income tax revenues. Grants and loans were moreover used by the central government to support small and medium sized enterprises in regard to energy efficiency and renewable energy (Cherni and Kentish, 2007). The Chinese government moreover launched programs to support renewable energy in selected sectors, including programs to electrify villages by renewable energy as well as large scale grid-connected PV programs and programs promoting wind energy. In 2006, the Renewable Energy Law was introduced providing a single framework for the promotion of renewable energy. In giving renewable energy policy legislative support, the Chinese government emphasizes that its promotion plays an important role (Ma and He, in press). At the center of the reform stands the possibility for the central government's energy authorities to set binding renewable energy targets. As a key element of the law the Chinese government established a mandatory market share for renewable energy generation. For all investors that have an installed capacity larger than 5 GW, non-hydro renewable generation capacity must account for 3 % in 2010 and 8% in 2020. Moreover, the renewable energy law commits the government to various policies that have been in place before, even though not on the legislative level. According to Cherni and Kentish (2007: pp. 3624), these policies include the construction of off-grid renewable power systems in rural areas, the establishment of a renewable energy development fund to support activities including the construction of remote areas and islands as well as research and development for renewable energies, preferential loans for renewable energy projects and tax benefits. In addition to that, the renewable energy law provides the conditions for establishing a feed-in tariff: Grid operators are required to purchase all renewable energy that is produced in the area of their grid; at the same time the price for electricity from renewable energy grid operators have to pay to generators is set by the government, "*in accordance with the principles of being beneficial to development and utilization of renewable energy*" (Cherni and Kentish, 2007: pp. 3624). In the power sector, the share of non-hydro resources must be 1% in 2010 and 3% in 2020 of total grid capacity as set by the NDRC (Ma and He, in press). Even though this goal does not seem to be very ambitious, it has to be regarded that currently the share of non-hydro renewables (wind, solar PV, geothermal) is lower than 0.5% and growth rates have to excel the growth in generation capacity, which is for itself thought to experience significant growth in the next years.

4.5 Mitigation Options in the Chinese Electricity Sector

In order to get an impression of the possible importance of various mitigation options, recent results from the ReMind-R model[37] are regarded (Leimbach et al., 2008). Promoting the 2°C goal, mitigation wedges for the whole Chinese economy are illustrated in Figure 4-17. The light grey area shows how much emissions will be emitted in the atmosphere, while the order of magnitude of various mitigation options is also illustrated.



a) Policy Scenario *b) Without CCS*



c) Without Nuclear Energy

Figure 4-17: Mitigation Possibilities in China as Calculated by the ReMind-R model. The top figures show a policy scenario based on contraction and convergence (a) and a scenario without CCS (b). In the figure (c) the possibility to use nuclear energy is excluded.

Source: Leimbach et al. (2008), Personal Communication with Lavinia Baumstark, PIK (01.04.2008)

Figure 4-17 shows mitigation options for China until the year 2100. In a policy scenario based on global emission trading with contraction and convergence (cp.

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[37] The ReMind-R model is a multi-regional hybrid model coupling an economic growth model with an energy system model developed at PIK. For more details see Leimbach et al. (2008: pp. 7).

Höhne et al., 2003) allowing all options, basically five mitigation options can be found of which nuclear energy and energy efficiency improvements as well as renewable energy play an important role until 2050. After 2050 the use of fossil fuel CCS quickly increases and dominates the mitigation options in China. The general impression changes when excluding the possibility to utilize CCS[38], as the importance of energy efficiency improvements dramatically increases. Moreover, nuclear energy will play a constant role all over the century, while the share of renewable energy will be doubled in comparison to the policy scenario. Excluding nuclear energy would lead to an earlier development of fossil fuels coupled with CCS, even though the overall amount of emissions being mitigated by this option decreases towards the year 2100. Energy efficiency improvements will have to play a more important role, while renewable energy plays a similar role in comparison to the policy scenario.

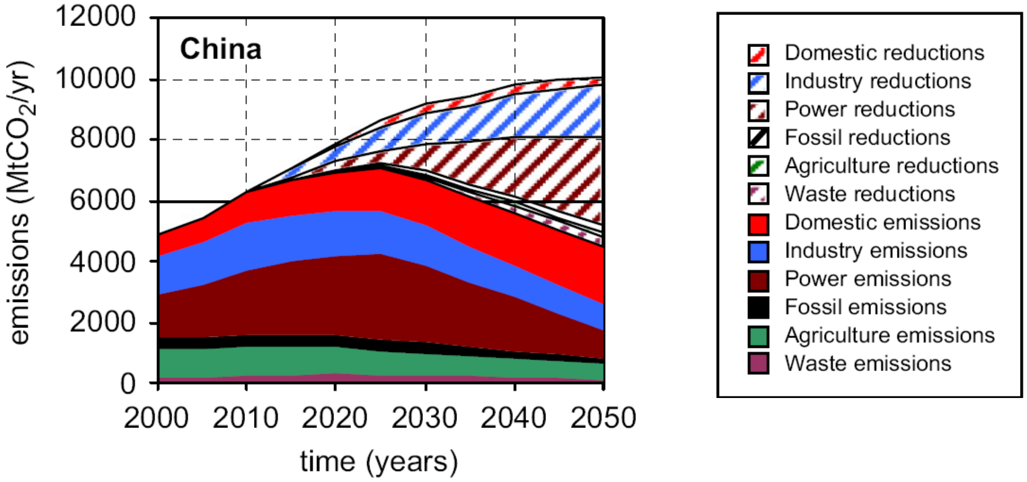

Figure 4-18: Reduction Contributions of different sectors for China between 2000 and 2050 using the IPCC B2 scenario as baseline emissions

Source: Den Elzen et al. (2008, p. 1120)

The role of the electricity sector in regard to future mitigation options is outstanding as it is a major contributor to Chinese CO_2 emissions today (see also section 4.4, pp. 81). This fact gets obvious when having a closer look to the current

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[38] As CCS is a technology that has not been proven to work in practice, it is linked to high uncertainties. Hence, it is useful to run models excluding the possibility to use CCS as there is a certain probability that current projections in regard to the technology might be wrong. The same is true for nuclear energy, which is linked to high risks and (political) uncertainties especially in regard to general security issues and the disposal of nuclear waste. Therefore it might be politically infeasible to develop nuclear energy the way it is assumed in the models.

generation structure being heavily dominated by coal. The electricity sector's outstanding role for future mitigation efforts can also be confirmed when looking at recent studies.

Figure 4-18 illustrates reduction contributions of different sectors as calculated by den Elzen et al. (2008). It shows that the power sector in China will have to contribute more than any other sector to future mitigation efforts.

In order to get an idea which abatement possibilities will be feasible and affordable in the upcoming decades, it is necessary to have a look on the marginal abatement costs of various options.Table 4-5 shows an assessment of mitigation options by Ogonowski et al. (2006) in the Chinese electricity sector and referring marginal abatement costs. According to their studies, 45% of overall abatement options can be found in the electricity sector. But, they are relatively expensive and abatement can partly be reached more cheaply in other sectors[39]. When considering a realistic carbon price of approximately $ 20 per tonne CO_2 (Stern, 2006), abatement options in other sectors are dominant, having a share of approximately 70 per cent.

Marginal Abatement Cost [$/ton CO2]	**Mitigation Option (in the Electricity Sector)**	**Reduction Potential in the Electricity Sector until 2020 [MMt CO2e]**	**Reduction Potential in Other Sectors until 2020 [MMt CO2e]**
-20 - - 5	N/A	0	202.7
-5 - 0	Circulating Fluidized Bed Combustion (CFBC)	5.7	79.4
	Demand Side Management	38	
0 - 5	N/A	0	131.3
5 - 10	Reconstruction of Conventional Thermal Power	25.1	107
	Supercritical/Ultracritical Plant	29.7	
10 - 20	Nuclear Power	136.9	3.7
20 - 50	Hydro Power	171.2	29
	Natural Gas	4.2	
	Wind Power	7.6	
	IGCC and PFBC (Pressurized FBC)	14.1	
50 - 100	CCS	5	33.2
> 100	Solar Thermal	11.4	5.7

Table 4-5: Marginal Abatement Costs in the Chinese Electricity Sector and Potential CO_{2e} Reductions until 2020

Source: Based on Ogonowski et al. (2006, p. 90)

The following sections will evaluate the major mitigation options in more detail, focusing on the possibilities that have been identified before: increasing energy efficiency, renewable energy, CCS and fuel switch.

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[39] Other sectors that are regarded by Ogonowski et al. (2006) are transportation, cement and iron and steel.

4.5.1 Efficiency Gains

From modeling results it gets obvious that efficiency gains will be a major contributor to emission reductions in China in the future. It is therefore necessary to look at potential savings in more detail. Chapter 3 could already show that energy intensity has decreased continuously in the last decades, which is highly driven by efficiency gains in the industrial, but also in the electricity sector. Yang (2008) shows that energy intensity and electricity intensity are highly correlated in China. It is therefore a tremendously important aspect to consider how efficiency can be raised in the electricity sector.

The Chinese government reacted to the mitigation opportunities that can be derived from energy efficiency gains in setting aggressive goals on the country's energy efficiency. Thus, the 11th five-year plan foresees a reduction of energy intensity (defined as primary energy input per unit GDP) by 20% in the period from 2005 to 2010. The goal would correlate to a reduction potential of 1.5 billion tons of CO_2 as expected by Lin et al. (2008). However, regarding recent trends (compare section 4.3) it seems to be unrealistic that the goal can be achieved as primary energy input and thus energy intensity has increased substantially in recent years.

One important option in regard to energy intensity improvements is to switch from inefficient small coal fired power plants, currently dominating the generation capacity to efficient large-scale power plants with a capacity higher than 600 MW. Chinese energy policy shows that the government aims to do this. Small-scale power plants with a capacity lower than 50 MW were forced to shut down, while new power plants need to be larger than 300 MW (Cai et al., 2007, p.6446). As currently 74% of Chinese coal-fired power plants have a capacity equal or lower than 300 MW, Yang (2008) estimates a reduction potential of 82.2 Mtce per year if all small-scale power plants could be substituted by larger ones. This would equal an annual reduction potential of 228 Mt CO_2, without considering fuel switch to less emission intensive natural gas power plants or the use of combined heat and power (CHP). Moreover, the efficient use of power plants in regard to the load factor also holds some potential for emission reductions. Yang (2008) estimates that raising the load factor by 1% could save 7 Mtce, which is equivalent to a reduction potential of approximately 2 Mt.

Relevant abatement potentials can also be found on the demand side in various sectors. Using more efficient appliances in regard to standby power could for example save 40% of the energy, compared to a business as usual case being 300 TWh in the period from 2007 to 2020 (Yang, 2008). In regard to electric motors, Yang (2008) finds that the electric saving potential accounts for 20% or 795 TWh[40]. There is probably more abatement potential to be found in all fields of the economy; however, it has to be considered that rising living standards in China collide with electric saving potentials, as the demand for electricity intensive appliances in the household and commerce sector (e.g. air conditioners) increases (Rosen and Houser, 2007: p.37). On the other hand, China tries to reduce energy intensity on the demand side by intensively promoting the use of solar thermal water heating. The country is the largest market for solar water heaters in the world, including a well developed domestic industry. Nearly two-thirds of the global capacity is installed in China, adding up to 40 million installed systems on an area of 80 million square meters (2005). Ten percent of Chinese households rely on solar heated hot water (Martinot and Li, 2007), mostly by advanced vacuum tube technology (Li et al, 2006: p.7). High growth rates and strong attention on the relevant national-level and local government departments imply that the technology will be further extended. Li et al. (2006) estimate a development potential of 300 million square meters in 2020 and 500 million square meters in 2050.

Having a closer look at various sectors, it can generally be stated that the industrial sector is the most important one. In recent years, its share in China's GDP has increased to approximately 50%, while the tertiary sector has basically remained flat at 40%. In the same period, the primary sector has decreased from over 20% in the early 1990s to approximately 10% in 2004. Compared to other countries the share of the Chinese tertiary sector is low. In India for example it accounts for 54% of the GDP, while it is 76.5% in the USA. Shifting the share of the tertiary sector in China on a level comparable to India, its energy intensity could drop by 22%. It could even decrease by 31% if the tertiary sector reached the US level (Lin et al., 2008, pp.355). However, it seems to be unrealistic in the short to medium run that the structure of the Chinese economy will transform significantly.

In regard to structural changes it is also interesting to recall that energy intensity

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[40] Compared to an annual generation of 2834 TWh in 2006 (Yang, 2006).

has increased in recent years, mainly driven by a shift in the industrial sector towards high energy-demanding technologies, such as steel and cement. Determining the reasons for the increasing demand, one driving factor is the ongoing urbanization, leading to an outstanding demand for steel and cement by the construction sector (Zeng et al., 2008).

Considering efficiency improvements in general, it should be kept in mind that rebound effects might occur. In the literature different rebound effects are described: direct, indirect and economy-wide effects (Sorrell and Dimitropoulos, 2008). For energy services, direct rebound effects refer to the fact that increasing energy efficiency for a particular energy service leads to decreasing effective prices, which in turn lead to increasing consumption of that energy service. In regard to China, this could for example be illustrated by a rising demand in steel, e.g. in the construction sector as a substitute for wood, as increasing efficiency in the steel production lowers prices. Moreover, indirect rebound effects could influence the demand for other energy intensive goods and services, as consumers can spend more money due to savings generated by increasing energy efficiency. Thirdly, the literature also refers to economy wide effects. As falling prices for energy services also automatically lead to decreasing prices for intermediate and final goods throughout the economy, energy-intensive goods and sectors gain a comparative advantage in comparison to less energy-intensive ones (Sorrell and Dimitopoulos, 2008: p.637).

4.5.2 Fuel Switch

In regard to the overall emissions in China, the potential of efficiency gains in the Chinese coal-based generation capacity seems to be rather low. The impression can be confirmed when reviewing the literature. Zhang et al. (2006) find that according to provincial projections and current orders, most coal fired generation after 2010 will be composed of power plants using less than 350 grams of standard coal equivalent (gsce) per kWh, as more and more new large scale power plants replace old small scale ones. A bigger potential to curb Chinese CO_2 emissions is seen in switching from coal-fired power plants to less emission-intensive fuels, as for example natural gas and nuclear power (renewables will be discussed separately below). China has neither significant natural gas nor uranium reserves. Strategic reasons have often been mentioned in order to justify the extensive use of coal, being locally available. It is commonly understood in China, that the reliance on foreign energy shall be reduced to a minimum. But, given the continuous scarcity of inland transportation capacity for coal, imported fuels – coal as well as other primary energy fuels – will automatically get more important. In regard to natural gas, this fact can be illustrated by China investing in LNG infrastructure including import deals with Qatar as well as in pipelines to get access to central Asian natural gas fields, i.e. in Russia (Li, 2008).

Having a look at the ReMIND-R model results, nuclear energy plays an important role for mitigation in the short run, but fades out after 2050 as CCS becomes more attractive. In case CCS is not an option, nuclear energy will continue to play a viable role, even though its importance decreases after 2050, as renewable energy and energy efficiency become more dominant. Current Chinese policy emphasizes that nuclear power is supposed to play a more important role in the future. First of all, medium term goals foresee the expansion of current nuclear energy by more than factor four to 40 GW of installed capacity in 2020, compared to an installed capacity of 8.6 GW and 5.6 GW being under construction. Regarding the envisaged primary energy import, China signed an agreement with the Australian government, securing the import of 20,000 tonnes of uranium per annum for the Chinese power sector for the next 20 years (Wu et al., 2008). Having in mind that the world nuclear industry consumes 66,000 tonnes each year of which only 60% or approximately 40,000 tonnes are supplied directly by mined uranium this number impressively emphasizes the political will to expand nuclear power dramatically.

4.5.3 Renewable Energy

As shown in earlier sections, the Chinese government has expressed its support for renewable energies. ReMIND-R model results (Leimbach et al., 2008) show that the development of substantial renewable energy capacity has to be enforced in the short and medium term, while in the long term the development of other mitigation options will play a more important role, at least as long as CCS is a feasible mitigation option (compare Figure 4-17, page 92). In order to be able to identify policy options in the post-2012 climate policy discussions the following section will deal with the overall potential for the development of renewable energy as well as key development possibilities and barriers for renewable energy. An overview of capacity being already installed is given in section 4.4.4, pp. 88.

The general potential for renewable energies is high in China as illustrated in Table

4-6[41].

Technology	Potential Capacity	
Small Hydro	GW	125
Large Hydro	GW	275
Onshore Wind	GW	253
Offshore Wind	GW	750
Solar PV	EJ/a	5000
Biomass Combustion	EJ/a	10
Biomass Digestion	EJ/a	2
Geothermal	EJ/a	4000
Wave/Tidal	N/A	N/A

Table 4-6: Renewable Energy Potentials in China[42]

Source: Data taken from Cherni and Kentish (2007), Li et al. (2006)

No reliable data on ocean energy potentials are available, but it is however in the focus of research and development in the Chinese energy sector. A 100 MW tidal power pilot plant is operating since 1999, while an initiative to build a 100 MW onshore wave energy demonstration plant in Guangdong province was launched by the Ministry of Science and Development (Chinese Renewable Energy Association, 2008).

There are some important barriers for the development of renewable energies in China. Generally, it can be claimed that the technical level of renewable energy industries in China lags behind other countries. As the scale of the manufacturing industry is small, technical equipment has to be purchased from abroad, with prices being up to 60% higher compared to being purchased locally. In addition to that, the general capability of renewable energy manufactures is lower than in other countries, so especially high-tech components (for example for wind turbines) need to be imported (Cherni and Kentish, 2007: pp.3620).

The status of the renewable energy industry in China is still not at a level where it can fully compete with foreign competitors. However, it is increasing, both in scale as well as in quality. The capacity of PV module production has increased dramatically between 2000 and 2006, going up from an initial capacity of 20 MW to 300 MW in 2006 (Li et al., 2006). However, the global scarcity of raw silicon also affects the

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[41] Check on Table 4-4, p. 90, for currently installed capacity.

[42] Note: It is not specified by Li et al. (2006) which form of geothermal energy is included in the potential calculations

industry in China. In 2005, 20 wind turbine manufactures existed in China, being able to handle a capacity level of 750 kW without difficulties. Some pilot projects on the megawatt level are envisaged. This is still significantly lower than the capacities levels that are commonly offered by European manufacturers whose modern turbines have a capacity of 2 – 5 MW. Biomass digestion is commonly used in rural areas, even though a large scale industry has not been developed, yet. In regard to hydro energy, China has developed an industry that can compete on world level being able to handle major large-scale projects, as for example the Three Gorges project and other large hydro dam projects.

In regard to government action, the Chinese government faces a general dilemma. Even though it promotes renewable energy, it also has a high motivation to keep electricity prices low, in order not to negatively impact GDP growth. In comparison to coal-generated electricity, generation costs for renewable energy are still significantly higher. Low environmental standards and weak pollution control, failing to internalize external costs caused by coal-based electricity generation, are one barrier to renewable energy development. Moreover, coal power plants often have fully depreciated their capital costs, making it difficult for new capital-intensive renewable energy projects to compete (Cherni and Kentish, 2007).

In addition to that, Cherni and Kentish (2007: p.3621) also identify transmission and distribution costs not being reflected in the Chinese electricity price to be another barrier for renewable energies: On the one hand coal has to be transported over long distances to reach the energy demanding regions in the south-west (either by train to be transformed into electricity where it is demanded or by long distance transmission of electricity in case electricity is produced close to the coal mining regions). On the other hand excellent wind resources can be found in the south western regions of China. Thus, according to them, not including transmission and distribution costs into the price indirectly supports the development of coal, as the comparative advantage of wind energy in regard to the location is not reflected in the price structure.

Even though it can be stated that the quality of transmission and distribution has an impact on the integration of renewables, the argument of Cherni and Kentish (2007) does not seem to be very strong. Grid operators being often not allowed to include additional costs for renewable energy in the sales price is probably a more important barrier for renewable energy development as Chinese officials want to keep electricity prices as low as possible (Cherni and Kentish, 2007: p.3622). Therefore, grid operators are reluctant to connect renewable energy sources (even though they theoretically have to do so) as they are additionally forced to pay higher prices to renewable energy generators. Moreover, intermittency of some renewables demands a higher technical grid standard than conventional fossil-fuel based power plants, leading to significant higher costs for grid operators.

