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Projections of carbon mitigation potential for electricity generation technologies in China and Austria and impact on national carbon trading

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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List of Abbreviations

AR4	The IPCC's 4th Assessment Report
EC	European Commission
EG	Electricity Generation
EU	European Union
GAINS	GHG-Air pollution Interaction and Synergies
GHG	Greenhouse gases
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized Cost of Electricity
LEAP	Long range Energy Alternatives Planning System
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaics
UNEP	United Nationals Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

Abstract

Electricity & Heat production is one of the main GHG emitting human activities worldwide. Internationally employed carbon mitigation models frequently provide mitigation potential and costs on aggregated sector and regional levels. However, analysts interested in the mitigation potential and costs of particular electricity generation technologies in particular countries require more detailed information to understand specific mitigation options. This paper builds a transparent model to assess the mitigation potential and associated costs/benefits of specific electricity supply technologies within the framework of an assumed international carbon trading regime for China and Austria in 2020 and 2030. Findings indicate that in Austria hydro power shows the greatest mitigation potential; however its costs are subject to significant uncertainty and therefore may require a relatively high carbon price to be offset. In China, hydro and nuclear power show the greatest mitigation potential, while already appearing to be competitive or even profitable at a carbon price of around 20EUR2008/tCO2eq.

Keywords: Mitigation Potential; Mitigation Cost; Electricity Generation Technologies; China; Austria; Projections;

1 Introduction

The mitigation potential of carbon emissions is a main area of interest for climate research today. However, results of carbon mitigation scenarios from different international organizations are typically presented at aggregated sector levels (such as industry, transport or energy) or aggregated geographic levels (such as global, OECD or Annex I countries), without further disaggregation. In their effort to compare greenhouse gas mitigation potentials from different approaches and models, (Hoogwijk et al. 2010) hence conclude that, “analysts interested in particular technologies [...] require more detailed information to understand specific mitigation options in relation to business-as-usual trends. Unfortunately, none of the modelling efforts provide detailed results per sub-sectors and per region.”

This thesis aims to overcome such shortages by building and employing a bottom-up model, providing detailed results per technology and country. This will be done by providing projections of carbon mitigation potential and national carbon trading impacts for electricity generation technologies in China and Austria. In doing so, this paper will provide detailed results on two levels:

- Sub-Sector level: The mitigation potential of specific electricity generation technologies (i.e. nuclear, wind, solar, hydro, bioenergy) will be assessed;
- Geographic level: The mitigation potential for these technologies will be shown for specific countries (China and Austria).

The carbon mitigation potential over the next 20 years for the implementation of particular electricity generating technologies in particular countries will be assessed. Furthermore, the economic impact of such mitigation measures on carbon trading will be shown within the framework of an assumed international carbon regime.

2 State of the Art Review

2.1 Climate Change and its Causes

2.1.1 A popular and polarizing science

Climate change has been a strongly researched and discussed science ever since the 1970s, when it slowly but steadily started to gain presence in scientific papers (even though early literature dates back to the 19th century). In order to illustrate the popularity of this science over time, the following graph plots the number of published journal articles which contain the phrase "climate change" in their title, abstract or keywords between 1970 and today, based on a ScienceDirect search[1]. Even though the ScienceDirect database is not a complete archive of all published journal articles in the discipline, the trend in the number of publications depicts a clear overall growth rate. Based on the number of published articles on ScienceDirect, climate change research today thus appears to be a more popular academic field than ever.

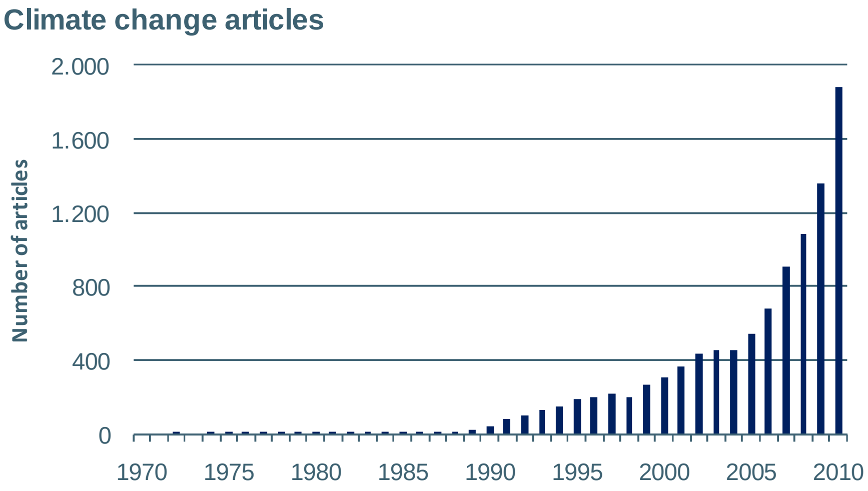

Figure 1: Number of published journal articles containing the phrase "climate change" in their title, abstract or keywords (Source: ScienceDirect)

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[1] Operated by the publisher Elsevier, ScienceDirect is one of the main online collections of published scientific research in the world and contains nearly 10 million articles. It is ranked as one of the top 8 journal databases used for research by the Vienna University of Techology (Vienna University of Technology 2011).

However, the origins of climate change research date back much further. Already in 1896, Svante Arrhenius, a Swedish scientist, calculated that a doubling of atmospheric CO2 concentrations would raise global temperatures by 5 – 6 ℃, though he figured accomplishing this would take 3.000 years of fossil fuel burning (Peterson et al. 2008, p.1328). In 1959, Science News (quoting Swedish scientist Bert Bolin) forecast a 25% increase in atmospheric CO2 in the years from 1850 to 2000, with a consequent warming trend (Science News 1959).

Yet climate change polarizes. According to Peterson et al. (2008, p. 1333), in the 1970s the majority of scientific papers assessing climate change predicted future warming, while a small amount of such papers inclined towards future cooling. Nonetheless, even though “the possibility of anthropogenic warming dominated the peer-reviewed literature” (Peterson et al. 2008, p.1325), the 1970s gave rise to a global cooling scare in public discussion. Numerous popular newspaper articles (e.g. the 1975 Newsweek article “The Cooling World”) of the era portrayed the global cooling scenario (Peterson et al. 2008, p.1330). Alas, scientific research and public discussion couldn’t have differed more.

In a move to provide the governments of the world with a clear scientific view of what is happening to the world's climate, the WMO and UNEP created the Intergovernmental Panel on Climate Change in 1988. An authoritative source by mandate, the IPCC has come to define the “standard” view of climate change. Without doubt, as the climate dispute continues to the present day, its authority has also been questioned by individual scientists. Nonetheless, a joint statement issued in 2001 by a group of sixteen national academies of science from all parts of the world recognises the IPCC as “the world’s most reliable source of information on climate change and its causes” (Royal Society Great Britain 2001, p.1). The IPCC’s assessments may thus be seen as common scientific consensus and as such provide the basic scientific grounds for this thesis with respect to climate change and mitigation.

2.1.2 Observed changes in climate and their effects

The IPCC's 4th Assessment Report published in 2007 concludes more than 100 years after Arrhenius' first global warming assessments that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level". More specifically, it finds that "average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years" (IPCC 2007b, p.30). Concerning the effects[1] of this development, the 4th Assessment Report concludes that "observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases" (IPCC 2007b, p.31).

2.1.3 Causes of the observed changes

Different factors have been identified to drive climate change (IPCC 2007b, p.37): Atmospheric concentrations of GHGs and aerosols, land cover and solar radiation. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. This in turn results in positive or negative changes in the energy balance of the climate system. These changes are expressed as *radiative forcing*. Radiative forcing is used to compare the climate drivers' warming or cooling influences on global climate. Figure 2 gives a comprehensive overview of the radiative forcing of the different climate change drivers.

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[1] The AR4 gives more detailed information on observed changes and effects. The AR4 Synthesis Report on www.ipcc.ch provides an excellent overview of the AR4's main findings.