Generally it can be claimed that the Chinese power grid lacks investment. The fact that regional grids are only limitedly connected leads to a diminished possibility of using the grid as capacity reserve. As some renewables (especially wind) are highly characterized by intermittency, a large interconnected area over which generating capacity is installed reduces the costs of integrating renewable energy into the grid as intermittencies can be leveled by regional diversification (DeCarolis and Keith, 2006). Establishing a well connected Chinese electricity grid is therefore crucial. Additionally, intermittency can be reduced if the generation mix is not dominated by inflexible coal or nuclear energy plants, but by hydro and natural gas (DeCarolis and Keith, 2006). On the first sight, the generation mix in China being characterized by coal fired electricity is not favorable for the development of renewables; on the other hand it has to be taken into consideration that hydro power capacity is outstanding, which might be in favor for the integration of renewable energy. But, well interconnected power grids are a precondition.

4.5.4 CCS

Model results show that CCS is the dominant mitigation possibility in the policy scenario, and still very important in case nuclear energy is excluded. But, at the same time, it is also the mitigation possibility showing the highest uncertainties in regard to future risks and the general feasibility. Basically, three possibilities for CCS are conceivable, namely deep saline reservoirs, depleted oil and gas fields and deep unmineable coal beds.

The available oil and natural gas fields can only be used limitedly for the storage of CO_2, with the known hydrocarbon pore space storage capacity being about four and a half times the annual CO_2 emissions of 1998 (APEC, 2005: pp. 44). Therefore, the potential to use hydrogen pore space storage in China on a large scale seems to be small. However, China is a world leader in using enhanced oil recovery (EOR) today, allowing the conclusion that CO_2-EOR could gain early implementation (IEA, 2007b: p. 348).

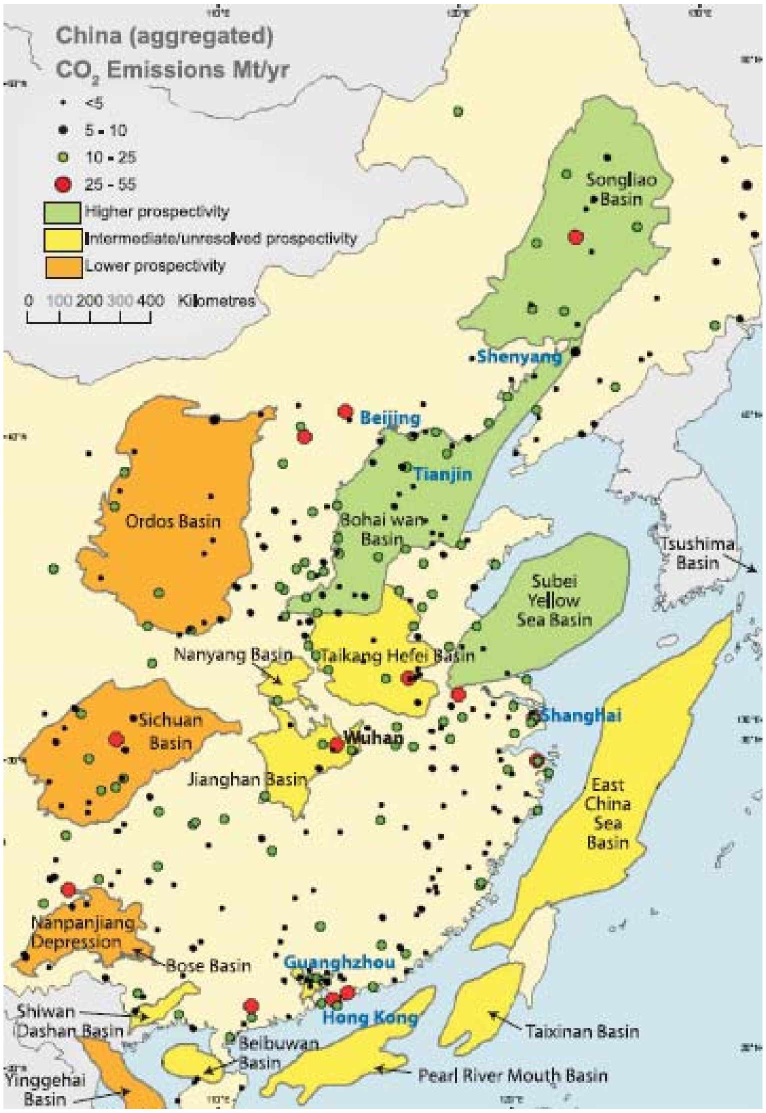

Figure 4-19: Major CO_2 Sources and Possible Basins for CO2 Storage in Eastern China.
Note: Basins are classified as determined by APEC (2005: pp. 35). Basins in Western provinces have not been regarded as they are considered to be too far away from the major emission sources.

Source: APEC (2005: p. 43)

China has huge coal reserves, which might be used for CO_2 storage in regard to enhanced coal-bed methane recovery (ECBM). The IEA (2007b: p. 348) estimates that roughly 30 trillion m³ of methane is covered in coal beds, which could – at least partly – be exploited and substituted by CO_2[43]. But, generally coal mines are far away

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[43] The typical ratio for CO_2 in ECBM is two molecules of CO_2 for one molecule of CH_4 (IEA, 2007:

from the Chinese centers of energy demand and thus also from the centers of CO_2 emissions. This would cause a need for a transportation infrastructure, either for electricity (in case of power generation is located close to the mines) or for CO_2. A micro pilot project for ECBM has been proven to be successful in the Shanxi province.

From a technical point of view, the challenge in regard to CCS is to generate a highly-concentrated CO_2 stream, excluding other flue gases as for example nitrogen (Bauer, 2005: pp. 153). Even though some industrial processes emit nearly pure CO_2 streams, most combustion technologies in the electricity sector lead to flue gases with a high content of other gases, mainly nitrogen, as air is used for the combustion. This fact can be avoided by using a high amount of oxygen for the combustion or alternatively by separating the CO_2 from the flue gas end of pipe. In regard to the electricity sector, current Chinese coal-based generation capacity is not equipped for CO_2 sequestration, being an important pre-condition for capturing the gas. As end of pipe technologies go along with high marginal efforts of capturing CO_2 and an air separation unit mostly needs to be planned before a power plant is constructed, realistically, CCS will not play a role for the current stock of Chinese coal-based power generation. Having a closer look to CCS, it needs to be taken into consideration that carbon capture is always linked to efficiency losses. Therefore coal demand increases in comparison to generation without CCS. In case the technology should fail to take out CO_2 from the atmosphere over an adequate time scale, CCS would have increased the coal demand compared to a business as usual scenario and thus would have a negative impact on global warming (Bauer, 2005: pp. 199). In this context it is interesting to mention that severe interest is shown in IGCC coal power plant technology, easily allowing for the sequestration of CO_2. A pilot project being planned in Yantai in the 1990s has not been constructed until today, though, but it can be observed that some generation facilities show interest in building IGCC power plants and launch “green coal power” programs as for example the China Huaneng Group (Liu et al., 2008). Moreover, IGCC technology is included in several national research and development programs.

Summing up different mitigation options, it can be stated that all identified

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p.348).

possibilities are linked to various risks which are difficult to quantify. This is not only true in regard to China, but also for the rest of the world. Which mitigation options will actually be developed is therefore not only driven by economic rationale, but also has a political component. It is likely that different countries find different solutions, based on their preferences and their specific national environmental and social-economic conditions. Most importantly, the level and measures of GHG mitigation will highly depend on the level of an international carbon price. The next section will therefore evaluate how an international carbon market can be established, exemplarily determining the Chinese electricity sector.

5 Including China into a Post-2012 Climate Regime

After having evaluated the Chinese energy system in the previous chapter, chapter five will discuss how China can be integrated into a post-2012 climate regime. Therefore, China's options are firstly determined on a very general level. Afterwards, sectoral no-lose intensity targets are regarded particularly, as they have been identified to be a promising post-2012 option in chapter 3. Firstly, the characteristics of intensity targets in general are discussed, before determining the nature of sectoral intensity targets. In order to understand how sectoral no-lose intensity targets can be applied in China, the Chinese electricity sector is exemplarily regarded. An extended Kaya identity is applied in order to understand driving factors of Chinese energy related CO_2 emissions in the electricity sector, which is necessary to make a statement on the efficiency of sectoral no-lose intensity targets. Finally, the amount of credits that could be generated by sectoral no-lose intensity targets is roughly calculated.

5.1 Post 2012 Climate Policy Options

China has more than one option to contribute to mitigating carbon emissions in the future and they do not necessarily have to be linked to an international climate agreement. Rather, one can also think of domestic policies that lead to emission reductions without being rewarded by an international carbon market. However, actively working on establishing a global carbon price is also one option for Chinese climate policy in the future. In any case, it can be stated that technology improvements are necessary in order to curb international carbon emissions: developing low carbon technologies is therefore also an important point of the agenda.

In the following, the relevant options for Chinese climate policy in a broader sense are discussed.

5.1.1 Domestic Programs

Not being linked to any international action, it is conceivable that China undertakes domestic action that will have a beneficial effect on reducing emissions. Even though domestic programs are not primarily designed to lower emissions, their implication might have a negative effect on emission growth. This effect could also be interpreted as a positive external effect of domestic policies. In general, China's policy is basically focused on increasing economic welfare as could be shown in chapter 4.

Environmental and climate considerations have not played an agenda-setting role in China for a long time, rather being seen as putting constraints on its economic growth. However, faced with serious local and regional environmental problems such as air pollution and acid rain, Chinese officials have called for a more sustainable growth. Measures introduced to tackle domestic environmental problems, will also have a general benefit in regard to decreasing emissions. Moreover, it can be observed that energy supply causes increasing difficulties in China. Domestic primary energy sources are not sufficient to satisfy demand. Therefore, China gets increasingly dependent on energy imports. As energy security is very important for China's officials, their motivation to increase the resource efficiency is high. In turn, increasing efficiency also leads to decreasing emissions, in general having a positive impact on global emissions. In addition to that, it is also conceivable that measures to increase the international competitiveness in energy intensive industries will also lead to co-benefits in the form of decreasing emissions.

To sum it up, domestic programs are reasonable for China even without considering the challenges that come with international climate change. Rather, they are related to considerations in regard to energy security, air pollution, international competitiveness and the general economic efficiency. A couple of measures that have been introduced in China can be interpreted as domestic programs:

a) Reducing subsidies for coal
b) Investment in energy infrastructure other than coal
c) Implementing market structures on the energy market that enable efficiency and market based regulations
d) Market Introduction of renewables including feed-in tariffs and quota systems
e) Energy taxation
f) Reducing emissions to reduce air pollution
g) Efficiency improvements by command and control
h) National Energy Efficiency Campaigns

Domestic programs can therefore have very different characteristics, leading from tax policy to information campaigns.

5.1.2 Technology Development

Chinese policies show some efforts to invest in low-carbon technologies. Next to being motivated by energy security issues and efficiency aspects especially in regard to renewable energies, low-carbon technology development is motivated by climate policy. It should not be forgotten that China is a country being highly vulnerable to international climate change, especially when it comes to agriculture and water resources (Cruz et al., 2007: pp. 471). In regard to the special political situation, the contrast between communist principles of social equity and the everyday realities, food and water scarcities could easily lead to mass protests. In the long run the CCP has an interest in global scale efforts to reduce GHG emissions and thus has also an incentive to curb emissions on the national level. In addition to that, technology development is also motivated by external pressure that is put on China by the international community to reduce emissions, especially Annex I countries. Technology transfer can play an important role and is discussed frequently in the literature and in the framework of international negotiations (Lisowski, 2002, Martinot et al., 1997). However, stimulating the technological progress is not a simple issue. Especially in the energy sector it faces challenges like long lived capital stocks (power plants can run over 50 years) and an underdeveloped energy infrastructure (Lisowski, 2002: p.169). Various forms of technology transfer can be differentiated, including licensed production, turnkey plants and long-term industrial cooperation in the form of joint-ventures (Martinot et al., 1997, pp. 373). The ongoing process of opening markets in China eases the process of technology transfer, as it has been allowed on the corporate level, while from an historical point of view, all technology that was imported to China needed to be approved by central state authorities. Determining ongoing policy in China, it can be found that several measures indicate a broad engagement in terms of technology cooperation in the energy sector including[44]:

a) Pilot Projects (CCS)
b) Joint ventures (CCS, Renewable Energy, Energy Efficiency)
c) Knowledge/technology transfer on energy efficient and low carbon power

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[44] The mitigation options that are outlined in brackets indicate current measures in China, based on the classification made in section 4.5.

plant technology (CCS, Renewable Energy, Energy Efficiency, Nuclear Energy)

d) Building a Chinese renewable energy industry

e) Enhancing the electricity grid to foster the integration of renewables

From an international climate policy point of view, supporting the efforts in technology development could be useful in order to modernize the Chinese industry structure and energy system. Technology cooperation is frequently discussed on the international level (cp. Lisowski, 2002: p. 169). One could think of various options, including technology protocols or research and development cooperation. However, especially high technology cooperation probably raises competitive concerns and companies might be reluctant to make their knowledge freely available.

5.1.3 Emission Pricing

From an economic point of view, the main problem in regard to climate change is the occurrence of external effects, respectively the un-priced or un-taxed GHG emissions. Stern (2006: pp. 468) finds that the main challenge for international mitigation policy is to find a common carbon price in order to use global emission abatement possibilities efficiently. Theoretically, a global carbon price can be implemented by carbon taxes or quota regulations, showing identical effects in theory but both having various advantages and disadvantages when considering real world implications[45]. For China, the motivation to participate in carbon pricing could be external pressure and climate policy. As China actively participates in the CDM, it can be presumed that some interest in carbon markets has been developed, which might be the basis for further negotiations.

Regarding post-2012 options to establish a carbon price in China, three possible pathways can basically be thought of, which not necessarily have to be incompatible: to continue the CDM in its current form, to upscale the CDM with sectoral intensity targets being one option and to include China in a global cap and trade scheme, comparable to the one that is established in the Kyoto Protocol for Annex I countries. From an economic point of view, it would be most efficient to include China into an

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[45] See Stern (2006) chapters 14 and 21 for a detailed discussion of emission taxes and trading regimes. However, the possibility to implement emission taxes shall not be discussed for this thesis.

international cap and trade scheme (compare e.g. Stern, 2006: pp. 308, Zhang, 2007). However, China, as well as most other developing countries, is reluctant to agree to binding reduction commitments that would go along with such a scheme. Policy makers in non-Annex I countries including China fear negative impacts on the growth of their economy and thus negative implications on their economic development. Binding emission caps are often seen as an attempt of developed countries to solidify the contemporary distribution of wealth, hindering developing countries to reach a development level comparable to developed countries (Zhang, 2007). Therefore, they expect developed countries to take the lead in climate policy. It is very unlikely that China as well as other major developing countries will accept binding caps on their emissions after 2012.

From a political point of view the easiest possibility one can think of is to continue the CDM in its current form. It has developed to be a well established instrument including a viable market with private as well as public stakeholders. Moreover, the relevant institutions have been built and proven to be working. However, there are some weaknesses that can hardly be ignored, which are discussed in detail in section 2.4.2 (pp. 24): First of all, in being a bottom-up instrument, the CDM does not seem to be the right instrument to support structural changes. It is hardly imaginable that the CDM will set sufficient incentives for developing countries to stabilize or even reduce their emissions. Rather, in its current form it could be an incentive for countries not to introduce climate policy as they could conflict with additionality regulations.

In general, proving additionality might be the most important shortcoming of the current CDM. In being a highly bureaucratic process, it still cannot guarantee the environmental integrity of CDM projects. In addition to that, the goal to provide sustainable development has been failed, also because sustainability standards are set by national DNAs instead of being defined centrally. Moreover, the CDM has allowed for low hanging fruits (especially HFC-23 destruction) to be credited under the scheme, which could have been handled more efficiently with other instruments. It can be argued that credits from HFC-23 projects as well as other so called ‘low hanging fruits’ have inflated the market, leading to the price for CERs being generally too low. Projects having higher transaction costs, for example due to higher sustainability standards or low political stability (as for example projects in Sub-Saharan Africa) are therefore less attractive for investors.

Sectoral no-lose intensity targets generally seem to overcome some of the major shortcomings that are connected to the current CDM. Furthermore they provide a good possibility to establish institutions that are necessary in regard to an international carbon market. Therefore, they are discussed in more detail in the following sections.

5.2 Discussion of Sectoral No-Lose Intensity Targets for China's Electricity Sector

Some shortcomings of the current CDM are reflected in post-2012 proposals generally referred to 'upscaling' of the CDM. The most important possibilities are introduced in chapter 3 (pp. 29). Sectoral no-lose intensity targets as proposed by Schmidt et al. (2006) seem to be an interesting possibility. On the first sight, the approach might reflect general burden-sharing aspects better than other proposals, as no negative implications have to be feared in the case of non-compliance. Therefore it could be argued that it is more 'politically feasible' than other proposals as for example including developing countries into a cap and trade scheme. In general, it is a major challenge of post-2012 negotiations to include all major emitters, as otherwise leakage and free rider issues occur. Especially the United States have been unwilling to sign an international climate treaty without China and other major emitting developing countries taking (binding) commitments to reduce their emissions. However, sectoral no-lose targets seem to be accepted by the US government to be a 'commitment of developing countries' being a precondition for the United States to join a post-2012 climate agreement (Point Carbon, 2008). On the other hand the no-lose regulation could comply with China not willing to accept binding caps, while intensity targets could ease the argument that a climate policy commitment must not negatively impact economic development.

5.2.1 The Nature of Intensity Targets

The following section discusses intensity targets in general. Economy-wide intensity targets have been frequently discussed in post-2012 discussions (e.g. Baumert et al., 1999, Ellerman and Wing, 2003, Fischer, 2003). In contrast to a fixed emission target as it is applied in the Kyoto Protocol, economy-wide intensity targets do not cap the overall emissions F, but the emission intensity γ, which can be described by the emissions divided by economic output. Therefore, the absolute emissions depend on the output Y. Ellerman and Wing (2003) show that if Y can be forecasted with certainty, an absolute cap and an intensity target have the same impact on absolute emissions. But, as in reality economic growth cannot be perfectly predicted over longer periods[46], absolute caps provide more certainty and environmental integrity in regard to absolute emissions, which could theoretically increase in case of an intensity target. Given the uncertainty of economic development, absolute caps however might lead to reduced economic output compared to a business as usual scenario in order to reach the cap. Intensity targets would on the other hand allow a nation to commit to limit (reduce) emission intensity, regardless of future development of GDP (Ellerman and Wing, 2003).

Figure 5-1 shows emission intensities for selected Annex I and non-Annex I countries[47]. In general, it can be claimed that economy-wide emission intensity tends to decrease with increasing wealth. But, it can also be found that some differences exist in-between non-Annex I countries. While India, China and South Africa have high emission intensities, they are much lower in Brazil, Mexico and South Korea. In regard to the electricity sector a similar picture can be drawn, with China, India and Mexico showing high intensities, while they are significantly lower in Brazil, South Africa and South Korea.

In regard to China, Figure 5-1 illustrates that emission intensities are significantly higher compared to developed nations. Therefore, a reasonable GHG emission reduction potential can be assumed when emission intensities will be reduced, economy-wide as well as in the electricity sector.

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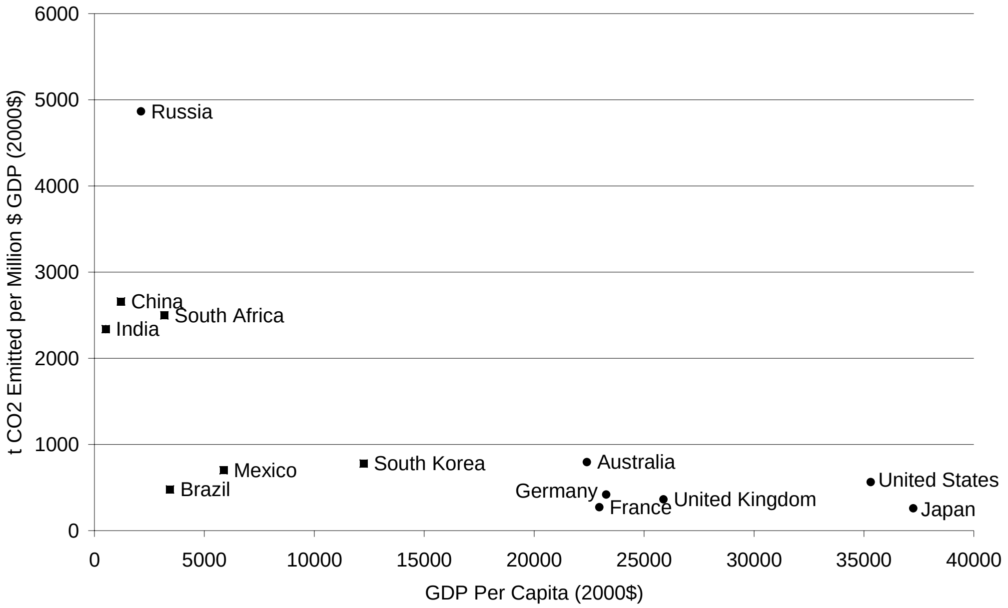
[46] Examples are the impacts of the new economy on economic growth in the US and worldwide (accelerated growth) or the disturbances on the world economy caused by the US hypothec crisis (decelerated growth).

[47] Developing countries are chosen with respect to how well they represent the countries that have been identified as the most important emitters in various sectors by Schmidt et al. (2006: p. 9). The outlined sectors are electricity, iron and steel, chemicals and petrochemicals, aluminum, cement and limestone, paper, pulp and printing. A more detailed outline can be found in Annex G.

a) Economy Wide Emission Intensities for Selected Countries



b) Sectoral Emission Intensities in the Electricity Sector for Selected Countries

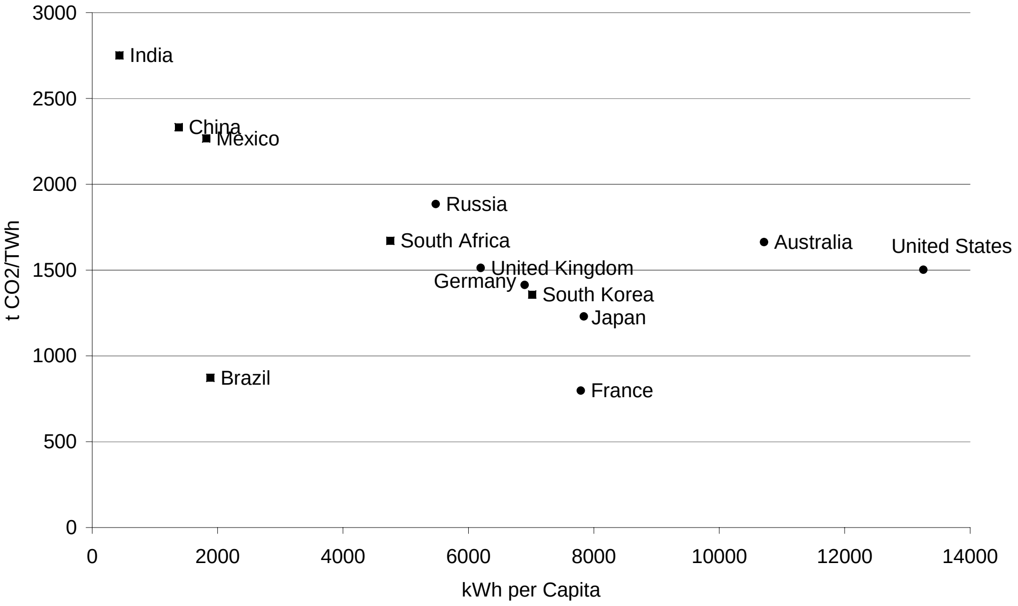


Figure 5-1: CO_2 Intensities (CO_2/GDP) relative to GDP per Capita (a) and CO_2 Intensities (CO_2/TWh) relative to kWh per Capita (b) for selected countries in 2003.
Annex I countries are marked by '●', non-Annex I countries by '■'.

Source: Own Illustration Based on World Bank Data (World Bank, 2007b)

5.2.2 Discussing Sectoral No-Lose Intensity Targets

In this section the general implications of a sectoral no-lose intensity target as proposed by Schmidt et al. (2006) are discussed (in the following also referred as CCAP proposal), at first comparing it to economy wide intensity targets[48].

Assuming that the emissions of an economy are F, they can generally be described as $F = Y \cdot \gamma$ with Y being the economic output and γ being the emission intensity $\gamma = \frac{F}{Y}$ for the entire economy. In case the emission intensity is applied for the whole economy, γ can also be expressed as the identity $\gamma = \frac{F}{E} \cdot \frac{E}{Y}$, with E being the primary energy input, including carbon intensity $c = \frac{F}{E}$ and energy intensity $e = \frac{E}{Y}$, which have been discussed in section 4.3. A change of either c or e has direct influence on the emission intensity γ, which can thus be described as $\gamma = c \cdot e$.

With respect to the CCAP proposal, it is pivotal to determine the consequences of linking intensity targets with absolute caps. Marschinski (2008) can show that emission trading between a country being subject to economy-wide intensity targets and a country with absolute targets would lead to decreasing global emissions with respect to the pre-trade state, if the country with intensity targets was a net seller[49]. This fact can be seen as a supportive argument for the implication of no-lose intensity targets for non-Annex I countries (or a group of them, e.g. NICs) as in the no-lose case, countries having applied an intensity target would always be the net seller of credits, as they are not obliged to buy credits in case they do not reach their target.

Having a look at the CCAP proposal of sectoral no-lose intensity targets, some general differences compared to economy-wide intensity targets can be found. Economy-wide emissions are no longer a function of the overall output Y and the

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[48] In general, Schmidt et al. (2006) suggest implementing no-lose intensity targets on selected energy intensive sectors in emerging economies. A detailed description of the proposal can also be found in section 3.2.3, pp. 39.

[49] Otherwise global emissions would rise. Marschinski (2008) assumes two countries that produce output by means of a concave production function with emissions as the sole input being subject of absolute or relative emission targets, respectively. It shall not be regarded at this point that trading between emission trading schemes with absolute and intensity targets always leads to a non-Pareto efficient equilibrium as the generated permits are not perfectly comparable (Marschinski, 2008).

emission intensity γ, but the sum of various sectoral outputs and their intensities, in addition to emissions from sectors not being covered by an intensity target. It is important to mention that only selected sectors shall be covered in the CCAP proposal, allowing in principle for regulative differences between sectors that can theoretically be substitutes for each other.

A difference between sectoral and economy-wide caps arises when regarding the generation of emission certificates. Assuming that the country which has applied economy-wide intensity targets is a net seller, the generation of tradable permits would be described by $\Pi = Y \cdot (\bar{\gamma} - \gamma)$ in case of economy wide emission intensities, with $\bar{\gamma}$ representing the targeted emission intensity and γ being the actual emission intensity. The CCAP proposal foresees sectoral output-based benchmarks for emission-intensive sectors, as for example cement, steel or electricity. Assuming that $\bar{\gamma}_i$ is the sectoral benchmark defined as $\bar{\gamma}_i = \frac{\overline{F}_i}{\overline{x}_i}$, thus the emissions per unit output, the generated tradable permits in the sector i are described by $\Pi_i = x_i \cdot (\bar{\gamma}_i - \gamma_i)$. The basic difference between economy-wide emission intensities and the CCAP proposal is that tradable permits in the CCAP proposal are solely output based on a sectoral level, not regarding other factors that influence the creation of value. Knowing how allowances are generally generated, the impacts on the profit can be determined. The sectoral profit Y_i can generally be described as $Y_i(x_i) = x_i \cdot p - C(x_i)$, with x being the output, p the price per unit output and C describes the costs of production. In case of carbon trading, which would generally be allowed in the CCAP proposal, the sellable permits lead to additional revenue in countries where a sectoral no-lose target is established, described by the index s. It can be described as $Y_{i,s}(x_{i,s}) = x_{i,s} \cdot p - C(x_{i,s}) + x_{i,s} \cdot (\bar{\gamma}_{i,s} - \gamma_{i,s}) \cdot p_c$, with p_c being the carbon price per allowance. In countries not having applied sectoral no-lose targets, the additional revenue cannot be gained. Given the (likely) scenario that Annex I countries (index b) have a fixed cap, additional costs have to be regarded, generated by the necessary efforts for emission certificates, that can be described as $Y_{i,b}(x_{i,b}) = x_{i,b} \cdot p - C(x_{i,b}) - x_{i,b} \cdot \gamma_{i,b} \cdot p_c$. In case $\bar{\gamma}_{i,s} > \gamma_{i,s}$, the profit is maximized in countries where sectoral no-lose intensity targets are applied. It can be stated that sectoral no-lose intensity targets will set an additional incentive for companies to outsource their emission-intensive production capacities away from Annex I countries. In regard to global emissions, this phenomenon could be seen as a leakage effect away from binding capped emission targets. Therefore the predictability of global emissions decreases.

In addition to that, one can argue that a sectoral no-lose target fixes the actual structure of the world economy, in favor for emerging economies with disadvantages for countries that have not established a heavy industry based economy yet. Sectoral no-lose intensity targets as foreseen by CCAP would not be established in least developed countries making it difficult for them to attract new investors under regular market conditions (meaning that no other incentives are given), as they cannot gain the additional revenue that is generated by the CCAP program. In other words, the marginal costs of production for energy intense goods are subsidized by the instrument and sanctioned in countries where absolute emissions are capped and where producers do not receive grandfathered emissions for free.

Furthermore, there are reasons to believe that a sectoral no-lose intensity target establishes perverse incentives in regard to climate protection. Decomposing γ_i in identities, as already done before for economy-wide emission intensities, it can be found that $\gamma_i = \frac{F_i}{E_i} \cdot \frac{E_i}{x_i}$, with E_i being the primary energy input. Therefore it can be stated that in the sectoral case, γ does not depend on carbon- and energy intensity as it is the case for economy wide intensities, but only singularly on (sectoral) carbon intensity and the energy input per unit output, which can be understood as conversion efficiency in the relevant sector. Therefore, the instrument sets a price signal singularly on the carbon intensity but not on energy intensity. For the sectoral no-lose intensity target there is therefore an incentive to use less emission intensive energy input, for example renewable energies in the electricity sector, but no incentive for using generally less energy intensive products in the economy, as for example reducing the electricity demand. Rather, it can be argued for the opposite: by introducing sectoral no-lose intensity targets an incentive for increasing production in the covered sectors is given as long as the sectoral intensity γ_i is lower than the sectoral intensity target $\bar{\gamma}_i$ because revenues are increased. This fact can also be illustrated when looking at Figure 5-1b: A sectoral no-lose target might lead to a shift along the vertical axis, but there is no incentive for reductions along the horizontal axis.

One could argue, that a 'perverse incentive' as described above is only given, when the no-lose target is not very ambitious and easy to reach. However, it is likely that the sectoral intensity target is set comparably low, as the participation of non-Annex I countries in the global carbon market is one major motivation to introduce intensity targets. In case no tradable permits are generated in non-Annex I countries, it will be difficult for Annex I countries to reach their ambitious mitigation targets. Therefore, an intensity target that is difficult to reach for non-Annex I countries is in nobody's interest. Thus, it will be likely that in reality the sectoral intensity γ_i will quickly be lower than the sectoral intensity target $\bar{\gamma}_i$.

Regarding Figure 5-1, a general difficulty in defining emission targets for different countries becomes obvious. Due to different structures of the economy, emission intensities demand different efforts in various countries. In negotiating intensity targets with different countries, as proposed by Schmidt et al. (2006), the environmental effectiveness of the target for the particular economy cannot be prognosticated with certainty. Therefore, some countries might cope better with the intensity targets than others, leading to relatively more credits, which might lead to competitive (dis)advantes for some countries. However, a country agreeing to an ambitious target could also be interpreted as the country taking more responsibility in regard to climate change, analogously to absolute caps in the Kyoto Protocol (Stern, 2006: p. 471).

In addition to that, other aspects can be found that might raise some difficulties when implementing sectoral no-lose targets. As some sectors are highly competitive, some industries might argue that publishing emission data has negative consequences as competitors might infer to secret product compositions when knowing the emission intensity or the total emissions, respectively. Also, the exact data surveillance might be problematic, especially in developing countries where state institutions are generally weaker than in developed countries. For the efficiency of the international regime it would be crucial that monitoring, registries and verification of emissions are reliable. Developing countries might be faced with additional difficulties when not having the personnel capacities and political power to enforce the scheme. Another aspect that needs to be discussed when considering sectoral no-lose targets is that the amount of credits generated under the scheme is hard to predict. Therefore, the price of credits is likely to be volatile, which would have negative impacts on the long term planning of companies. Moreover, the market could become highly speculative[50]. If many countries reached their no-lose target, a 'flooding of credits' could inflate the market price. Due to such uncertainty there would be insufficient incentive for investment in abatement, which in turn would have a negative influence on GHG mitigation in general, especially if the generation of credits under the scheme does not correspond to absolute reductions, as described above. The effect might be eased in introducing a fixed amount of credits that is allowed for sale in a selected trading period. Alternatively, a threshold could be considered, which would be triggered once a certain amount of credits is generated or the price for carbon drops below a baseline price, then leading to a decreasing intensity target. However, unwanted incentives could be set by implementing such a threshold that shall not be further discussed for this thesis. Given the uncertainties for sectoral no-lose intensity targets, one could also think of implementing no-lose intensity targets for the whole economy, which would also ease many of the discussed shortcomings.

In this context, it needs to be clarified that an intensity target is discussed having the political constraints against absolute targets in regard to economic development in mind. These concerns are frequently brought up by developing countries with regard to equity issues. However, it needs to be kept in mind that reacting to political constraints also limits the economic efficiency as well as the environmental effectiveness of an approach. When discussing intensity targets, the political component that is linked to the approach needs to be kept in mind.

Discussing sectoral no-lose targets, one might get the impression that the uncertainties and risks are outstanding compared to the opportunities. However, the CCAP proposal must be seen in the context of other proposals. In case of implementing binding caps with very high baselines as an alternative, also trying to refer to developing countries' constraints in regard to economic development, the implication of binding, but not very ambitious caps could have negative impacts as

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[50] It is assumed that a price that can only be foreseen imperfectly causes a high attraction for trade in derivates.

well, especially in regard to ‘hot air’[51]. Additionally, it needs to be discussed for which timeframe sectoral no-lose targets shall be applied. In case they are introduced as an intermediate step towards the implication of economy-wide binding caps many effects described above such as emission leakage will probably not occur in the real world to a relevant extent, as investment decisions take time to be realized.

In regard to a post-2012 CDM, sectoral no-lose targets might also have positive implications. Having a look at the current CDM and various post-2012 proposals, i.e. programmatic CDM, sectoral CDM and policy CDM, it can be found that the additionality issue remains unsolved for all of them. In regard to no-lose intensity targets, it is however not a crucial issue as credits are automatically issued once the sectoral intensity is lower than the sectoral baseline, being negotiated in advance. How to set the baseline is probably a highly difficult process, as business as usual projections are not satisfyingly available.

However, as being implemented on the sectoral level, credits would be issued to the government and not – as it is the case in the current CDM – to the project developer. This fact raises difficulties how and if the incentives to lower the GHG emissions are passed on to the private sector. It is in the host country’s national authority to implement a relevant policy, including all conceivable market instruments, also allowing in principle for a domestic cap and trade scheme. In general, it can be claimed that sectoral no-lose targets would require higher government capacity compared to the CDM and other post-2012 CDM proposals.

5.2.3 Possible Implications for the Chinese Electricity Sector

The general conclusion presented in the previous section can be exemplified by considering the electricity sector. As mainly constraints in regard to the economic efficiency are brought up, the section will first focus on the economic considerations. Furthermore, it is a crucial question how many credits would be generated by a sectoral no-lose intensity target, which will be faced in the second subsection of this section.

Economic Considerations

As found in section 5.2.2, sectoral no-lose intensity targets put a price signal on

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[51] See also chapter 3

carbon intensity and conversion efficiency within a sector, but not on the energy intensity of the economy, that is on the demand side. In order to comment on the real-world implications that are caused by this effect, it is important to understand the importance of conversion efficiency and energy intensity on the emission growth. Therefore, the Kaya identity, as described in section 4.3.1 can be extended and applied to the electricity sector. The emissions in the electricity sector F_e can thus be described as

$$\begin{aligned} F_e &= POP \cdot \frac{GDP}{POP} \cdot \frac{SO_e}{GDP} \cdot \frac{PE_e}{SO_e} \cdot \frac{CO_{2e}}{PE_e} \\ &= P \cdot A \cdot e_s \cdot \frac{1}{\eta} \cdot c \end{aligned}$$

Equation 12: Extension of the Kaya Identity by Conversion Efficiency

In Equation 12, e_s is the ‘commodity intensity’, defined as the sectoral output (SO, i.e. electricity) divided by GDP; in regard to the electricity sector it can be named electricity intensity. The conversion intensity $\frac{1}{\eta}$ is defined as sectoral primary energy use (PE) divided by sectoral output while c is the sectoral carbon intensity[52]. As the effects on the electricity sector are regarded, the sectoral primary energy as well as the sectoral emissions are taken into consideration for the analysis at this point.

Figure 5-2 shows the importance of electricity intensity, conversion intensity and carbon intensity in the electricity sector. In the past, conversion intensity as well as electricity intensity have contributed to increasing or decreasing CO_2 emissions in the electricity sector. An efficient policy instrument should therefore address both, electricity intensity as well as conversion intensity. In the past, neither carbon intensity, nor electricity intensity, nor conversion intensity could contribute significantly to emission reductions in the electricity sector, opposing the effects that could be observed for the whole economy, where energy intensity as well as carbon intensity both could contribute to decreasing carbon emissions. It also gets obvious that an instrument leaving out one important part of the determining factors necessarily raises inefficiency constraints. The result– thus an incentive to increase

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[52] Changes in emissions are calculated by summing the single effects P_{eff}, A_{eff}, e_{eff}, $1/\eta_{eff}$ and c_{eff} in analogy to the Kaya identity as described in section 4.3.1, pp. 66. The exact calculation of residual terms is shown in Annex E.

the production of the covered commodity in this case – would need to be faced by additional instruments having negative implications on the transaction costs as well as the general clarity of the instrument.

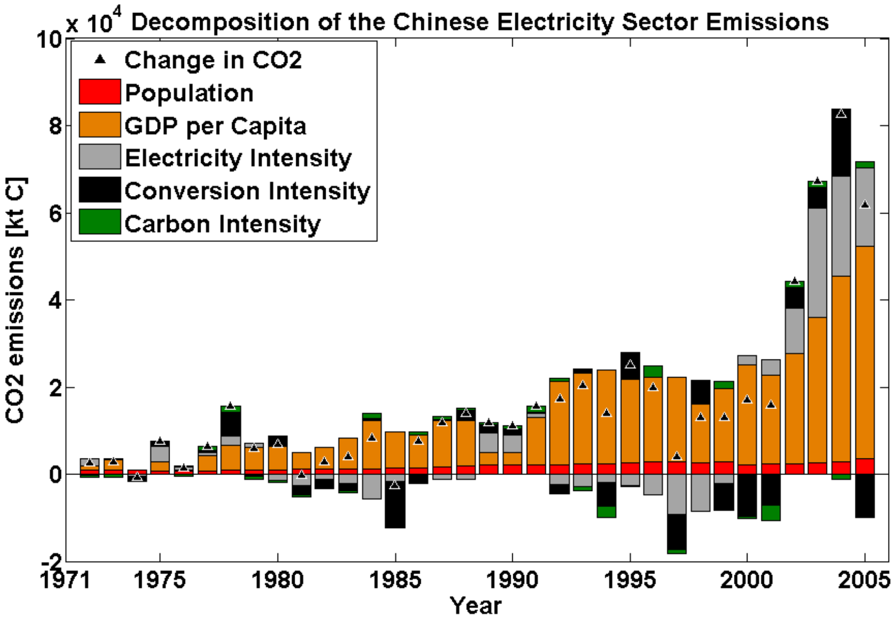


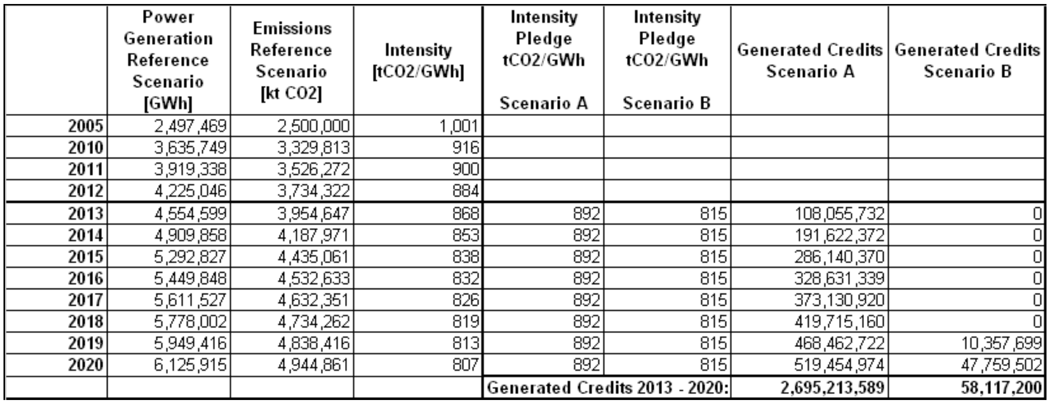
Figure 5-2: Decomposition of CO_2 Emissions in the Chinese Electricity Sector.