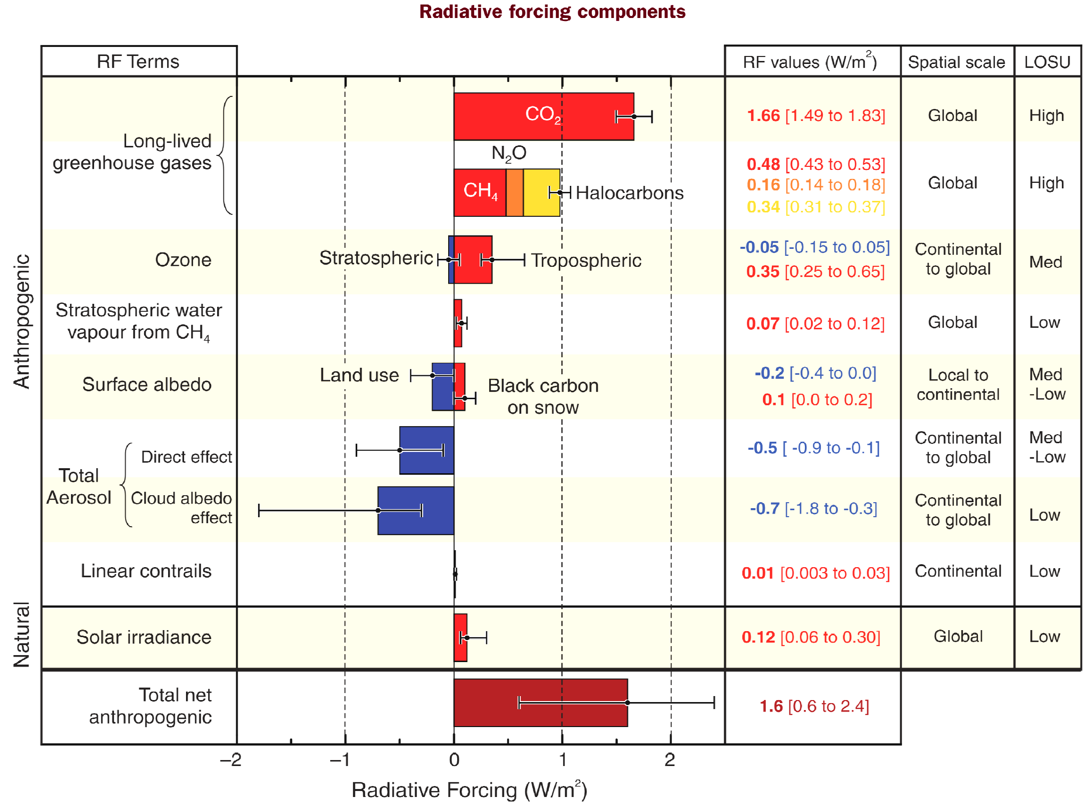

Figure 2: Global mean radiative forcing (RF) in 2005 since 1750 (best estimates and 5 to 95% uncertainty ranges) for CO2, CH4, N2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). When two numbers are present for the value uncertainty, the distribution is non-normal. Source: (IPCC 2007b, p.39; IPCC 2007a, 2, p.204)

Alas, the AR4 concludes that “there is very high confidence that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m²” (IPCC 2007b, p.37). Particularly relevant for this paper, CO2 today has a high level of scientific understanding and the highest anthropogenic radiative forcing of 1.66 (±0.17) W/m². CO2 was thus the single most significant anthropogenic radiative forcing driver in the period from 1750 to 2005: Global atmospheric concentration of CO2 increased from a pre-industrial value of about 280ppm to 379ppm in 2005 (Figure 3). Likewise, CO2 is today the single most important GHG in terms of current emissions, accounting for over 75% of annual emissions in terms of CO2eq (WRI 2011).

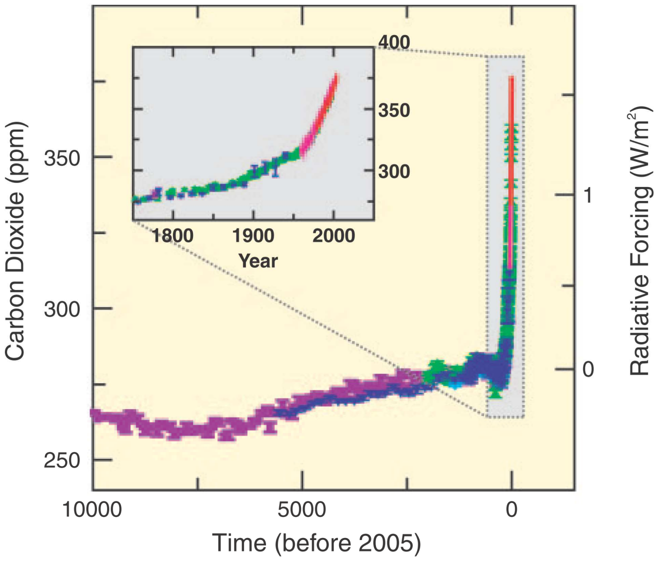

Figure 3: Atmospheric concentrations of CO2 over the last 10,000 years (large panels) and since 1750 (inset panels). The corresponding radiative forcing relative to 1750 is shown on the right hand axes of the large panels. Source: (IPCC 2007, p.38)