Source: Own Illustration Based on IEA (2007a) Data.

Quantitative Considerations

Another important aspect that needs to be discussed is the potential amount of credits that would be generated by sectoral no-lose intensity targets. In order to be able to make a statement on that, a baseline scenario needs to be set for being able to calculate emissions and output in the electricity sector. Knowing these two input factors, the annual emission intensity can be calculated. For this thesis, IEA world energy outlook projections are taken as a base (IEA, 2007b). Annual power generation and emissions are calculated based on the annual growth rate assumed by the IEA (2007b), being 7.8% in the period from 2005 to 2015 and 3.0% in the period from 2015-2020 for power generation and 5.9% (2005 – 2015) and 2.2% (2015 – 2020) for the emission growth. The detailed assumptions of the IEA reference scenario are also outlined in Annex F.

Moreover, a realistic intensity target as foreseen in the CCAP approach needs to be assumed. In the following, two scenarios are imagined. Scenario A builds on the fact that China has committed to reduce the emission intensity for coal based electricity generation by approximately 1% per annum (cp. IEA, 2007b: p. 276) in the period from 2000 to 2010. This rate of reduction is extrapolated until 2020. Given a current emission intensity of 1,001 t CO_2/GWh in the electricity sector, an annual reduction of 1% is taken into account in order to calculate the generated credits. Scenario B assumes an annual reduction of 2% per annum beginning in 2013, following an annual reduction of 1% from 2005 to 2012. The year of 2013 is chosen as it would be the starting point of any post-2012 climate regime. The pre-2012 reduction can be justified by the current Chinese five year plan aiming for a one percent annual reduction of coal fired intensity. The assumed annual reduction rates are transformed into intensity pledges in calculating the average intensity from 2013 to 2020. This methodology leads to intensity pledges of 892 t CO_2/GWh for an average annual reduction of 1% and 815 t CO_2/GWh in case the intensity is reduced by 2% per annum from 2013. Calculating these pledges against the IEA BAU projections for intensities and production levels then yields the amount of generated credits for each scenario.



	Power Generation Reference Scenario [GWh]	Emissions Reference Scenario [kt CO2]	Intensity [tCO2/GWh]	Intensity Pledge tCO2/GWh Scenario A	Intensity Pledge tCO2/GWh Scenario B	Generated Credits Scenario A	Generated Credits Scenario B
2005	2,497,469	2,500,000	1,001				
2010	3,635,749	3,329,813	916				
2011	3,919,338	3,526,272	900				
2012	4,225,046	3,734,322	884				
2013	4,554,599	3,954,647	868	892	815	108,055,732	0
2014	4,909,858	4,187,971	853	892	815	191,622,372	0
2015	5,292,827	4,435,061	838	892	815	286,140,370	0
2016	5,449,848	4,532,633	832	892	815	328,631,339	0
2017	5,611,527	4,632,351	826	892	815	373,130,920	0
2018	5,778,002	4,734,262	819	892	815	419,715,160	0
2019	5,949,416	4,838,416	813	892	815	468,462,722	10,357,699
2020	6,125,915	4,944,861	807	892	815	519,454,974	47,759,502
				Generated Credits 2013 - 2020:		**2,695,213,589**	**58,117,200**

Table 5-1: Calculating the Possible Amount of Credits under a Sectoral No-Lose Intensity Target for the Chinese Electricity Sector until the Year 2020 using IEA World Energy Outlook 2007 Reference Scenario Assumptions.

Regarding Table 5-1 it gets obvious that any calculation of the actual amount of credits can only be a rough estimate, as the development of power generation and the sectoral emissions can only be imperfectly foreseen. Moreover, as setting the intensity baseline would be matter of international negotiations, it is highly arbitrary to assume exact baselines for the calculation of credits. In addition to that, possible incentives to reduce the given emission path are not regarded with the methodology outlined above as a fixed development of emissions and power generation is assumed exogenously.

With regard to the idea of scaling up the CDM, it is necessary to compare the calculated scenarios for a sectoral no-lose target to the CDM. Currently, approximately 225 Mt CO_{2eq} are abated in average by the CDM per year as of May 11th 2008, including credits from projects in the project pipeline (UNFCCC, 2008). Therefore, it can be claimed that scenario B generates a lower amount of credits than the current CDM, while scenario A would lead to a significant increase of credits compared to today's volume. It has to be kept in mind that the calculations outlined above only consider the Chinese electricity sector; in the real world, the instrument would be applied to more countries and additional sectors, leading to additional credits.

Concluding Remarks

It can be found that sectoral no-lose intensity targets are problematic in two respects: Its sectoral character might raise difficulties as well as the fact that intensity targets are chosen, instead of absolute and binding reduction goals. In regard to the sectoral character it can be stated that three factors need to be considered in regard to emission reductions: the conversion intensity, the sectoral commodity intensity and the carbon intensity. A sectoral no-lose target would not set a price signal on the sectoral commodity intensity, therefore giving an incentive to increase the commodity's production. Other policy instruments would be needed to curb demand[53]. With respect to intensity targets in general, the predictability of real measurable carbon emissions is diminished compared to absolute targets. In regard to the sectoral character of the approach, it might be useful to think of no-lose intensity target for the whole economy, as major constraints could be addressed.

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[53] Other instruments could include measures on the demand side as for example pledges to reduce electricity generation. In regard to the electricity sector, a good example could be the Chinese program to increase the share of solar thermal water heating as no electricity would be needed for water heating. Moreover, demand side management might be a feasible solution.

6 Conclusion and Future Research

Regarding the global carbon market today, the CDM is by far the most important international instrument. Furthermore, it is the only instrument that includes developing countries into a global carbon market. However, it also faces serious shortcomings:

- Its project-by-project identity leads to high transaction costs.
- The environmental integrity is difficult to guarantee by the current instrument.
- The instrument does not provide for incentives to change the structure of an economy towards lower GHG emissions.
- While it has helped to establish a global carbon market, it failed to contribute to increasing sustainability in its host countries.

Many proposals have been made to reform the current CDM: to include additional aspects in the current structure (programmatic, policy CDM), to include entire sectors into the CDM (sectoral CDM), to mainstream climate relevant policies in developing policy (SD-PAMs) and to introduce sectoral no-lose intensity targets. Compared to other proposals, sectoral no-lose intensity targets are considered to overcome shortcomings of the current instrument best. At the same time they can set an incentive towards the establishment of a global carbon market. However, the exact impacts of sectoral no-lose intensity targets are not sufficiently understood so far. Summing up the concerns that could be identified in this thesis, the environmental effectiveness of the instrument cannot be guaranteed. Rather, some constraints in regard to perverse incentives occur, even though it is not possible to quantify their impacts at the current state of the discussion. However, when applying sectoral no-lose intensity targets, policies and measures need to be implemented that counteract the incentive to increase the production of a commodity once a sectoral no lose intensity target is met. Quantitative modeling is necessary in the future, focusing on the interactions between the implication of sectoral no-lose targets, baseline setting and intensity development.

As sectoral no-lose intensity targets do not apply for the whole economy, but only for selected, mostly heavy industry related sectors, it is likely that in other parts of the economy, as for example households, other climate policy instruments need to be implemented, for example the (up-scaled) CDM. Therefore, it is conceivable that many of the discussed post-2012 approaches will play a role at different levels.

In regard to the overall goal of the thesis it can be concluded that the question how to include developing countries into a post-2012 climate regime is still highly controversial and far from being answered satisfyingly. One main dilemma could be identified: On the one hand urgent global action is needed to reduce global GHG emissions significantly; on the other hand global emissions rise, driven by the economic development of some developing countries, with China being the most important player. With regard to poverty concerns these countries are not willing to accept emission reductions as they could harm their economic development. At the same time they stress the historical responsibility of developed countries for global climate change. But, developed countries will not be capable to face the challenges of international climate change without the participation of developing countries. The equity issue is therefore tremendously important and needs to be addressed in any post-2012 climate regime. Discussing the CDM and post-2012 CDM options needs to be seen in this context.

It seems to be reasonable to assume that the existing group of non-Annex I countries today will be further specified in a post-2012 regime (Ott et al., 2008). In regard to climate policy, a specification could make it possible to find interim solutions for high emitting newly industrialized countries, e.g. China, without harming the development needs of developing countries, as for example countries in Sub-Saharan Africa, thus addressing equity issues.

One possibility how to integrate various trading approaches is the multi-stage approach. The basic idea of the approach is to

> *"divide countries into groups with different levels of effort and types of commitments (stages)"* (Den Elzen et al., 2006: p.2).

Different stringencies of emissions targets would occur in different country groups. Therefore pre-defined thresholds characterize the country groups, e.g. in form of emissions per capita (Höhne, 2005: p. 198). Thus, the multi-stage approach results in an incremental evolution of the climate change regime, namely the steady growth of the group of countries adopting binding emission targets, i.e. Annex I countries (Den Elzen et al., 2006). The multi-stage approach allows including rather "soft" commitments at a certain level of development, turning into binding commitments at another stage. Höhne (2005: pp. 197) describes four stages of commitments: no commitments, sustainable development pledges, moderate absolute targets and ambitious absolute reductions. These stages could e.g. be applied to the current CDM structure and introduced post-Kyoto CDM proposals. Thus, ‘no commitments’ would qualify for the current CDM only, while SD PAMs would be applied in step two (sustainable development pledges). ‘Moderate absolute targets’ could be reached on the sectoral level, in the form that absolute targets would not be applied to the whole economy. No-lose intensity targets could also be introduced in this step or alternatively could be handled in a fifth step. Finally countries would have to take binding emission reduction targets as currently done by Annex I countries.

As a post-Kyoto agreement and thus any post-2012 CDM agreement targets an international environmental problem, participation and compliance are important subjects to consider. Free-rider and leakage problems could otherwise undermine the environmental integrity of the agreement. Thus, the efficiency would be negatively affected. Ideally, a post-Kyoto commitment secures the participation of all countries, even though full participation is not a sufficient condition. This thesis could show, that solutions can be considered, that focus on some major emitting sectors instead of every sector in every economy. Aldy et al. (2003: p.378) differ two options for an international agreement: a ‘narrow-but-deep’ agreement, which would achieve a substantial per-party mitigation versus a ‘broad-but-shallow’ agreement achieving only little overall reduction but attracting nearly full participation of nations. In regard to the outlined scenario of a multi-stage agreement, sectoral no-lose intensity targets can play a role to shift the international community to towards a ‘broad-and-deep’ scenario that would be necessary to address challenges of international climate change.

In addition to the theoretical framework, the thesis also aimed to understand the outstanding role of China. It can be found that political goals and economic realities differ significantly, especially when it comes to GHG related policies. While Chinese officials stress their internal goal to lower emission intensity significantly, it has risen in recent years, basically driven by structural changes of the economy towards more emission intensive industries. It can however be concluded that China has realized the challenges that come with international climate change and tries to reflect this fact in its domestic policies and measures. In order to make better statements regarding the impacts of various policy instruments in the future, more sectors and more countries need to be determined and – as already mentioned above – included in quantitative models.

With respect to future research, it needs to be seen that this thesis focuses on newly industrialized countries. Even though this can be justified by significant emission- and economic growth in the last decades, the role of least developed countries is not regarded in detail. However, in regard to an international climate agreement in the future and to reduce emissions in the necessary order of magnitude, solutions need to be found how least developed countries can develop without locking into a carbon-intensive economy. The world’s climate cannot afford a second China.

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8 Appendix

A. Kyoto Commitments of Annex I Countries

Country	Commitment (% from base year*)	2004 emissions (% from base year)	Non CO_2 GHGs (% GWP in base year)
OECD			
Australia	+ 8	+ 25.1	33.8
Canada	- 6	+ 26.6	22.9
European Union 15	- 8	- 0.6	21.6
Austria***	- 13	+ 15.7	
Belgium***	- 7.5	+ 1.4	
Denmark***	- 21	- 1.1	
Finland***	0	+ 14.5	
France***	0	- 0.8	
Germany***	- 21	- 17.2	
Greece***	+ 25	+ 26.6	
Ireland***	+ 13	+ 23.3	
Italy***	- 6.5	+ 12.1	
Luxembourg***	- 28	+ 0.3	
Netherlands***	- 6	+ 2.4	
Portugal***	+ 27	+ 41	
Spain***	+ 15	+ 49	
Sweden***	+ 4	- 3.5	
United Kingdom***	- 12.5	- 14.3	
Iceland	+ 10	- 5	25.7
Japan	- 6	+ 5.5	8.0
Liechtenstein	- 8	+ 18.5	N/A
Monaco	- 8	- 3.1	2.7
New Zealand	+ 1	+ 21.3	65.1
Norway	0	+10.3	35.6
Switzerland	- 8	+ 0.4	16.1
United States**	- 7	+ 15.8	17.6
EIT			
Bulgaria (1988)	- 8	- 49	28.8
Croatia	- 5	- 5.4	N/A
Czech Republic	- 8	- 25	13.9
Estonia	- 8	- 51	7.2
Hungary (1985 - 1987)	- 6	- 31.8	17.7
Latvia	- 8	- 58.5	30.6
Lithuania	- 8	- 60.4	23.3
Poland (1988)	- 6	- 31.2	15.5
Romania (1989)	- 8	- 41	28.8
Russian Federation	0	- 32	22.0
Slovakia	- 8	- 30.4	17.2
Slovenia (1986)	-8	- 0.8	27.5
Ukraine	0	- 55.3	22.7
* Base Year refers to 1990, discrepancies are outlined in brackets			
** Countries have not ratified the Kyoto protocol			
*** Countries are part of the EU bubble			

Table 8-1: Kyoto Commitments by Annex B Countries

Source: Grubb et al. (1999), UNFCCC (2007c), EEA (2006)

B. List of DOEs and Sectoral Scopes

Designated Operational Entity Name	Sectoral Scopes for Validation	Sectoral Scopes for Verification and Certification
Japan Quality Assurance Organization	1,2,3,4,5,6,7,10,11,12,13	
JACO CDM.,LTD	1,2,3	1,2,3
Det Norske Veritas Certification AS	1,2,3,4,5,6,7,8,9,10,11,12,13,15	1,2,3,4,5,6,7,8,9,10,11,12,13,15
TÜV SÜD Industrie Service GmbH	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,15
Tohmatsu Evaluation and Certification Organization Co., Ltd.	1,2,3	
Japan Consulting Institute	1,2,13	
Bureau Veritas Certification Holding S.A.	1,2,3	1,2,3
SGS United Kingdom Ltd.	1,2,3,4,5,6,7,10,11,12,13,15	1,2,3,4,5,6,7,10,11,12,13,15
The Korea Energy Management Corporation	1	
TÜV Rheinland Japan Ltd.	1,2,3,13	
KPMG Sustainability B.V.	1,2,3,13	
British Standards Institution	1,2,3	
Spanish Association for Standardisation and Certification	1,2,3	1,2,3
TÜV NORD CERT GmbH	1,2,3,4,5,6,7,10,11,12,13	1,2,3
Lloyd’s Register Quality Assurance Ltd	4,5,6,7,10,11,12,13	
Korean Foundation for Quality	1,2,3	
PricewaterhouseCoopers - South Africa	1,2,3	

Table 8-2: List of DOEs and Sectoral Scopes[54]

Source: UNFCCC (2007d)

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[54] 1. Energy industries (renewable- /non renewable sources), 2. Energy Distribution, 3. Energy Demand, 4. Manufacturing industries, 5. Chemical industry, 6. Construction, 7. Transport, 8. Mining/Mineral Production, 9. Metal Production, 10. Fugitive emissions from fuels (solid, oil and gas), 11. Fugitive emissions from production and consumption of halocarbons and sulphur hexafluoride, 12. Sovents use, 13. Waste handling and disposal, 14. Afforestation and reforestation, 15. Agriculture

C. Tool for the Demonstration and assessment of Additionality

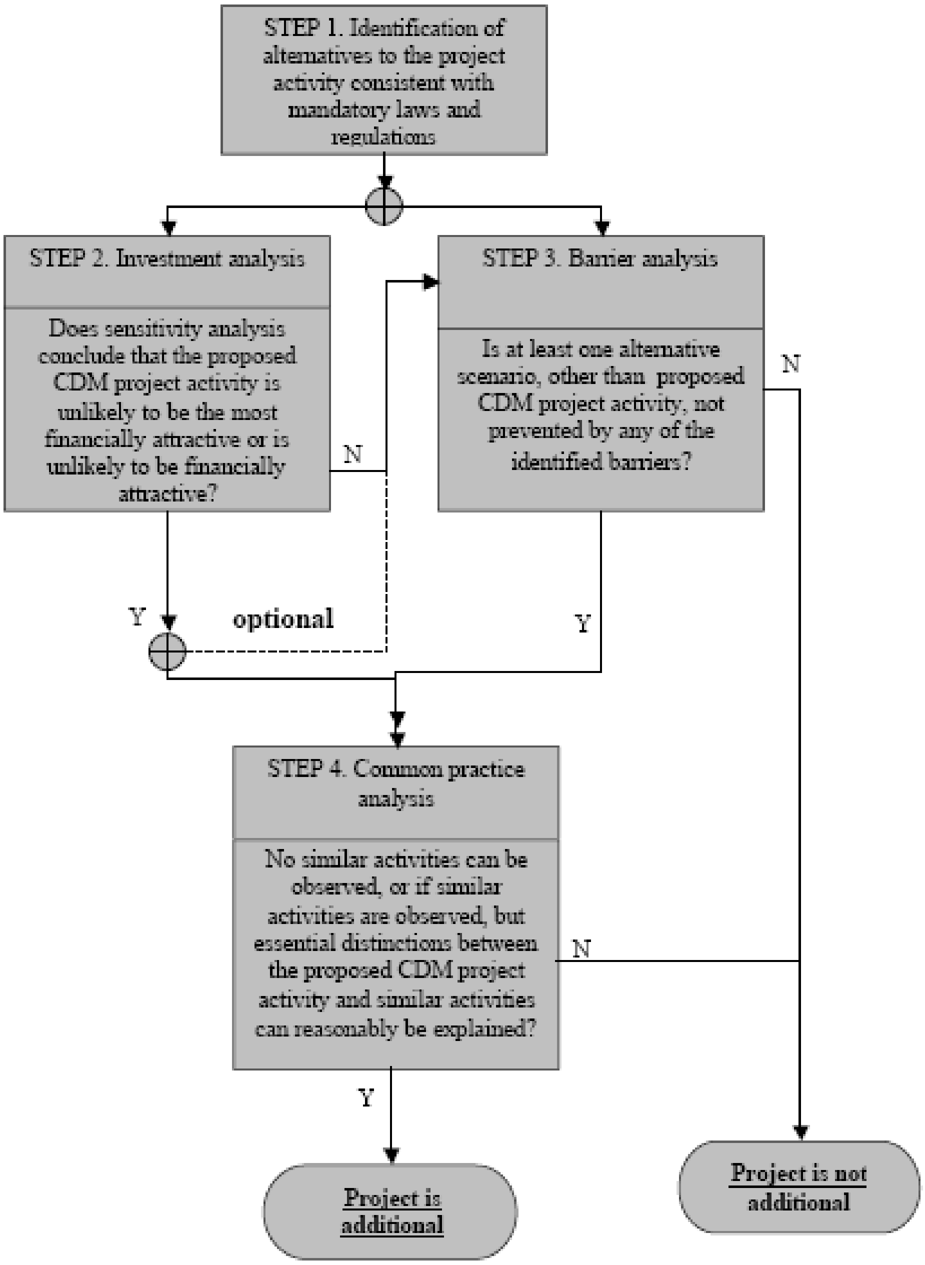


Figure 8-1: Tool for the demonstration and assessment of additionality

Source: UNFCCC (2007e: p.2)

D. Energy Policy Making and Administration in China

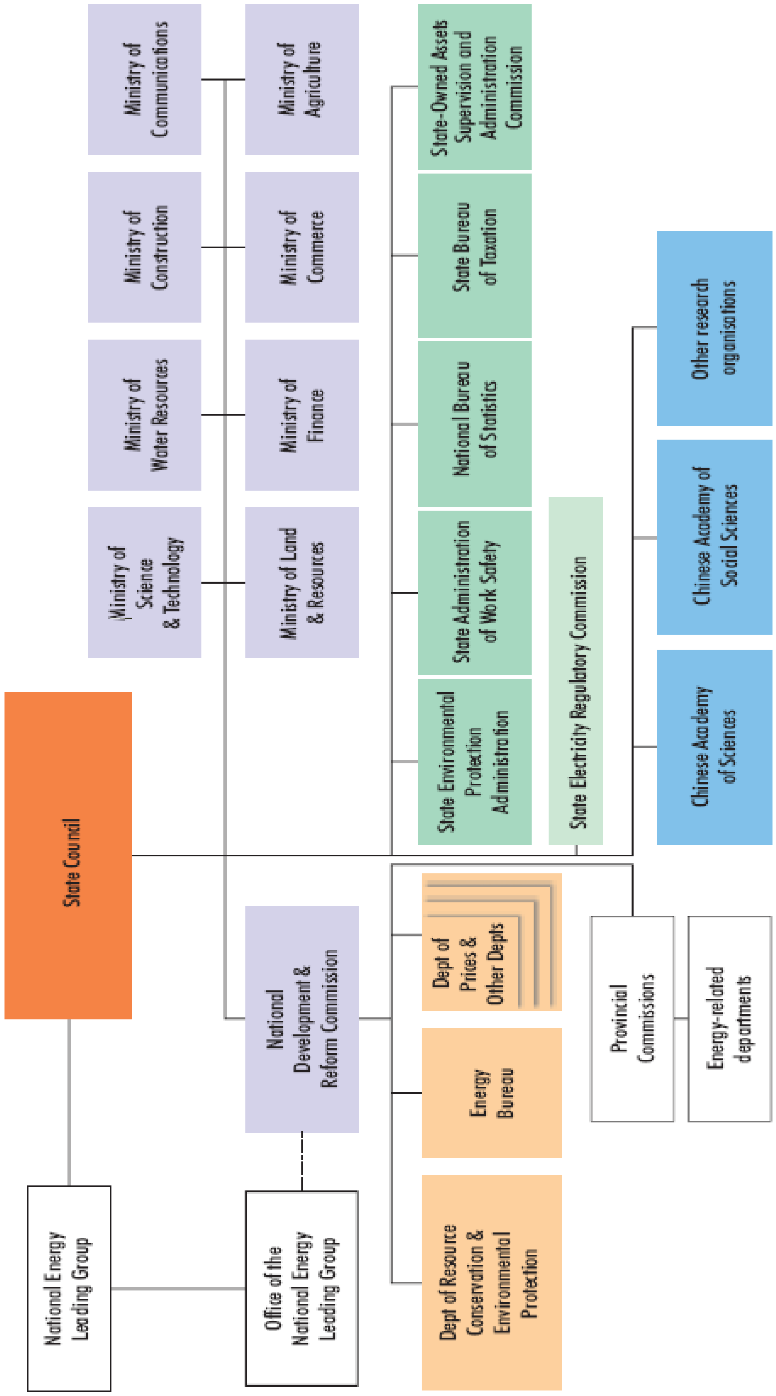


Figure 8-2: Energy Policy Making and Administration in China

Source: IEA, 2007b: p. 269

E. Decomposition

i. Mathematical Proof of Equation 4

To show: $C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0} = \Delta C \cdot B_{t_0} + C_{t_0} \cdot \Delta B + \Delta C \cdot \Delta B$

Prove:

$$\begin{aligned}
&\Delta A = A_{t_1} - A_{t_0} = C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0} \\
&= C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0} + \left(C_{t_1} \cdot B_{t_0} - C_{t_1} \cdot B_{t_0}\right) + \left(C_{t_0} \cdot B_{t_0} - C_{t_0} \cdot B_{t_0}\right) + \left(C_{t_0} \cdot B_{t_1} - C_{t_0} \cdot B_{t_1}\right) \\
&= C_{t_1} \cdot B_{t_0} - C_{t_0} \cdot B_{t_0} + C_{t_0} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0} + C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_1} - C_{t_1} \cdot B_{t_0} + C_{t_0} \cdot B_{t_0} \\
&= \left(C_{t_1} \cdot B_{t_0} - C_{t_0} \cdot B_{t_0}\right) + \left(C_{t_0} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0}\right) + \left(C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_1} - C_{t_1} \cdot B_{t_0} + C_{t_0} \cdot B_{t_0}\right) \\
&= \left[\left(C_{t_1} - C_{t_0}\right) \cdot B_{t_0}\right] + \left[C_{t_0} \cdot \left(B_{t_1} - B_{t_0}\right)\right] + \left[\left(C_{t_1} - C_{t_0}\right) \cdot B_{t_1} - \left(C_{t_1} + C_{t_0}\right) \cdot B_{t_0}\right] \\
&= \left[\left(C_{t_1} - C_{t_0}\right) \cdot B_{t_0}\right] + \left[C_{t_0} \cdot \left(B_{t_1} - B_{t_0}\right)\right] + \left[\left(C_{t_1} - C_{t_0}\right) \cdot \left(B_{t_1} - B_{t_0}\right)\right] \\
&= \Delta C \cdot B_{t_0} + C_{t_0} \cdot \Delta B + \Delta C \cdot \Delta B \\
&\overline{q.e.d.}
\end{aligned}$$

For the decomposition analysis in this thesis, the Laspeyres Index method has been used, as the literature identifies it as most resilient in comparison to other possibilites. Therefore, the term $C_{t_1} \cdot B_{t_1} - C_{t_0} \cdot B_{t_0}$ has been expanded, in order to have a reference to the basis period t_0 in the end. Mathematically, one could also expand the mathematical equation differently, e.g. in a way that would put ΔC and ΔB relative to t_1, which would then be referred to the ideas of the Paasche Index method.

ii. Mathematical Proof of Equation 11

To show: :

$$\sum_i (c_i - \bar{c}) \cdot \Delta q_i = \sum_i c_i \cdot \Delta q_i$$

This can also be written as:

$$\sum_i \left(\frac{CO_{2i,t}}{PE_{i,t}} - \frac{CO_{2t}}{PE_t} \right) \cdot \left(\frac{PE_{i,t}}{PE_t} - \frac{PE_{i,t_0}}{PE_{t_0}} \right) = \sum_i \left(\left(\frac{CO_{2i,t}}{PE_{i,t}} \right) \cdot \left(\frac{PE_{i,t}}{PE_t} - \frac{PE_{i,t0}}{PE_{t0}} \right) \right)$$

Proof:

$$\sum_i \left(\frac{CO_{2i,t}}{PE_{i,t}} - \frac{CO_{2t}}{PE_t}\right)\cdot\left(\frac{PE_{i,t}}{PE_t} - \frac{PE_{i,t_0}}{PE_{t_0}}\right)$$

$$= \sum_i \left(\left(\frac{CO_{2i,t}}{PE_{i,t}}\right)\cdot\left(\frac{PE_{i,t}}{PE_t} - \frac{PE_{i,t0}}{PE_{t0}}\right)\right) - \frac{CO_{2t}}{PE_t}\cdot\sum_i\left(\underbrace{\frac{PE_{i,t}}{PE_t}}_{1} - \underbrace{\frac{PE_{i,t_0}}{PE_{t_0}}}_{1}\right)$$

$$= \sum_i \left(\left(\frac{CO_{2i,t}}{PE_{i,t}}\right)\cdot\left(\frac{PE_{i,t}}{PE_t} - \frac{PE_{i,t0}}{PE_{t0}}\right)\right)$$

$$\overline{q.e.d.}$$

iii. Including Conversion Intensity into the Kaya Identity

In analogy to the calculation of effects in the Kaya identity, effects need to be calculated when including the conversion intensity into the equation. However, in extending the formula, the mathematical effort increases. The effects can be calculated as illustrated below. In Equation 13, the effect for the population component is illustrated; all other effects can be calculated analogously.

$$\begin{aligned}
Peff &= \Delta P\cdot A_{t_0}\cdot e_{t_0}\cdot c_{t_0}\cdot s_{t_0}\\
&+\frac{1}{2}\cdot(\Delta P)\cdot\left[(\Delta A)\cdot e_{t_0}\cdot c_{t_0}\cdot s_{t_0} + A_{t_0}\cdot(\Delta e)\cdot c_{t_0} + A_{t_0}\cdot e_{t_0}\cdot(\Delta c)\cdot s_{t_0} + A_{t_0}\cdot e_{t_0}\cdot c_{t_0}\cdot(\Delta s)\right]\\
&+\frac{1}{3}\cdot(\Delta P)\cdot\left[\begin{array}{l}(\Delta A)\cdot(\Delta e)\cdot c_{t_0}\cdot s_{t_0} + (\Delta A)\cdot e_{t_0}\cdot(\Delta c)\cdot s_{t_0} + (\Delta A)\cdot e_{t_0}\cdot c_{t_0}\cdot(\Delta s) + A_{t_0}\cdot(\Delta e)\cdot(\Delta c)\cdot s_{t_0}\\ + A_{t_0}\cdot e_{t_0}\cdot(\Delta c)\cdot(\Delta s) + A_{t_0}\cdot(\Delta e)\cdot c_{t_0}\cdot(\Delta s)\end{array}\right]\\
&+\frac{1}{4}\cdot(\Delta P)\cdot\left[(\Delta A)\cdot(\Delta e)\cdot(\Delta c)\cdot s_{t_0} + (\Delta A)\cdot(\Delta e)\cdot c_{t_0}\cdot(\Delta s) + (\Delta A)\cdot e_{t_0}\cdot(\Delta c)\cdot(\Delta s) + A_{t_0}\cdot(\Delta e)\cdot(\Delta c)\cdot(\Delta s)\right]\\
&+\frac{1}{5}\cdot(\Delta P)\cdot(\Delta A)\cdot(\Delta e)\cdot(\Delta c)\cdot(\Delta s)
\end{aligned}$$

Equation 13: Calculating the Effects when Including Conversion Intensity into the Kaya Identity