With respect to the *sources* of this rapid CO2 concentration increase, the AR4 reasons that the increases in atmospheric CO2 since the industrial revolution are mainly due to CO2 emissions from the combustion of fossil fuels, gas flaring and cement production (other sources include emissions due to land use changes such as deforestation and biomass burning). In fact, the IPCC argues that the combustion of “fossil fuel and cement production have likely contributed about three-quarters of the current [CO2] RF” (IPCC 2007a, chap.2, p.138-140). Indeed current assessments of CO2 emissions in the year 2005 show that the fossil fuel combusting energy sector accounts for about 78% of total CO2 emissions (including land use change & international bunkers[1]), as shown in Table 1.

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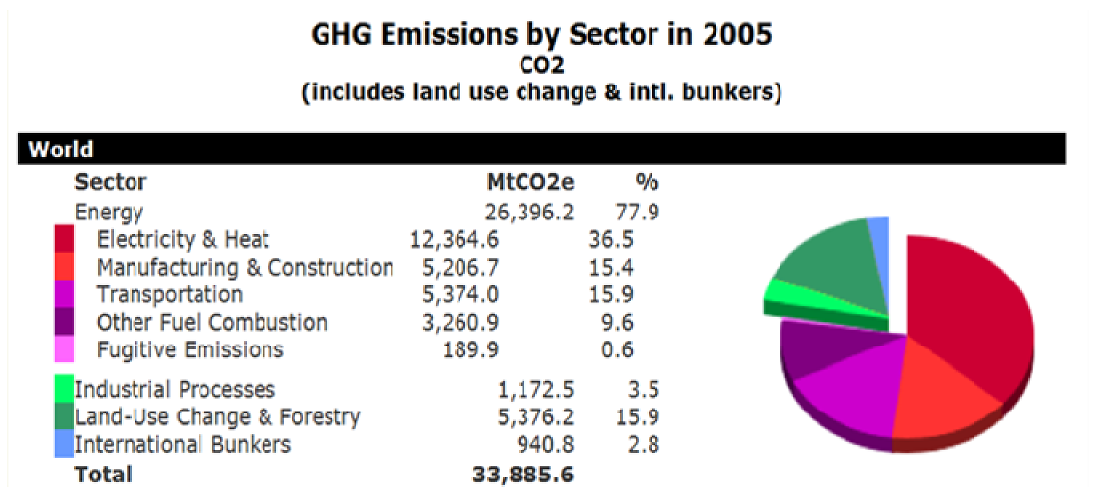
[1] International bunker fuel emissions are emissions from international aviation and maritime transport (UNFCCC 2010)



GHG Emissions by Sector in 2005
CO2
(includes land use change & intl. bunkers)

World

	Sector	**MtCO2e**	**%**
	Energy	26,396.2	77.9
🟥	Electricity & Heat	12,364.6	36.5
🟥	Manufacturing & Construction	5,206.7	15.4
🟪	Transportation	5,374.0	15.9
🟪	Other Fuel Combustion	3,260.9	9.6
🟪	Fugitive Emissions	189.9	0.6
🟩	Industrial Processes	1,172.5	3.5
🟩	Land-Use Change & Forestry	5,376.2	15.9
🟦	International Bunkers	940.8	2.8
	Total	**33,885.6**	

Table 1: Global CO2 emissions by sector in 2005 (WRI 2011)

In fact, the *Electricity & Heat sector*[1] is the main category in terms of global anthropogenic CO2 emissions, being accountable for more than 36% of total anthropogenic CO2 emissions in 2005. In order to reduce global CO2 emissions, the electricity & heat sector is thus key when it comes to developing mitigation strategies.