iv. ‘Matlab’ Calculation Scripts

a) Chinese Energy System

```
22.05.08 19:15  H:\Decomposition\Matlab\Effektgleichungen_73.m            1 of 10

%Data
%GDP [constant US $, source: World Bank]
%Population (p) [mio, source: World Bank]
%Primary Energy (PE and PEX) [kt OE, source: IEA]
%CO2 Emissions [kt C, source: own calculations based on IPCC (1996) conversion
%factors

GDP=[1.32898E+11    1.39808E+11 1.52226E+11 1.55659E+11 1.66464E+11 1.70025E+11 1.84658↙
E+11 2.04988E+11 2.22561E+11 2.4128E+11  2.56257E+11 2.75466E+11 3.02489E+11 3.44698↙
E+11 3.81058E+11 4.16346E+11 4.65795E+11 5.15228E+11 5.34755E+11 5.53023E+11 5.99998↙
E+11 6.76496E+11 7.61807E+11 8.51744E+11 9.35003E+11 1.0204E+12  1.10906E+12 1.17562↙
E+12 1.25874E+12 1.36723E+12 1.46778E+12 1.58902E+12 1.73616E+12 1.90883E+12 2.09786↙
E+12];
p=[845150300    866153600   886181600   904684200   920856600   935203000   948038700↙
960832500   973934700   986298100   999068400   1013894500  1028655100  1042222900↙
1056496200  1072314600  1089625500  1107257600  1124336200  1140889500  1156532000↙
1170770500  1184341000  1197870400  1211011100  1223985500  1236564300  1248478700↙
1260341500  1269310000  1278574900  1287187000  1295203100  1303040072  1311443600];
PE=[391717  412004  427319  438360  484050  500518  545041  590547  600343  598503↙
594034  612634  637070  675755  692077  716697  753513  794295  810852  863213  856712↙
885802  937433  980380  1047702 1086473 1090132 1089634 1093630 1104904 1103115 1194894↙
1360366 1582611 1717153];
PEO=[39865  45818   52662   60761   68236   79889   86279   94754   94172   93112↙
88385   88133   91619   92841   96588   103170  108438  113626  117688  115500  123162↙
131608  140431  140340  148174  160316  176533  173594  190910  213823  215764  229382↙
253436  292124  301325];
PEG=[3129   4052    5004    6295    7395    8438    10118   11436   12070   11861↙
10594   9909    10109   10468   10757   11419   11549   11887   12540   12846   13392↙
13214   14092   14732   15016   15562   16997   17597   19005   20749   23391   25591↙
27899   33475   40195];
PEC=[192056 201230  204804  202770  236896  238023  272077  305854  313017  310122↙
308899  325817  344289  379854  389362  404936  433414  465187  473575  522809  507891↙
526026  563884  602140  659546  683167  666934  666951  648818  633664  620427  690645↙
824293  992861  1107079];
PEN=[0  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0↙
0   420 3857    3349    3763    3790    3703    3926    4362    4561    6597    11365↙
13244   13855];
PEH=[2578   2922    3265    3692    3861    3913    4082    3822    4287    4965↙
5593    6340    7337    7386    7899    8064    8547    9353    10141   10937   10716↙
11396   13116   14437   16415   16278   17003   18025   17660   19127   23902   24950↙
24549   30615   34192];
PER=[154089 157982  161584  164842  167662  170255  172485  174681  176797  178443↙
180563  182435  183716  185206  187471  189108  191565  194242  196908  201121  201551↙
203558  205490  204874  205202  207387  208875  209764  213311  213179  215070  217729↙
218824  220292  220507];
CO2=[242843 258329  268530  273943  317769  329412  372625  417051  424707  420558↙
414467  432092  455093  494764  508357  531116  566371  605254  618133  669679  660332↙
686880  735722  777380  846132  882163  879128  877068  872885  876819  865837  954499↙
1120486 1338539 1473925];
CO2C=[207458    217368  221228  219031  255894  257111  293896  330382  338119  334992↙
333671  351945  371899  410316  420587  437410  468171  502493  511553  564735  548622↙
568211  609104  650428  712438  737953  720418  720436  700850  684480  670181  746030↙
890396  1072482 1195860];
CO2G=[2004  2595    3205    4033    4737    5405    6482    7326    7732    7598↙
6786    6348    6476    6706    6891    7315    7398    7615    8033    8229    8579↙
8465    9027    9437    9619    9968    10888   11272   12174   13292   14984   16393↙
```

```
17872   21444 25748];
CO2O=[33381 38366   44097   50879   57138   66896   72247   79343   78856   77968↙
74010   73799   76718   77742   80879   86391   90802   95146   98547   96715   103131↙
110204  117591  117515  124075  134242  147822  145360  159861  179047  180672  192076↙
212218  244613 252317];
CO2H=[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0↙
0   0   0   0   0   0   0   0   0   0   0   0   0 0];
CO2N=CO2H;
CO2R=CO2N;
%Stammvariablen
%p
a=GDP./p;
e=PE./GDP;
k=CO2./PE;
%Variables set for 'Effektgleichungen'

%Anteile der jeweiligen Primärenergieträager am Gesamtenergierverbrauch (Variable q)
qC=PEC./PE;
qO=PEO./PE;
qG=PEG./PE;
qN=PEN./PE;
qH=PEH./PE;
qR=PER./PE;
Q=[qC' qO' qG' qN' qH' qR'];
A=[p' a' e' k' qC' qO' qG' qN' qH' qR'];
%Werte des jeweiligen Vorjahres xo
for i=(1:35)
    if i==1
     p0 (i) =A(1,1);
     else
    p0(i)= A(i-1,1);
    end;
    if i==1
     a0 (i) =A(1,2);
     else
     a0(i) =A(i-1,2);
    end;
    if i==1
     e0 (i) =A(1,3);
     else
     e0(i) =A(i-1,3);
    end;
    if i==1
     k0 (i) =A(1,4);
     else
     k0(i) =A(i-1,4);
    end;
    if i==1
    qC0(i)=A(1,5);
    else
        qC0 (i)=A(i-1,5);
    end;
     if i==1
    qO0(i)=A(1,6);
    else
        qO0 (i)=A(i-1,6);
```

```
    end;
     if i==1
    qG0(i)=A(1,7);
    else
        qG0 (i)=A(i-1,7);
    end;
     if i==1
    qN0(i)=A(1,8);
    else
        qN0 (i)=A(i-1,8);
    end;
     if i==1
    qH0(i)=A(1,9);
    else
        qH0 (i)=A(i-1,9);
    end;
     if i==1
    qR0(i)=A(1,10);
    else
        qR0 (i)=A(i-1,10);
    end;
end;
%Differenzen zum jeweiligen Vorjahr
for i=(1:35)
    dp (i) =A(i,1)-p0 (i);
    da (i) =A(i,2)-a0 (i) ;
    de  (i) =A(i,3)-e0 (i);
    dk (i) = A(i,4)-k0 (i);
dqC (i)= A(i,5)-qC0 (i);
dqO (i)=A(i,6)-qO0 (i);
dqG (i)=A(i,7)-qG0 (i);
dqN (i)=A(i,8)-qN0 (i);
dqH (i)=A(i,9)-qH0 (i);
dqR (i)=A(i,10)-qR0 (i);
end;
%Calculation of Variable dkX
for i=(1:35)
dkC (i) =(CO2C(i)./PEC(i)-k(i))*dqC(i);
dkO (i) =(CO2O(i)./PEO(i)-k(i))*dqO(i);
dkG (i) =(CO2G (i)./PEG(i)-k(i))*dqG(i);
for i=(1:22)
    dkN (i) = 0;
end;
for i=(23:35)
dkN (i) =(CO2N (i)./PEN(i)-k(i))*dqN(i);
end;
dkH (i) =(CO2H(i)./PEH(i)-k(i))*dqH(i);
dkR (i) =(CO2R(i)./PER(i)-k(i))*dqR(i);
end;
%Effektgleichungen
Pf=dp.*a0.*e0.*k0+(1/2).*dp.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dp.*(da.*de.↙
*k0+a0.*de.*dk+da.*e0.*dk)+(1/4).*dp.*da.*dk.*de;
Af=da.*p0.*e0.*k0+(1/2)*da.*(dp.*e0.*k0+de.*p0.*k0+dk.*p0.*e0)+(1/3)*da.*(dp.*de.↙
*k0+de.*dk.*p0+dp.*dk.*e0)+(1/4)*da.*dp.*dk.*de;
Ef=de.*p0.*a0.*k0+(1/2)*de.*(da.*p0.*k0+dp.*a0.*k0+dk.*p0.*a0)+(1/3)*de.*(da.*dp.↙
*k0+dp.*dk.*a0+da.*dk.*p0)+(1/4)*de.*dp.*da.*dk;
```

```
Kf=dk.*p0.*a0.*e0+(1/2)*dk.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dk.*(dp.*da.↙
*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dk.*dp.*da.*de;
    KCf=dkC.*p0.*a0.*e0+(1/2)*dkC.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkC.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkC.*dp.*da.*de;
    KOf=dkO.*p0.*a0.*e0+(1/2)*dkO.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkO.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkO.*dp.*da.*de;
    KGf=dkG.*p0.*a0.*e0+(1/2)*dkG.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkG.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkG.*dp.*da.*de;
    KNf=dkN.*p0.*a0.*e0+(1/2)*dkN.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkN.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkN.*dp.*da.*de;
    KHf=dkH.*p0.*a0.*e0+(1/2)*dkH.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkH.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkH.*dp.*da.*de;
    KRf=dkR.*p0.*a0.*e0+(1/2)*dkR.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dkR.*(dp.↙
*da.*e0+dp.*de.*a0+da.*de.*p0)+(1/4)*dkR.*dp.*da.*de;
Ff=[Pf' Af' Ef' KCf' KOf' KGf' KNf' KHf' KRf']

%Kontrollrechnungen
sumFf=sum(sum(Ff))
res_P=((1/2).*dp.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dp.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dp.*da.*dk.*de)./Pf
res_A=((1/2)*da.*(dp.*e0.*k0+de.*p0.*k0+dk.*p0.*e0)+(1/3)*da.*(dp.*de.*k0+de.*dk.↙
*p0+dp.*dk.*e0)+(1/4)*da.*dp.*dk.*de)./Af
res_E=((1/2)*de.*(da.*p0.*k0+dp.*a0.*k0+dk.*p0.*a0)+(1/3)*de.*(da.*dp.*k0+dp.*dk.↙
*a0+da.*dk.*p0)+(1/4)*de.*dp.*da.*dk)./Ef
res_K=((1/2)*dk.*(da.*p0.*e0+dp.*a0.*e0+de.*p0.*a0)+(1/3)*dk.*(dp.*da.*e0+dp.*de.↙
*a0+da.*de.*p0)+(1/4)*dk.*dp.*da.*de)./Kf
res_KC=((1/2).*dkC.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkC.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkC.*da.*dk.*de)./KCf
res_KO=((1/2).*dkO.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkO.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkO.*da.*dk.*de)./KOf
res_KG=((1/2).*dkG.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkG.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkG.*da.*dk.*de)./KGf
res_KN=((1/2).*dkN.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkN.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkN.*da.*dk.*de)./KNf
res_KH=((1/2).*dkH.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkH.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkH.*da.*dk.*de)./KHf
res_KR=((1/2).*dkR.*(da.*e0.*k0+a0.*de.*k0+a0.*e0.*dk)+(1/3).*dkR.*(da.*de.*k0+a0.*de.↙
*dk+da.*e0.*dk)+(1/4).*dkR.*da.*dk.*de)./KRf
CI_breakdown=(KCf+KOf+KGf+KNf+KHf+KRf)./Kf
keyboard
%Visualization
Pfp=Pf(find(Pf>=0));
Pfn=CO2H;
for i=[1:35]
    if Af (i) >= 0
        Afp (i) = Af(i);
        Afn (i) = 0;
    elseif Af (i) <0
        Afp (i) = 0;
        Afn (i) = Af (i);
    end
end

for i=[1:35]
    if Ef (i) >= 0
        Efp (i) = Ef(i);
```

```
        Efn (i) = 0;
    elseif Ef (i) <0
        Efp (i) = 0;
        Efn (i) = Ef (i);
    end
end

for i=[1:35]
    if Kf(i) >=0
        Kfp (i) =Kf(i);
        Kfn (i) =0;
    elseif Kf (i) <0
        Kfp (i) =0;
        Kfn (i) = Kf (i);
    end;
end

for i=[1:35]
    if KCf (i) >= 0
        KCfp (i) = KCf(i);
        KCfn (i) = 0;
    elseif KCf (i) <0
        KCfp (i) = 0;
        KCfn (i) = KCf (i);
    end
end

for i=[1:35]
    if KGf (i) >= 0
        KGfp (i) = KGf(i);
        KGfn (i) = 0;
    elseif KGf (i) <0
        KGfp (i) = 0;
        KGfn (i) = KGf (i);
    end
end

for i=[1:35]
    if KOf (i) >= 0
        KOfp (i) = KOf(i);
        KOfn (i) = 0;
    elseif KOf (i) <0
        KOfp (i) = 0;
        KOfn (i) = KOf (i);
    end
end

for i=[1:35]
    if KNf (i) >= 0
        KNfp (i) = KNf(i);
        KNfn (i) = 0;
    elseif KNf (i) <0
        KNfp (i) = 0;
        KNfn (i) = KNf (i);
    end
end
```

```
for i=[1:35]
    if KHf (i) >= 0
        KHfp (i) = KHf(i);
        KHfn (i) = 0;
    elseif KHf (i) <0
        KHfp (i) = 0;
        KHfn (i) = KHf (i);
    end
end

for i=[1:35]
    if KRf (i) >= 0
        KRfp (i) = KRf(i);
        KRfn (i) = 0;
    elseif KRf (i) <0
        KRfp (i) = 0;
        KRfn (i) = KRf (i);
    end
end

Ffpn=[Pfp' Pfn' Afp' Afn' Efp' Efn' KCfp' KCfn' KGfp' KGfn' KOfp' KOfn' KNfp' KNfn' ↙
KHfp' KHfn' KRfp' KRfn'];
Ffp=[Pfp' Afp' Efp' KCfp' KGfp' KOfp' KNfp' KHfp' KRfp'];
Ffn=[Pfn' Afn' Efn' KCfn' KGfn' KOfn' KNfn' KHfn' KRfn'];
for i=(1:35)
    if i==1
     dCO2 (i) =0;
     else
    dCO2(i)= CO2(i)-CO2(i-1);
    end
end;

fig_1 = figure('NumberTitle', 'off', 'Name','Driving Factors of Chinese CO2 Emissions↙
1971 - 2005');
% subplot(2,2,1:2)
graph3=plot(dCO2,':.')
hold on
graph1=bar(Ffp,'stacked')
hold on
graph2=bar(Ffn,'stacked')
hold on
graph3
set(graph1(1), 'FaceColor',[1 0 0],'EdgeColor','black')
set(graph1(2),'FaceColor',[0.9 0.5 0],'EdgeColor','black')
set(graph1(3),'FaceColor',[0.65 0.65 0.65],'EdgeColor','black')
set(graph1(4),'FaceColor',[0.55 0.15 0.11],'EdgeColor','black')
set(graph1(5),'FaceColor',[1 0 1],'EdgeColor','black')
set(graph1(6),'FaceColor',[0 0 0],'EdgeColor','black')
set(graph1(7),'FaceColor',[1 0.8 0],'EdgeColor','black')
set(graph1(8),'FaceColor',[0 0 1],'EdgeColor','black')
set(graph1(9),'FaceColor',[0 1 0],'EdgeColor','black')

set(graph2(1), 'FaceColor',[1 0 0],'EdgeColor','black')
set(graph2(2),'FaceColor',[0.9 0.5 0],'EdgeColor','black')
set(graph2(3),'FaceColor',[0.65 0.65 0.65],'EdgeColor','black')
```

```
set(graph2(4),'FaceColor',[0.55 0.15 0.11],'EdgeColor','black')
set(graph2(5),'FaceColor',[1 0 1],'EdgeColor','black')
set(graph2(6),'FaceColor',[0 0 0],'EdgeColor','black')
set(graph2(7),'FaceColor',[1 0.8 0],'EdgeColor','black')
set(graph2(8),'FaceColor',[0 0 1],'EdgeColor','black')
set(graph2(9),'FaceColor',[0 1 0],'EdgeColor','black')

set(graph3(1),'Color',[0 0 0],'LineWidth',↙
1,'MarkerEdgeColor','k','MarkerFaceColor','black','MarkerSize',5)


xlabel('Year');
ylabel('CO2 emissions [kt C]');
title('Influence of Socio Economic Determinants Broken Down by Carbon Intensity in↙
China 1971 - 2005');
legend('Annual Change in CO2 Emissions','Population','GDP per Capita','Energy↙
Intensity');

set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));

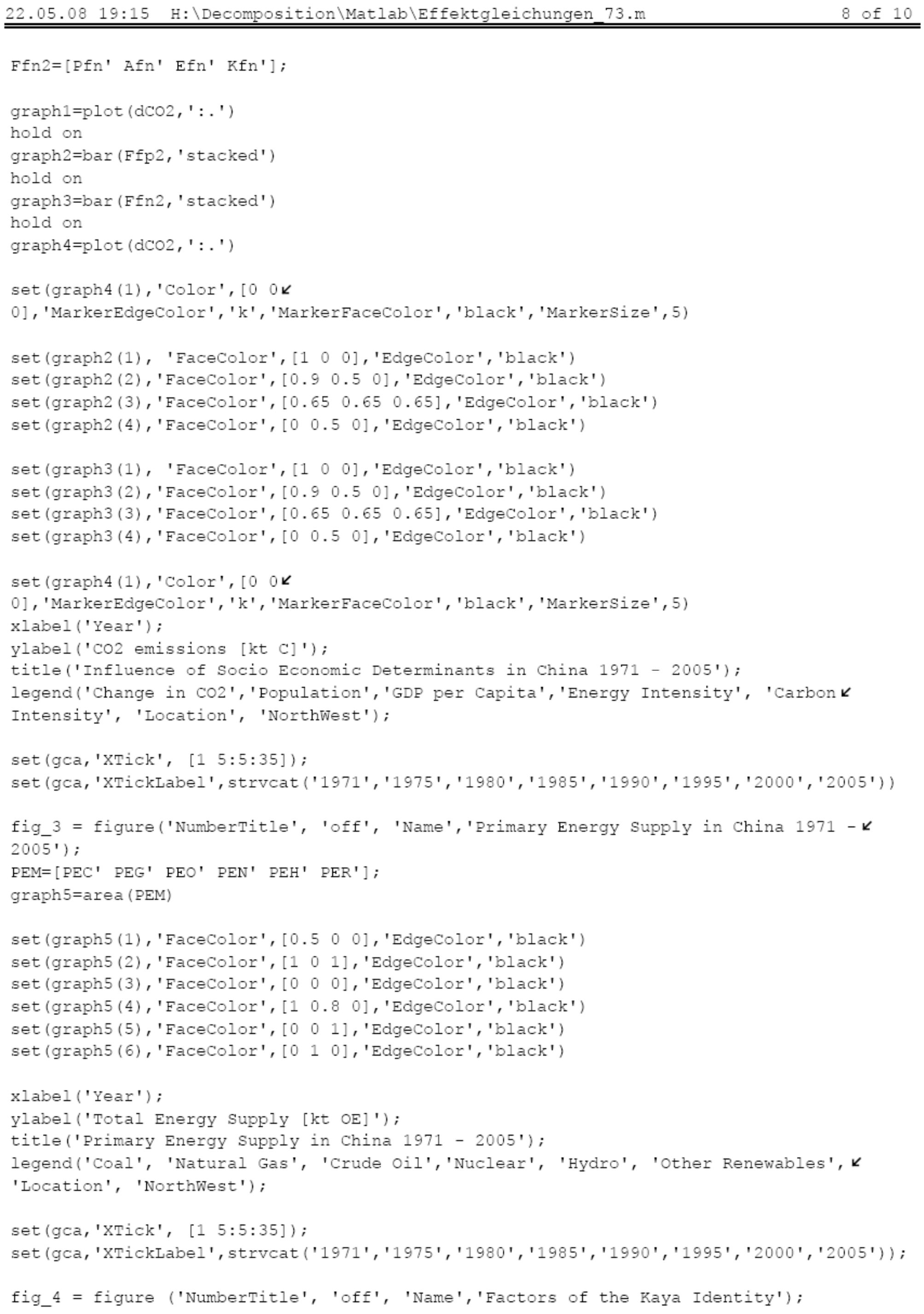
fig_11 = figure('NumberTitle', 'off', 'Name','Driving Factors of the Carbon Intensity↙
in China 1971 - 2005');
FCIp=[KCfp' KGfp' KOfp' KNfp' KHfp' KRfp'];
FCIn=[KCfn' KGfn' KOfn' KNfn' KHfn' KRfn'];
% subplot(2,2,3:4)
graph1=bar(FCIp,'stacked')
hold on
graph2=bar(FCIn,'stacked')
set(graph1(1),'FaceColor',[0.55 0.15 0.11],'EdgeColor','black')
set(graph1(2),'FaceColor',[1 0 1],'EdgeColor','black')
set(graph1(3),'FaceColor',[0 0 0],'EdgeColor','black')
set(graph1(4),'FaceColor',[1 0.8 0],'EdgeColor','black')
set(graph1(5),'FaceColor',[0 0 1],'EdgeColor','black')
set(graph1(6),'FaceColor',[0 1 0],'EdgeColor','black')

set(graph2(1),'FaceColor',[0.55 0.15 0.11],'EdgeColor','black')
set(graph2(2),'FaceColor',[1 0 1],'EdgeColor','black')
set(graph2(3),'FaceColor',[0 0 0],'EdgeColor','black')
set(graph2(4),'FaceColor',[1 0.8 0],'EdgeColor','black')
set(graph2(5),'FaceColor',[0 0 1],'EdgeColor','black')
set(graph2(6),'FaceColor',[0 1 0],'EdgeColor','black')

xlabel('Year');
ylabel('CI Induced CO2 Emissions [kt]');
title('Influence of PE Carriers on CI: China');
legend('CI Coal', 'CI Natural Gas', 'CI Crude Oil','CI Nuclear', 'CI Hydro', 'CI Other↙
Renewables', 'Location', 'NorthWest');

set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));

fig_2 = figure('NumberTitle', 'off', 'Name','Driving Factors of Chinese CO2 Emissions↙
1971 - 2005');
Ffpn2=[Pfp' Pfn' Afp' Afn' Efp' Efn' Kfp' Kfn'];
Ffp2=[Pfp' Afp' Efp' Kfp'];
```



```
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Ffn2=[Pfn' Afn' Efn' Kfn'];

graph1=plot(dCO2,':.')
hold on
graph2=bar(Ffp2,'stacked')
hold on
graph3=bar(Ffn2,'stacked')
hold on
graph4=plot(dCO2,':.')

set(graph4(1),'Color',[0 0↙
0],'MarkerEdgeColor','k','MarkerFaceColor','black','MarkerSize',5)

set(graph2(1), 'FaceColor',[1 0 0],'EdgeColor','black')
set(graph2(2),'FaceColor',[0.9 0.5 0],'EdgeColor','black')
set(graph2(3),'FaceColor',[0.65 0.65 0.65],'EdgeColor','black')
set(graph2(4),'FaceColor',[0 0.5 0],'EdgeColor','black')

set(graph3(1), 'FaceColor',[1 0 0],'EdgeColor','black')
set(graph3(2),'FaceColor',[0.9 0.5 0],'EdgeColor','black')
set(graph3(3),'FaceColor',[0.65 0.65 0.65],'EdgeColor','black')
set(graph3(4),'FaceColor',[0 0.5 0],'EdgeColor','black')

set(graph4(1),'Color',[0 0↙
0],'MarkerEdgeColor','k','MarkerFaceColor','black','MarkerSize',5)
xlabel('Year');
ylabel('CO2 emissions [kt C]');
title('Influence of Socio Economic Determinants in China 1971 - 2005');
legend('Change in CO2','Population','GDP per Capita','Energy Intensity', 'Carbon↙
Intensity', 'Location', 'NorthWest');

set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'))

fig_3 = figure('NumberTitle', 'off', 'Name','Primary Energy Supply in China 1971 -↙
2005');
PEM=[PEC' PEG' PEO' PEN' PEH' PER'];
graph5=area(PEM)

set(graph5(1),'FaceColor',[0.5 0 0],'EdgeColor','black')
set(graph5(2),'FaceColor',[1 0 1],'EdgeColor','black')
set(graph5(3),'FaceColor',[0 0 0],'EdgeColor','black')
set(graph5(4),'FaceColor',[1 0.8 0],'EdgeColor','black')
set(graph5(5),'FaceColor',[0 0 1],'EdgeColor','black')
set(graph5(6),'FaceColor',[0 1 0],'EdgeColor','black')

xlabel('Year');
ylabel('Total Energy Supply [kt OE]');
title('Primary Energy Supply in China 1971 - 2005');
legend('Coal', 'Natural Gas', 'Crude Oil','Nuclear', 'Hydro', 'Other Renewables',↙
'Location', 'NorthWest');

set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));

fig_4 = figure ('NumberTitle', 'off', 'Name','Factors of the Kaya Identity');
```

```
kp=[p./p(10)];
ka=[a./a(10)];
ke=e./e(10);
kk=k./k(10);
kpe=PE./PE(10);
kCO2=CO2./CO2(10);
paCO2=CO2./GDP;
kpaCO2=paCO2./paCO2(10);
KQ=[kCO2' kp' ka' kpe' ke' kk' kpaCO2'];

graph6=plot(KQ)
set(graph6(1),'Color',[0 0 0],'LineWidth',2)
set(graph6(2),'Color','red','linewidth',2)
set(graph6(3),'Color','blue','linewidth',2)
set(graph6(4),'Color',[1 0 1],'linewidth',2)
set(graph6(5),'Color',[0.5 0.5 0.5],'linewidth',2)
set(graph6(6),'Color','green','linewidth',2)
set(graph6(7),'Color',[1 0.5 0],'linewidth',2)
grid on
xlabel('Year');
ylabel('Index 1980=1');
title('Factors of the Kaya Identity');
legend('CO2 Emissions', 'Population', 'GDP/Capita','Primary Energy','Energy↙
Intensity','Carbon Intensity','CO2 per↙
GDP','Location','BestOutside','Orientation','Horizontal');

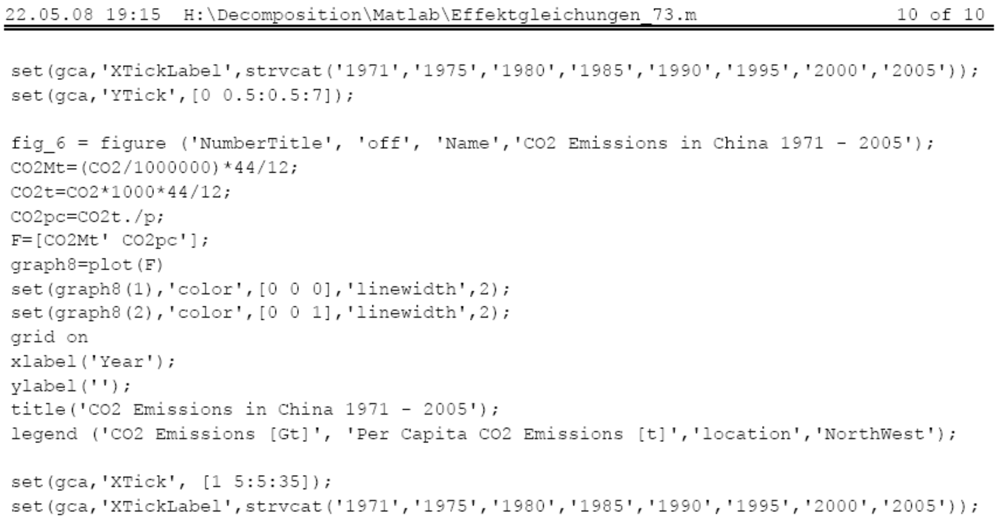
set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));
set(gca,'YTick',[0 0.5:0.5:8]);

fig_5 = figure ('NumberTitle', 'off', 'Name','Primary Energy Supply in China 1971 -↙
2005');
PECM=PEC./PEC(10);
PEOM=PEO./PEO(10);
PEGM=PEG./PEG(10);
PENM=PEN./PEN(25);
PEHM=PEH./PEH(10);
PERM=PER./PER(10);
PEQ=[PECM' PEOM' PEGM' PENM' PEHM' PERM'];

graph7=plot(PEQ)

set(graph7(1),'Color',[0.5 0 0],'linewidth',2)
set(graph7(2),'Color',[1 0 1],'linewidth',2)
set(graph7(3),'Color',[0 0 0],'linewidth',2)
set(graph7(4),'Color',[1 0.5 0],'linewidth',2)
set(graph7(5),'Color',[0 0 1],'linewidth',2)
set(graph7(6),'Color',[0 1 0],'linewidth',2)
grid on
xlabel('Year');
ylabel('Index 1980 = 1 (Nuclear Energy Index 1995 =1)');
title('Primary Energy Supply in China 1971 - 2005');
legend ('Coal', 'Natural Gas', 'Crude Oil','Nuclear', 'Hydro', 'Other↙
Renewables','Location','BestOutside','Orientation','Horizontal');

set(gca,'XTick', [1 5:5:35]);
```



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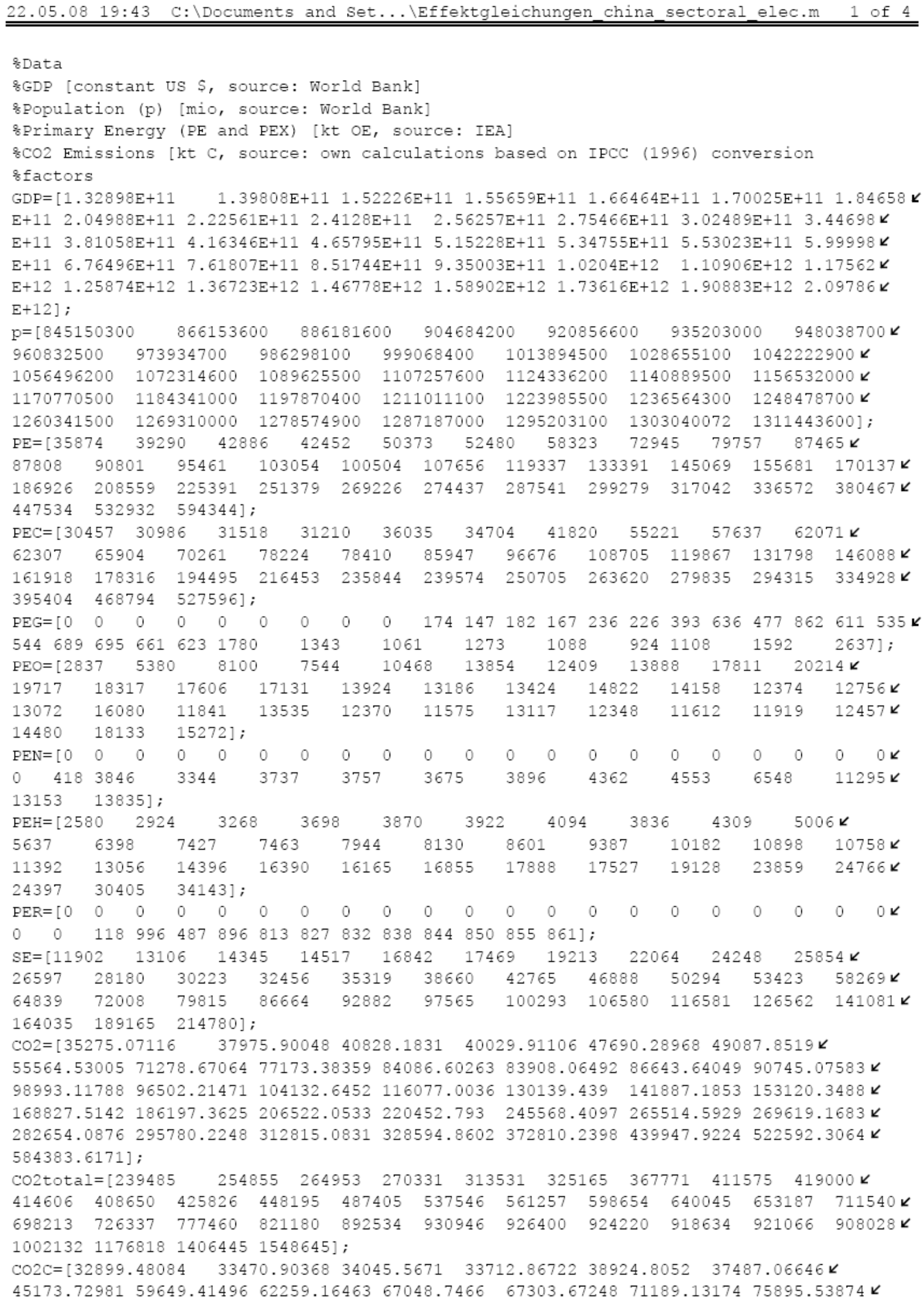
```
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));
set(gca,'YTick',[0 0.5:0.5:7]);

fig_6 = figure ('NumberTitle', 'off', 'Name','CO2 Emissions in China 1971 - 2005');
CO2Mt=(CO2/1000000)*44/12;
CO2t=CO2*1000*44/12;
CO2pc=CO2t./p;
F=[CO2Mt' CO2pc'];
graph8=plot(F)
set(graph8(1),'color',[0 0 0],'linewidth',2);
set(graph8(2),'color',[0 0 1],'linewidth',2);
grid on
xlabel('Year');
ylabel('');
title('CO2 Emissions in China 1971 - 2005');
legend ('CO2 Emissions [Gt]', 'Per Capita CO2 Emissions [t]','location','NorthWest');

set(gca,'XTick', [1 5:5:35]);
set(gca,'XTickLabel',strvcat('1971','1975','1980','1985','1990','1995','2000','2005'));
```

b) Chinese Electricity Sector[55]



```
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%Data
%GDP [constant US $, source: World Bank]
%Population (p) [mio, source: World Bank]
%Primary Energy (PE and PEX) [kt OE, source: IEA]
%CO2 Emissions [kt C, source: own calculations based on IPCC (1996) conversion
%factors
GDP=[1.32898E+11    1.39808E+11 1.52226E+11 1.55659E+11 1.66464E+11 1.70025E+11 1.84658↙
E+11 2.04988E+11 2.22561E+11 2.4128E+11  2.56257E+11 2.75466E+11 3.02489E+11 3.44698↙
E+11 3.81058E+11 4.16346E+11 4.65795E+11 5.15228E+11 5.34755E+11 5.53023E+11 5.99998↙
E+11 6.76496E+11 7.61807E+11 8.51744E+11 9.35003E+11 1.0204E+12  1.10906E+12 1.17562↙
E+12 1.25874E+12 1.36723E+12 1.46778E+12 1.58902E+12 1.73616E+12 1.90883E+12 2.09786↙
E+12];
p=[845150300    866153600   886181600   904684200   920856600   935203000   948038700↙
960832500   973934700   986298100   999068400   1013894500  1028655100  1042222900↙
1056496200  1072314600  1089625500  1107257600  1124336200  1140889500  1156532000↙
1170770500  1184341000  1197870400  1211011100  1223985500  1236564300  1248478700↙
1260341500  1269310000  1278574900  1287187000  1295203100  1303040072  1311443600];
PE=[35874   39290   42886   42452   50373   52480   58323   72945   79757   87465↙
87808   90801   95461   103054  100504  107656  119337  133391  145069  155681  170137↙
186926  208559  225391  251379  269226  274437  287541  299279  317042  336572  380467↙
447534  532932  594344];
PEC=[30457  30986   31518   31210   36035   34704   41820   55221   57637   62071↙
62307   65904   70261   78224   78410   85947   96676   108705  119867  131798  146088↙
161918  178316  194495  216453  235844  239574  250705  263620  279835  294315  334928↙
395404  468794  527596];
PEG=[0  0   0   0   0   0   0   0   0   174 147 182 167 236 226 393 636 477 862 611 535↙
544 689 695 661 623 1780    1343    1061    1273    1088    924 1108    1592    2637];
PEO=[2837   5380    8100    7544    10468   13854   12409   13888   17811   20214↙
19717   18317   17606   17131   13924   13186   13424   14822   14158   12374   12756↙
13072   16080   11841   13535   12370   11575   13117   12348   11612   11919   12457↙
14480   18133   15272];
PEN=[0  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0↙
0   418 3846    3344    3737    3757    3675    3896    4362    4553    6548    11295↙
13153   13835];
PEH=[2580   2924    3268    3698    3870    3922    4094    3836    4309    5006↙
5637    6398    7427    7463    7944    8130    8601    9387    10182   10898   10758↙
11392   13056   14396   16390   16165   16855   17888   17527   19128   23859   24766↙
24397   30405   34143];
PER=[0  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0↙
0   0   118 996 487 896 813 827 832 838 844 850 855 861];
SE=[11902   13106   14345   14517   16842   17469   19213   22064   24248   25854↙
26597   28180   30223   32456   35319   38660   42765   46888   50294   53423   58269↙
64839   72008   79815   86664   92882   97565   100293  106580  116581  126562  141081↙
164035  189165  214780];
CO2=[35275.07116    37975.90048 40828.1831  40029.91106 47690.28968 49087.8519↙
55564.53005 71278.67064 77173.38359 84086.60263 83908.06492 86643.64049 90745.07583↙
98993.11788 96502.21471 104132.6452 116077.0036 130139.439  141887.1853 153120.3488↙
168827.5142 186197.3625 206522.0533 220452.793  245568.4097 265514.5929 269619.1683↙
282654.0876 295780.2248 312815.0831 328594.8602 372810.2398 439947.9224 522592.3064↙
584383.6171];
CO2total=[239485    254855  264953  270331  313531  325165  367771  411575  419000↙
414606  408650  425826  448195  487405  537546  561257  598654  640045  653187  711540↙
698213  726337  777460  821180  892534  930946  926400  924220  918634  921066  908028↙
1002132 1176818 1406445 1548645];
CO2C=[32899.48084   33470.90368 34045.5671  33712.86722 38924.8052  37487.06646↙
45173.72981 59649.41496 62259.16463 67048.7466  67303.67248 71189.13174 75895.53874↙
```

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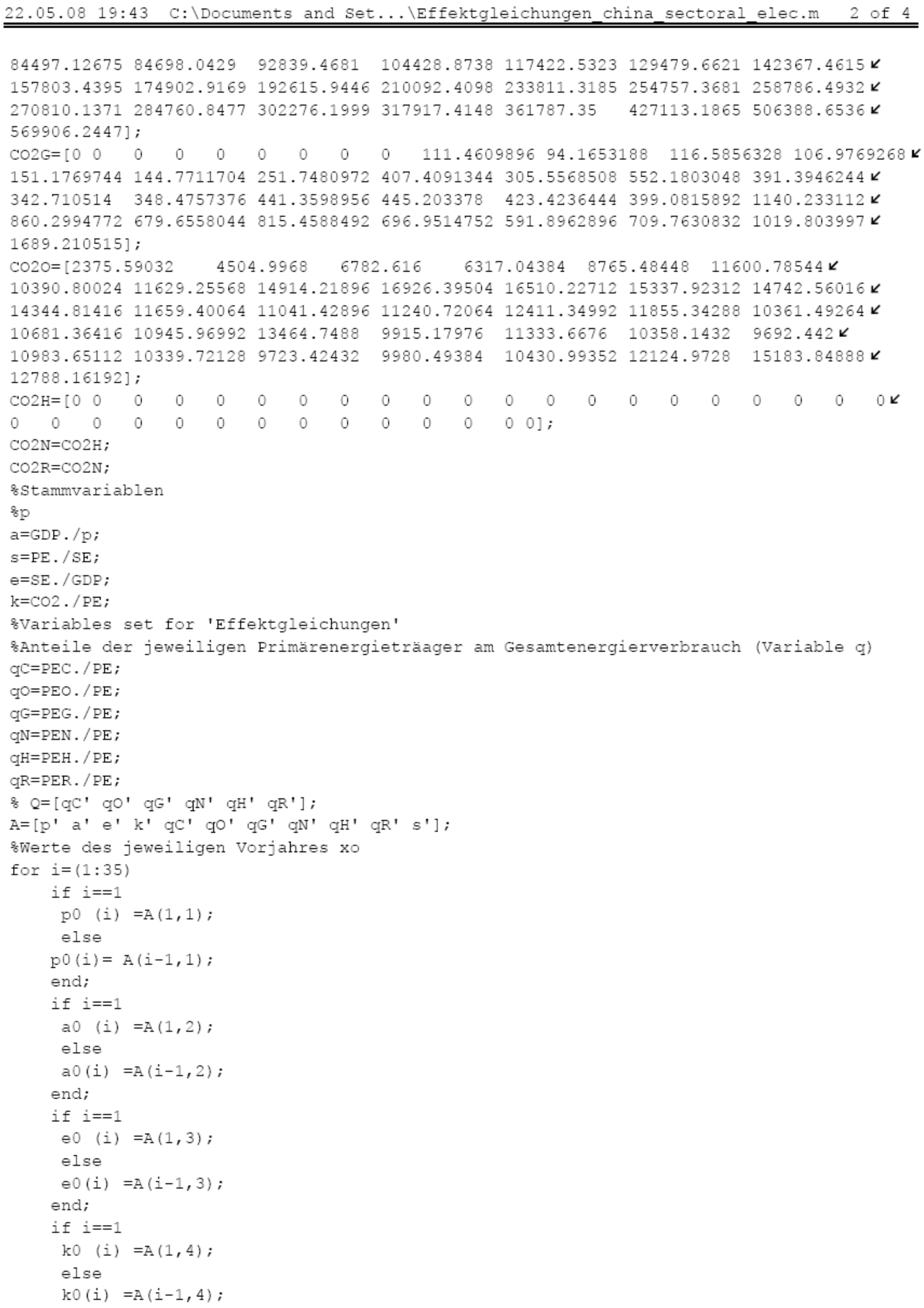
[55] Note: Visualization is not shown for the Chinese electricity sector, as being basically similar to a).



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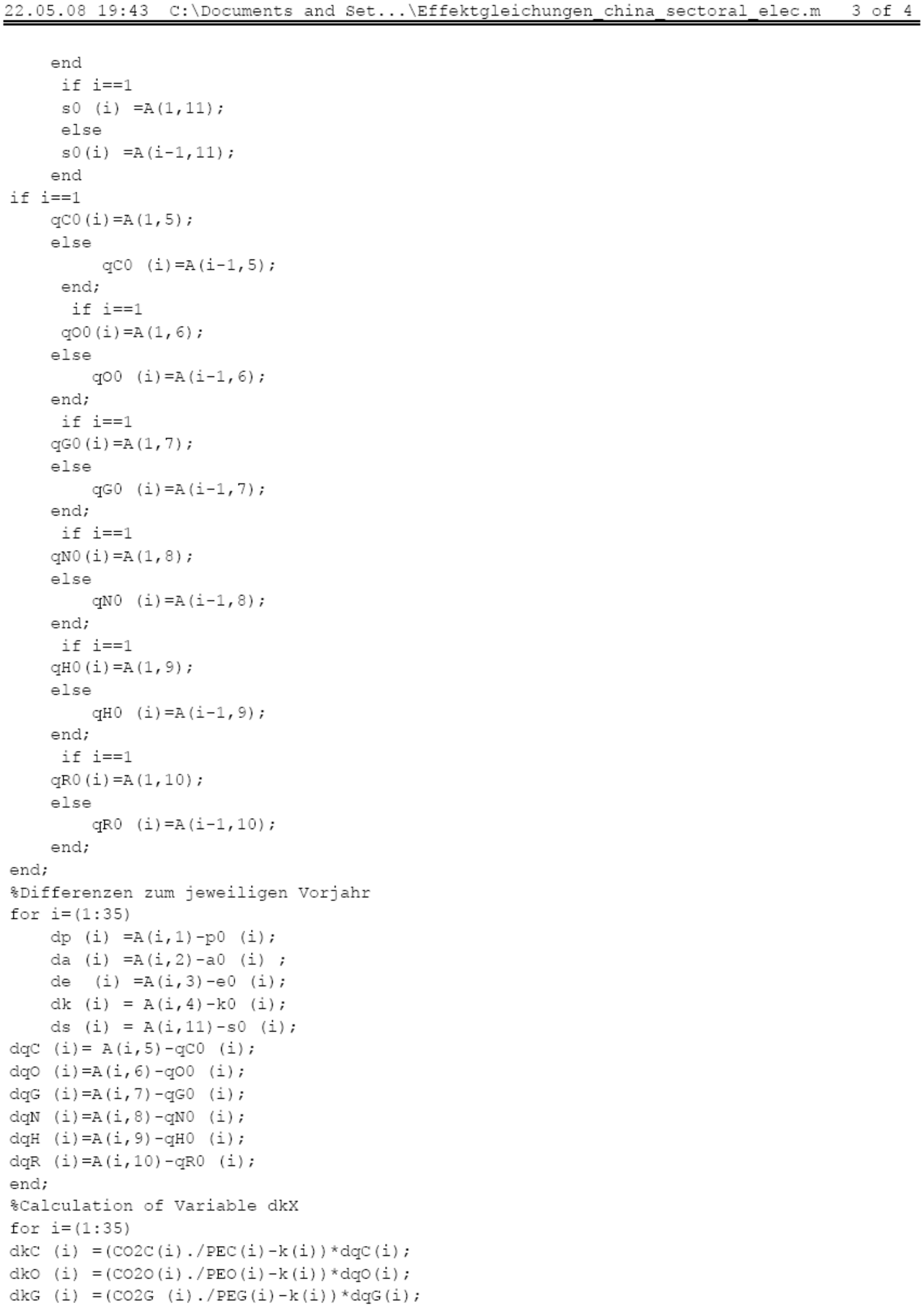
84497.12675 84698.0429  92839.4681  104428.8738 117422.5323 129479.6621 142367.4615↙
157803.4395 174902.9169 192615.9446 210092.4098 233811.3185 254757.3681 258786.4932↙
270810.1371 284760.8477 302276.1999 317917.4148 361787.35   427113.1865 506388.6536↙
569906.2447];
CO2G=[0 0   0   0   0   0   0   0   0   111.4609896 94.1653188  116.5856328 106.9769268↙
151.1769744 144.7711704 251.7480972 407.4091344 305.5568508 552.1803048 391.3946244↙
342.710514  348.4757376 441.3598956 445.203378  423.4236444 399.0815892 1140.233112↙
860.2994772 679.6558044 815.4588492 696.9514752 591.8962896 709.7630832 1019.803997↙
1689.210515];
CO2O=[2375.59032    4504.9968   6782.616    6317.04384  8765.48448  11600.78544↙
10390.80024 11629.25568 14914.21896 16926.39504 16510.22712 15337.92312 14742.56016↙
14344.81416 11659.40064 11041.42896 11240.72064 12411.34992 11855.34288 10361.49264↙
10681.36416 10945.96992 13464.7488  9915.17976  11333.6676  10358.1432  9692.442↙
10983.65112 10339.72128 9723.42432  9980.49384  10430.99352 12124.9728  15183.84888↙
12788.16192];
CO2H=[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0↙
0   0   0   0   0   0   0   0   0   0   0   0   0 0];
CO2N=CO2H;
CO2R=CO2N;
%Stammvariablen
%p
a=GDP./p;
s=PE./SE;
e=SE./GDP;
k=CO2./PE;
%Variables set for 'Effektgleichungen'
%Anteile der jeweiligen Primärenergieträager am Gesamtenergierverbrauch (Variable q)
qC=PEC./PE;
qO=PEO./PE;
qG=PEG./PE;
qN=PEN./PE;
qH=PEH./PE;
qR=PER./PE;
% Q=[qC' qO' qG' qN' qH' qR'];
A=[p' a' e' k' qC' qO' qG' qN' qH' qR' s'];
%Werte des jeweiligen Vorjahres xo
for i=(1:35)
    if i==1
     p0 (i) =A(1,1);
     else
    p0(i)= A(i-1,1);
    end;
    if i==1
     a0 (i) =A(1,2);
     else
     a0(i) =A(i-1,2);
    end;
    if i==1
     e0 (i) =A(1,3);
     else
     e0(i) =A(i-1,3);
    end;
    if i==1
     k0 (i) =A(1,4);
     else
     k0(i) =A(i-1,4);
```



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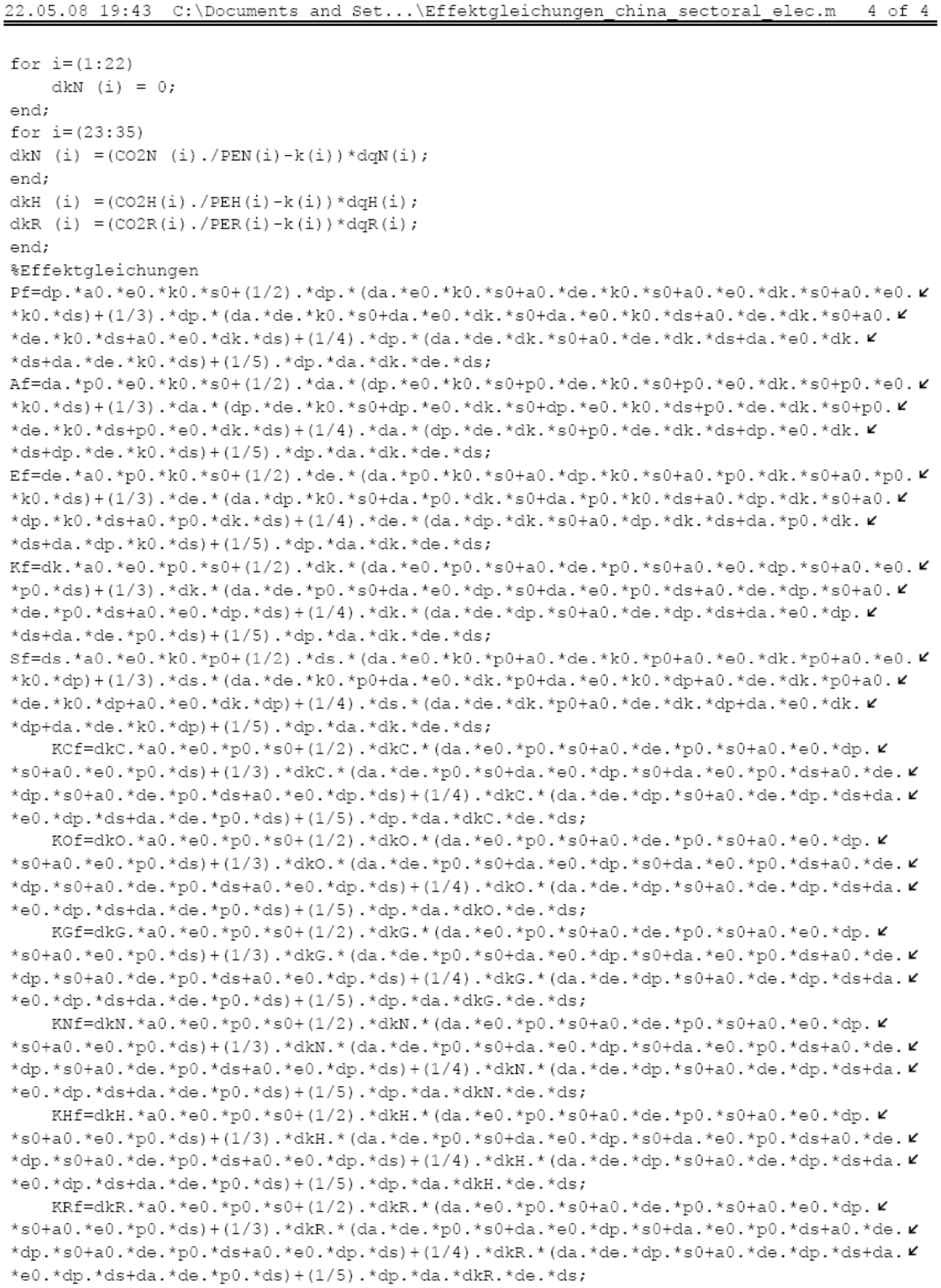
```
    end
     if i==1
     s0 (i) =A(1,11);
     else
     s0(i) =A(i-1,11);
    end
if i==1
    qC0(i)=A(1,5);
    else
         qC0 (i)=A(i-1,5);
     end;
      if i==1
     qO0(i)=A(1,6);
    else
        qO0 (i)=A(i-1,6);
    end;
     if i==1
    qG0(i)=A(1,7);
    else
        qG0 (i)=A(i-1,7);
    end;
     if i==1
    qN0(i)=A(1,8);
    else
        qN0 (i)=A(i-1,8);
    end;
     if i==1
    qH0(i)=A(1,9);
    else
        qH0 (i)=A(i-1,9);
    end;
     if i==1
    qR0(i)=A(1,10);
    else
        qR0 (i)=A(i-1,10);
    end;
end;
%Differenzen zum jeweiligen Vorjahr
for i=(1:35)
    dp (i) =A(i,1)-p0 (i);
    da (i) =A(i,2)-a0 (i) ;
    de  (i) =A(i,3)-e0 (i);
    dk (i) = A(i,4)-k0 (i);
    ds (i) = A(i,11)-s0 (i);
dqC (i)= A(i,5)-qC0 (i);
dqO (i)=A(i,6)-qO0 (i);
dqG (i)=A(i,7)-qG0 (i);
dqN (i)=A(i,8)-qN0 (i);
dqH (i)=A(i,9)-qH0 (i);
dqR (i)=A(i,10)-qR0 (i);
end;
%Calculation of Variable dkX
for i=(1:35)
dkC (i) =(CO2C(i)./PEC(i)-k(i))*dqC(i);
dkO (i) =(CO2O(i)./PEO(i)-k(i))*dqO(i);
dkG (i) =(CO2G (i)./PEG(i)-k(i))*dqG(i);
```