Key messages:

- Global warming affects many natural systems worldwide;
- CO2 is the single most important anthropogenic global warming driver in terms of past radiative forcing and current emissions (accountable for about 75% of annual GHG emissions in terms of CO2eq);
- Electricity & Heat production is the main CO2 emitting human activity, (accountable for about 36% of annual anthropogenic CO2 emissions).

2.2 Carbon Mitigation as a Response to Climate Change

In dealing with climate change, there are two basic possibilities to proceed: *Adaptation* and *Mitigation.* Adaptation seeks to reduce the vulnerability of natural and human systems to global warming. Mitigation, by contrast, seeks to reduce the sources or enhance the sinks of greenhouse gases (UNFCCC

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[1] For a definition of the “Electricity & Heat” sector, see Annex.

2011). Both are required, as the AR4 finds: “There is high confidence that neither adaptation nor mitigation alone can avoid all climate change impacts; however, they can complement each other and together can significantly reduce the risks of climate change” (IPCC 2007c, p.19).

At the time of the Third Assessment Report (AR3) in 2001, information was mainly available to derive climatic changes and impacts from socio-economic information and emissions. However, the level of scientific understanding has increased considerably by the time of the AR4 in 2007, so that it is now also possible to evaluate possible development pathways and global emissions constraints that would reduce the risk of future global warming impacts (IPCC 2007b, p.26). Mitigation, providing the basis for this thesis, thus can reduce climate change and associated adaptation needs. In fact, the AR4 concludes that “both bottom-up and top-down studies indicate that there is high agreement and much evidence of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels” (IPCC 2007b, p.58).

2.2.1 Analytical Approaches to projecting GHG mitigation potential

Mitigation Potential

“Mitigation Potential” is used to express the amount of GHG reduction that can be achieved by a mitigation option over a given period, compared with a baseline or reference case. The mitigation potential is usually expressed as million tonnes carbon- or CO2-equivalent emissions avoided compared with baseline emissions (IPCC 2007b, chap.Technical Summary, p. 35). The AR4 lists different ways of defining the potential for CO2 mitigation, based on (IPCC 2007b, p.7f) and (IPCC 2007b, chap.2, p.140):

- **Market Potential** is the mitigation potential based on private costs and private discount rates, which might be expected to occur under forecast market conditions, including policies and measures currently in place;

- **Economic Potential** is the potential which takes into account social costs and benefits and social discount rates, assuming that market efficiency is improved by policies and measures;
- **Technical Potential** is the potential which can be achieved by implementing a technology or practice that has already been demonstrated. There is no specific reference to cost, but to practical constraints, although in some cases implicit economic considerations are taken into account.

Within the framework of this thesis, the technical mitigation potential of different electricity generation technologies will be shown, based on exogenic projections of electricity generation (which in turn implicitly consider economic influences).

Projecting Mitigation Potential

There are different types of approaches to estimate mitigation potential. The IPCC defines two broad classes of approaches (IPCC 2007b, chap.Summary for Policy Makers, p. 8):

- **Bottom-up studies** are based on the assessment of different mitigation options. They are typically sectoral studies and assess specific technologies or policies for specific countries or regions.
- **Top-down studies** generally focus on the macro-economy and assess the economy-wide potential of mitigation options. They apply globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

The bottom-up approach is generally based on technological and sectoral data and mostly physical indicators. The top-down approach, on the other hand, describes processes within the economy as a whole, including interactions on the basis of historical behaviour (Hoogwijk et al. 2010, p.3044).

Such models are needed in order to obtain estimations of GHG mitigation potential projected in the future. There are a number of different models (e.g. LEAP, GAINS), and models as well as model results have been compared with each other. The writings of (Amann et al. 2009), (van Vuuren et al. 2009) and (IEA 2009) are recommended to get an overview of the topic matter.

The model employed within the framework of this thesis embraces a *bottom-up approach*. A similar approach has been taken in (Sims et al. 2003) and (Cai et al. 2010).

2.2.2 Mitigation Potential in the Electricity Supply Sector

A scenario review in the IPCC's Special Report on Renewable Energy Sources (IPCC 2011, Summary for Policy Makers, p.20) finds that renewable energy has a large potential to mitigate GHG emissions. Between 2010 and 2050 four scenarios span a range of global CO2 savings from about 220 to 560 Gt CO2, compared to about 1530 GT cumulative fossil and industrial CO2 emissions in the IEA World Energy Outlook 2009 reference scenario during the same period.

With regards to the variety of mitigation options in the electricity generation sector, it is important to stress that "no single technological option has sufficient mitigation potential to meet the economic potential of the electricity-generation sector" (IPCC 2007c, chap.4, p.303). Hence a mix of different mitigation options will be required to meet the economic mitigation potential of the electricity supply sector.

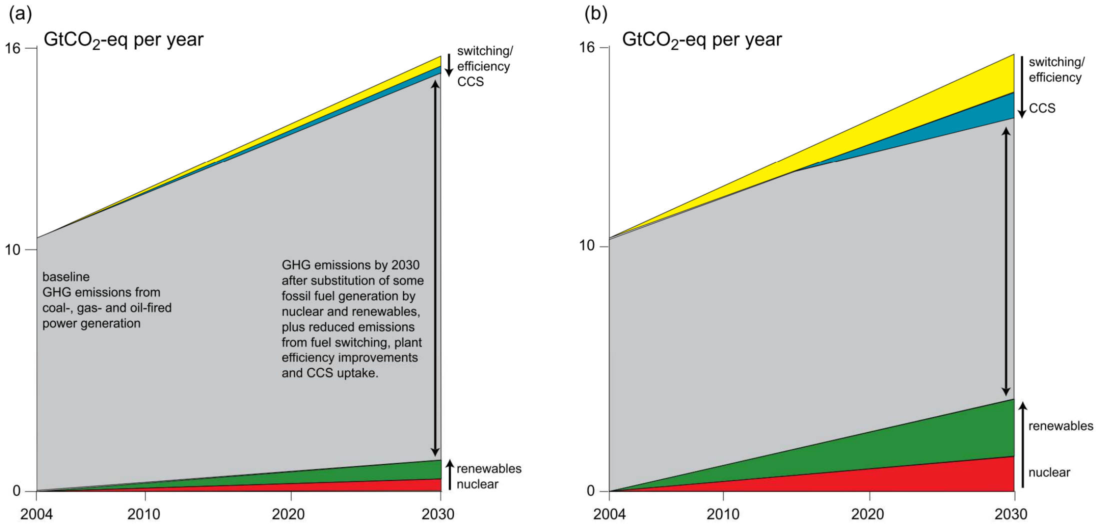


Figure 4: Indicative low (a) and high (b) range estimates of the mitigation potential in the electricity supply sector (IPCC 2007c, chap.4, p.304)

Figure 4 shows the low (a) and high (b) range estimates of the mitigation potential in the global electricity sector, based on substituting existing fossil-fuel thermal power plants with nuclear and renewable energy power generation. It also shows the energy-efficiency improvements that can be made in power-plants and power-transmission, including switching from coal to gas and the uptake of CCS. Figure 4b illustrates that significant reductions in emissions from the electricity-supply sector are technically and economically feasible using currently available as well as close to market technology (IPCC 2007c, chap.4, p.304).

2.2.3 The Government’s Toolkit: Tradeable Emission Permits

Governments have a variety of policy options at their disposal to purse the reduction of GHG emissions. Most energy supply related climate policies come from three policy groups (IPCC 2007c, chap.4, p.305):

- Economic Instruments (e.g. subsidies, taxes, Tradeable emission permits);
- Regulatory Instruments (e.g. mandated targets, minimum performance standards, vehicle-exhaust emission controls);

- Policy Processes (e.g. voluntary agreements and consultation, dissemination of information, strategic planning).

The main choice for governments is thus between direct regulation (i.e. setting standards with which polluters must comply), and more indirect tools that use economic incentives/disincentive to change polluters’ behaviour (i.e. tradeable emission permits). Economists tend to agree that indirect economic measures are likely to be more efficient, because polluters are assumed to have better knowledge of least-cost pollution abatement and mitigation methods than do government regulators (Pearson 2000, p.148).

In tradeable emission permit schemes, the regulatory authority sets a maximum quantity of emissions to be discharged over some fixed time period. It then divides that quantity into permits, and auctions or otherwise distributes the permits to polluters. The polluters in turn are free to buy additional permits or sell their excess. Essentially, the regulatory authority has created limited property rights, providing the foundation for a private market of tradeable emission permits (Pearson 2000, p.155). A basic assumption of the model in this thesis is that the individual countries analysed (China and Austria) are both parties to a fully functioning international emission permits trading scheme, thus being free to buy and sell carbon permits on an international market.