```
22.05.08 19:43  C:\Documents and Set...\Effektgleichungen_china_sectoral_elec.m   4 of 4

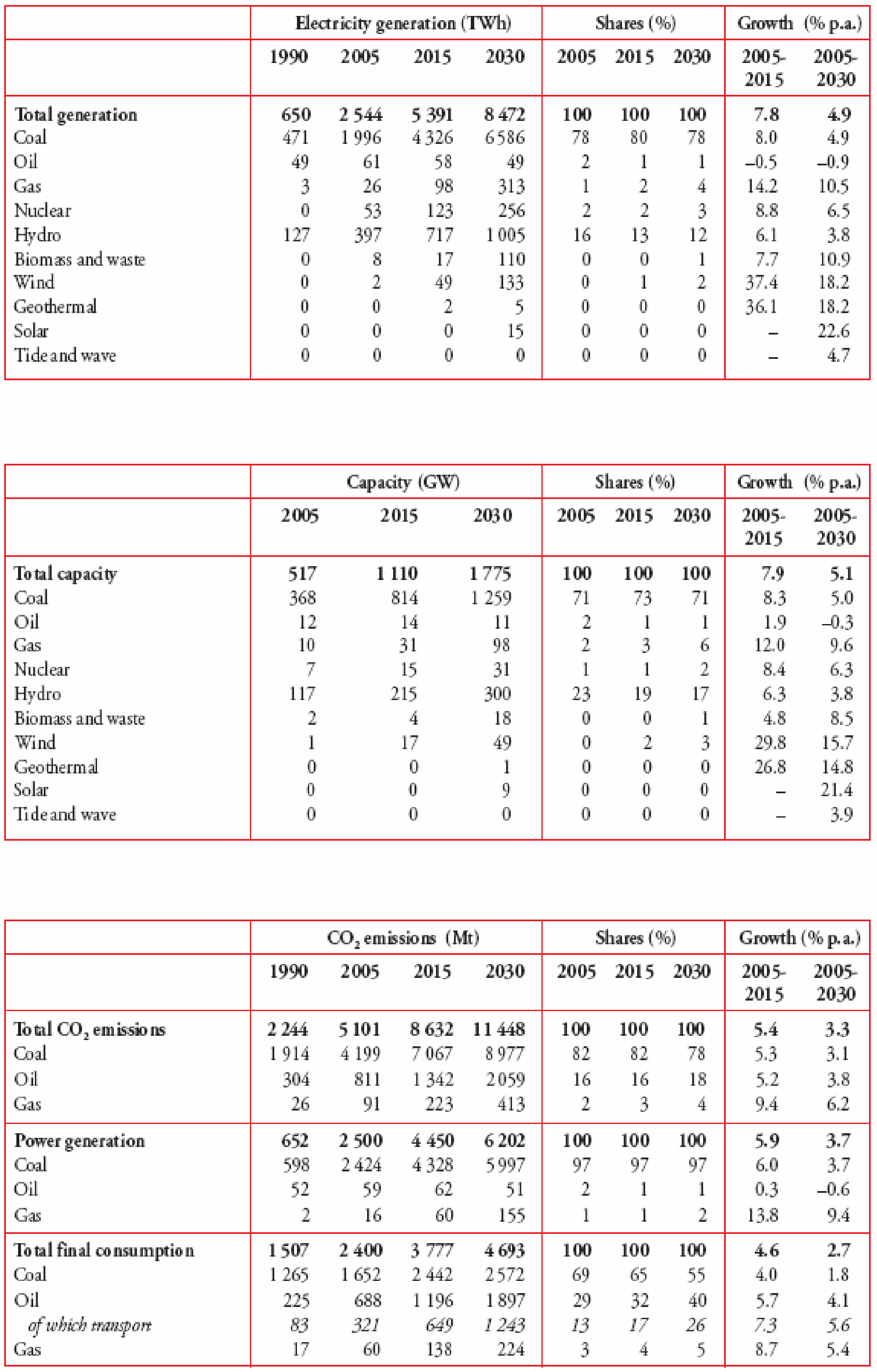
for i=(1:22)
    dkN (i) = 0;
end;
for i=(23:35)
dkN (i) =(CO2N (i)./PEN(i)-k(i))*dqN(i);
end;
dkH (i) =(CO2H(i)./PEH(i)-k(i))*dqH(i);
dkR (i) =(CO2R(i)./PER(i)-k(i))*dqR(i);
end;
%Effektgleichungen
Pf=dp.*a0.*e0.*k0.*s0+(1/2).*dp.*(da.*e0.*k0.*s0+a0.*de.*k0.*s0+a0.*e0.*dk.*s0+a0.*e0.↙
*k0.*ds)+(1/3).*dp.*(da.*de.*k0.*s0+da.*e0.*dk.*s0+da.*e0.*k0.*ds+a0.*de.*dk.*s0+a0.↙
*de.*k0.*ds+a0.*e0.*dk.*ds)+(1/4).*dp.*(da.*de.*dk.*s0+a0.*de.*dk.*ds+da.*e0.*dk.↙
*ds+da.*de.*k0.*ds)+(1/5).*dp.*da.*dk.*de.*ds;
Af=da.*p0.*e0.*k0.*s0+(1/2).*da.*(dp.*e0.*k0.*s0+p0.*de.*k0.*s0+p0.*e0.*dk.*s0+p0.*e0.↙
*k0.*ds)+(1/3).*da.*(dp.*de.*k0.*s0+dp.*e0.*dk.*s0+dp.*e0.*k0.*ds+p0.*de.*dk.*s0+p0.↙
*de.*k0.*ds+p0.*e0.*dk.*ds)+(1/4).*da.*(dp.*de.*dk.*s0+p0.*de.*dk.*ds+dp.*e0.*dk.↙
*ds+dp.*de.*k0.*ds)+(1/5).*dp.*da.*dk.*de.*ds;
Ef=de.*a0.*p0.*k0.*s0+(1/2).*de.*(da.*p0.*k0.*s0+a0.*dp.*k0.*s0+a0.*p0.*dk.*s0+a0.*p0.↙
*k0.*ds)+(1/3).*de.*(da.*dp.*k0.*s0+da.*p0.*dk.*s0+da.*p0.*k0.*ds+a0.*dp.*dk.*s0+a0.↙
*dp.*k0.*ds+a0.*p0.*dk.*ds)+(1/4).*de.*(da.*dp.*dk.*s0+a0.*dp.*dk.*ds+da.*p0.*dk.↙
*ds+da.*dp.*k0.*ds)+(1/5).*dp.*da.*dk.*de.*ds;
Kf=dk.*a0.*e0.*p0.*s0+(1/2).*dk.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.*s0+a0.*e0.↙
*p0.*ds)+(1/3).*dk.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.*dp.*s0+a0.↙
*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dk.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.*e0.*dp.↙
*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dk.*de.*ds;
Sf=ds.*a0.*e0.*k0.*p0+(1/2).*ds.*(da.*e0.*k0.*p0+a0.*de.*k0.*p0+a0.*e0.*dk.*p0+a0.*e0.↙
*k0.*dp)+(1/3).*ds.*(da.*de.*k0.*p0+da.*e0.*dk.*p0+da.*e0.*k0.*dp+a0.*de.*dk.*p0+a0.↙
*de.*k0.*dp+a0.*e0.*dk.*dp)+(1/4).*ds.*(da.*de.*dk.*p0+a0.*de.*dk.*dp+da.*e0.*dk.↙
*dp+da.*de.*k0.*dp)+(1/5).*dp.*da.*dk.*de.*ds;
    KCf=dkC.*a0.*e0.*p0.*s0+(1/2).*dkC.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkC.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkC.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkC.*de.*ds;
    KOf=dkO.*a0.*e0.*p0.*s0+(1/2).*dkO.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkO.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkO.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkO.*de.*ds;
    KGf=dkG.*a0.*e0.*p0.*s0+(1/2).*dkG.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkG.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkG.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkG.*de.*ds;
    KNf=dkN.*a0.*e0.*p0.*s0+(1/2).*dkN.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkN.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkN.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkN.*de.*ds;
    KHf=dkH.*a0.*e0.*p0.*s0+(1/2).*dkH.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkH.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkH.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkH.*de.*ds;
    KRf=dkR.*a0.*e0.*p0.*s0+(1/2).*dkR.*(da.*e0.*p0.*s0+a0.*de.*p0.*s0+a0.*e0.*dp.↙
*s0+a0.*e0.*p0.*ds)+(1/3).*dkR.*(da.*de.*p0.*s0+da.*e0.*dp.*s0+da.*e0.*p0.*ds+a0.*de.↙
*dp.*s0+a0.*de.*p0.*ds+a0.*e0.*dp.*ds)+(1/4).*dkR.*(da.*de.*dp.*s0+a0.*de.*dp.*ds+da.↙
*e0.*dp.*ds+da.*de.*p0.*ds)+(1/5).*dp.*da.*dkR.*de.*ds;
```

F. IEA World Energy Outlook Data Assumptions

	2005	2010	2015	2020	2025	2030
Population						
All Scenarios	1311443600	1351261869	1392289107	1413299126	1434626192	1456275089
GDP [2000 US $]						
Reference, Alternative Policy	2.0979E+12	3.0399E+12	4.4049E+12	5.5951E+12	7.107E+12	9.0274E+12
High Growth	2.0979E+12	3.0117E+12	4.3237E+12	6.2073E+12	8.9114E+12	1.2793E+13
Primary Energy Demand Reference Scenario [Mtoe]						
Coal	1094	1430	1869	2031	2207	2399
Oil	327	421	543	620	708	808
Gas	42	68	109	133	163	199
Nuclear	14	21	32	41	52	67
Hydro	34	46	62	69	77	86
Biomass + Waste	227	226	225	226	226	227
Other renewables	3	6	12	17	24	33
Total	1741	2218	2852	3137	3457	3819
Primary Energy Demand Alternative Policy Scenario [Mtoe]						
Coal	1094	1381	1743	1775	1808	1842
Oil	327	412	518	560	604	653
Gas	42	73	126	153	185	225
Nuclear	14	25	44	61	86	120
Hydro	34	50	75	85	96	109
Biomass + Waste	227	225	223	233	244	255
Other renewables	3	6	14	22	34	52
Total	1741	2172	2743	2889	3057	3256
Primary Energy Demand High Growth Scenario [Mtoe]						
Coal	1094	1493	2037	2294	2584	2910
Oil	327	452	626	743	883	1048
Gas	42	72	125	163	212	276
Nuclear	14	22	34	46	61	82
Hydro	34	47	65	75	87	100
Biomass + Waste	227	231	235	234	232	231
Other renewables	3	6	13	19	29	43
Total	1741	2323	3135	3574	1504	4690

Table 8-3: Data Input for Kaya Decomposition of IEA Scenarios using growth rates outlined in IEA (2007b)

	Energy demand (Mtoe)				Shares (%)			Growth (% p.a.)	
	1990	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total primary energy demand	**874**	**1 742**	**2 851**	**3 819**	**100**	**100**	**100**	**5.1**	**3.2**
Coal	534	1 094	1 869	2 399	63	66	63	5.5	3.2
Oil	116	327	543	808	19	19	21	5.2	3.7
Gas	13	42	109	199	2	4	5	10.0	6.4
Nuclear	0	14	32	67	1	1	2	8.8	6.5
Hydro	11	34	62	86	2	2	2	6.1	3.8
Biomass and waste	200	227	225	227	13	8	6	–0.1	0.0
Other renewables	0	3	12	33	0	0	1	14.4	9.9
Power generation	**181**	**682**	**1 222**	**1 774**	**100**	**100**	**100**	**6.0**	**3.9**
Coal	153	605	1 073	1 487	89	88	84	5.9	3.7
Oil	16	18	18	15	3	1	1	–0.0	–0.8
Gas	1	7	25	64	1	2	4	13.8	9.4
Nuclear	0	14	32	67	2	3	4	8.8	6.5
Hydro	11	34	62	86	5	5	5	6.1	3.8
Biomass and waste	0	3	6	38	0	1	2	6.7	10.2
Other renewables	0	0	6	17	0	0	1	36.5	18.4
Other energy sector	**94**	**204**	**375**	**513**	**100**	**100**	**100**	**6.3**	**3.8**
of which electricity	*12*	*43*	*85*	*118*	*21*	*23*	*23*	*6.9*	*4.1*
Total final consumption	**670**	**1 129**	**1 808**	**2 375**	**100**	**100**	**100**	**4.8**	**3.0**
Coal	315	373	573	605	33	32	25	4.4	1.9
Oil	88	278	480	734	25	27	31	5.6	4.0
Gas	10	32	79	127	3	4	5	9.3	5.6
Electricity	43	175	379	610	15	21	26	8.0	5.1
Heat	13	43	73	93	4	4	4	5.3	3.1
Biomass and waste	200	224	218	189	20	12	8	–0.2	–0.7
Other renewables	0	3	6	16	0	0	1	8.1	7.1
Industry	**242**	**478**	**833**	**1 046**	**100**	**100**	**100**	**5.7**	**3.2**
Coal	177	280	443	473	59	53	45	4.7	2.1
Oil	21	39	52	57	8	6	5	3.1	1.5
Gas	3	12	30	48	3	4	5	9.3	5.5
Electricity	30	117	262	395	24	32	38	8.5	5.0
Heat	11	29	44	51	6	5	5	4.2	2.2
Biomass and waste	0	1	2	22	0	0	2	5.5	13.6
Other renewables	0	0	0	0	0	0	0	–	–
Transport	**41**	**121**	**240**	**460**	**100**	**100**	**100**	**7.0**	**5.5**
Oil	30	115	231	442	95	96	96	7.2	5.5
Biofuels	0	1	2	8	0	1	2	11.6	11.7
Other fuels	10	6	7	9	5	3	2	2.3	1.9
Residential, services and agriculture	**333**	**421**	**540**	**642**	**100**	**100**	**100**	**2.5**	**1.7**
Coal	99	64	70	63	15	13	10	1.0	–0.0
Oil	18	62	95	123	15	18	19	4.4	2.8
Gas	2	13	32	59	3	6	9	9.7	6.3
Electricity	11	45	94	182	11	17	28	7.6	5.7
Heat	2	13	27	41	3	5	6	7.5	4.6
Biomass and waste	200	222	215	159	53	40	25	–0.3	–1.3
Other renewables	0	3	6	16	1	1	2	8.2	7.1
Non–energy use	**55**	**109**	**196**	**227**	**100**	**100**	**100**	**6.0**	**3.0**



	Electricity generation (TWh)				Shares (%)			Growth (% p.a.)	
	1990	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total generation	**650**	**2 544**	**5 391**	**8 472**	**100**	**100**	**100**	**7.8**	**4.9**
Coal	471	1 996	4 326	6 586	78	80	78	8.0	4.9
Oil	49	61	58	49	2	1	1	–0.5	–0.9
Gas	3	26	98	313	1	2	4	14.2	10.5
Nuclear	0	53	123	256	2	2	3	8.8	6.5
Hydro	127	397	717	1 005	16	13	12	6.1	3.8
Biomass and waste	0	8	17	110	0	0	1	7.7	10.9
Wind	0	2	49	133	0	1	2	37.4	18.2
Geothermal	0	0	2	5	0	0	0	36.1	18.2
Solar	0	0	0	15	0	0	0	–	22.6
Tide and wave	0	0	0	0	0	0	0	–	4.7

	Capacity (GW)			Shares (%)			Growth (% p.a.)	
	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total capacity	**517**	**1 110**	**1 775**	**100**	**100**	**100**	**7.9**	**5.1**
Coal	368	814	1 259	71	73	71	8.3	5.0
Oil	12	14	11	2	1	1	1.9	–0.3
Gas	10	31	98	2	3	6	12.0	9.6
Nuclear	7	15	31	1	1	2	8.4	6.3
Hydro	117	215	300	23	19	17	6.3	3.8
Biomass and waste	2	4	18	0	0	1	4.8	8.5
Wind	1	17	49	0	2	3	29.8	15.7
Geothermal	0	0	1	0	0	0	26.8	14.8
Solar	0	0	9	0	0	0	–	21.4
Tide and wave	0	0	0	0	0	0	–	3.9

	CO_2 emissions (Mt)				Shares (%)			Growth (% p.a.)	
	1990	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total CO_2 emissions	**2 244**	**5 101**	**8 632**	**11 448**	**100**	**100**	**100**	**5.4**	**3.3**
Coal	1 914	4 199	7 067	8 977	82	82	78	5.3	3.1
Oil	304	811	1 342	2 059	16	16	18	5.2	3.8
Gas	26	91	223	413	2	3	4	9.4	6.2
Power generation	**652**	**2 500**	**4 450**	**6 202**	**100**	**100**	**100**	**5.9**	**3.7**
Coal	598	2 424	4 328	5 997	97	97	97	6.0	3.7
Oil	52	59	62	51	2	1	1	0.3	–0.6
Gas	2	16	60	155	1	1	2	13.8	9.4
Total final consumption	**1 507**	**2 400**	**3 777**	**4 693**	**100**	**100**	**100**	**4.6**	**2.7**
Coal	1 265	1 652	2 442	2 572	69	65	55	4.0	1.8
Oil	225	688	1 196	1 897	29	32	40	5.7	4.1
of which transport	*83*	*321*	*649*	*1 243*	*13*	*17*	*26*	*7.3*	*5.6*
Gas	17	60	138	224	3	4	5	8.7	5.4

Table 8-4: IEA Reference Scenario Assumptions

Source: IEA, 2007b: pp. 596

G. Top Ten Developing Country GHG Emitters in Selected Sectors

Electricity	Iron & Steel	Chemical & Petrochemical	Aluminum	Cement & Limestone	Paper, Pulp & Printing
China	China	China	China	China	China
India	India	India	Brazil	India	Brazil
South Africa	Brazil	U.A.E.	India	South Korea	South Korea
South Korea	South Africa	South Africa	Venezuela	Brazil	India
Mexico	Mexico	South Korea	Chile	Indonesia	Indonesia
Iran	South Korea	Brazil	Argentina	Mexico	Mexico
Saudi Arabia	Venezuela	Mexico	Bahrain	Thailand	Colombia
Kazakhstan	Indonesia	Iran	Kazakhstan	Pakistan	Thailand
Indonesia	Kazakhstan	Indonesia	South Korea	Egypt	Argentina
Thailand	Iran	Venezuela	Macedonia	Iran	Chile

Table 8-5: Top Ten Developing Country Emitters in the Electricity Sector and Major Industry Sectors in 2000.
Note: Solid lines indicate 80% of the overall sectoral emissions, while dotted lines indicate 90% of the overall sectoral emissions. In the electricity sector, countries outlined account for 80% of the emissions.

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I. Declaration of Honor

I declare that the work in this assignment is completely my own work. No part of this assignment is taken from other people's work without giving them credit. All references have been clearly cited.

Potsdam, June 10, 2008