2.3 Life-cycle GHG emissions of electricity generation technologies

Producing electricity emits greenhouse gases and thus contributes to global climate change (Weisser 2007, p.1543). Knowing the life-cycle GHG emissions is in this respect paramount when assessing the carbon mitigation potential for different electricity generating technologies. The overview of life-cycle GHG emissions that follows throughout this chapter is based on Daniel Weisser’s research in “A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies” (Weisser 2007).

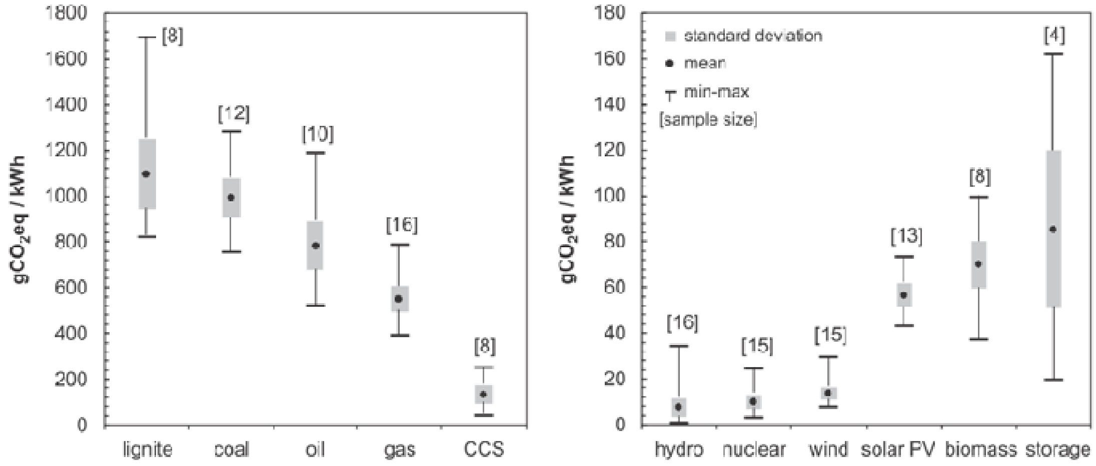


Figure 5: Life-cycle GHG emissions for selected power plants (Weisser 2007, p.1549)

Figure 5 illustrates the estimated life-cycle GHG emission from selected power plants. The graph shows the mean, the standard deviation and the minimum and maximum emissions reported for each technology as in (Weisser 2007). In the subsequent calculations, this paper's model uses the mean values and their standard deviations. The author of this paper has gratefully received the data from Daniel Weisser as illustrated in the above table. This data is a fundamental building block for the model developed in this thesis.

The generation of electricity is currently largely based on fossil fuels in many countries worldwide: Globally, in 2007 the share of fossil-fuelled electricity generation was close to 70%, with coal (about 40% of total electricity production) and gas (more than 15% of total electricity production) being the main sources for fossil-based electricity generation (IEA 2010b, p.114). For fossil fuel technologies, life-cylce GHG emissions largely originate from the operation of the power plant. While GHG emissions from downstream activities are often negligible, upstream emissions can be significant (Weisser 2007, p.1548). The following life-cycle emissions are based on the findings of (Weisser 2007):

In **coal-fired plants**, most of the life-cycle emissions are emitted during the operation of the power plant. Operating emissions range between 800 and

1000 gCO2eq/kWh, while cumulative emissions range between approximately 850 and 1250 gCO2eq/kWh. GHG emissions from construction, decommissioning and waste disposal are negligible. However, emissions from coal mining and transport can be significant. (Weisser 2007, p.1550)

In **oil-fired plants**, the largest part of life-cycle GHG emissions arises at the power plant, ranging between approximately 700 and 800 gCO2eq/kWh. Emissions from plant construction and decommissioning are negligible. On the other hand, emissions from upstream activities like exploration, extraction, refinery and transport are significant: 40 – 110 gCO2eq/kWh (Weisser 2007, p.1550). The IEA expects global electricity generation from oil to dwindle to almost zero by 2050 (IEA 2010b, p.113).

Natural **gas-fired power generation** exhibits higher efficiencies, lower capital costs, shorter construction times and lower CO2 emissions over coal-fired power generation. The availability and relative costs of coal and gas have largely determined technology choices (IEA 2010b, p.116). GHG emissions from gas-fired plants largely arise during operation of the plant and range between 360 and 575 gCO2eq/kWh. Emissions during construction and decommissioning are negligible, while fuel-cycle GHG emissions are significant, arising mainly from gas processing, venting wells, pipeline operation and system leakage in transportation. Upstream and downstream GHG emissions from gas-fired plants lie between 60 and 130 gCOeq/kWh. (Weisser 2007, p.1550)

Nuclear power has the capacity to provide large-scale electricity production with very low life-cycle CO2 emissions. Nuclear power is being used in 30 countries worldwide and provides about 14% of global electricity supply. The IEA considers that “nuclear power has the potential to play a very significant role in the decarbonisation of electricity generation in many countries”. (IEA 2010b, pp.134-135). The operating stage of nuclear power plants contributes only a small share to cumulative GHG emissions. The majority of GHG emissions arise at the upstream stages of the nuclear fuel cycle, with values ranging between approximately 1.5 and 20 gCO2eq/kWh. Cumulative emissions for the studies assessed in (Weisser 2007) lie between 2.8 and 24 gCO2eq/kWh. (Weisser 2007, pp.1551 - 1552)

Hydropower is globally the largest source of renewable electricity today. Hydro has a particular advantage in that it can adjust quickly and flexibly to sudden load changes and hydro reservoirs can serve as a means of power storage, enabling them to cover peak loads and sudden losses of power from other sources, i.e. variable technologies such as wind. Hydro is also cheap to operate and maintain (IEA 2010b, p.127). For hydro-power plants, most of the GHG emissions originate from the production and construction of the plant. The overall life-cycle GHG Emissions for the cases assessed in (Weisser 2007) range approximately between 1 and 34g CO2eq/kWh. In this respect it has to be added that life-cycle emissions from the different hydroelectric plants (i.e. pumped storage, run-of-river and reservoir) do vary significantly.

Wind power is globally the second-largest contributor to renewable electricity today. Wind power is subject to variability, with power output particularly varying with wind speed. According to the IEA, this variability will become increasingly significant when wind generation rises above approximately 10% of total electricity in the grid. A substantially higher share of wind power is expected to require additional system flexibility through quickly dispatchable generation, demand-side response, interconnection, and/or storage. (IEA 2010b, p.130) Most of the GHG emissions for wind turbines originate from turbine and plant production, varying between 72% and 90% of cumulative emissions. In general, life-cycle GHG emissions from wind turbines are very site-specific and sensitive to wind velocity. Cumulative emissions range approximately between 8 and 30 gCO2eq/kWh. (Weisser 2007, p.1552)

Biomass is a bioenergy feedstock, converted to electricity through conversion technologies such as combustion or gasification. Biomass can be used as an interesting source of electricity in parts of the world where supplies of residues e.g. from agriculture are abundant. (IEA 2010b, pp.127 - 128) The majority of biomass emissions originate at the fuel-cycle stage.

Emissions arising from the combustion of the biofuel are believed to be carbon neutral, because the CO2 released during combustion is absorbed during fuel growth. Life-cycle emissions vary greatly, depending particularly on combustion efficiency or type of feed. The range of life-cycle emissions for the plants studied in (Weisser 2007) lies between approximately 35 and 99 gCO2eq/kWh. (Weisser 2007, p.1553)

“Other renewables” is a group consisting of a number of different renewable technologies for the production of electricity, including solar, tidal or geothermal. Their share in the current and future (2020 resp. 2030) electricity mix in China and Austria is limited, as generation projections in Chapter 3.2.3 indicate.

2.4 The Electricity Supply Sector in China and Austria

Austria

As illustrated in Figure 6, the electricity generation sector in Austria is traditionally strongly influenced by hydropower, which by far makes up for the largest share of electricity production in Austria. What’s more, since the year 2000, HydroPower has not increased far beyond 40.000 GWh/yr while total electricity production has increased from around 60.000 GWh/yr in 2000 to almost 70.000 GWh/yr in 2009, indicating that hydro’s further growth potential may be limited. Additional capacity since 2000 primarily comes from thermal power, and recently to a smaller extent from other renewables (wind, PV and geothermal).

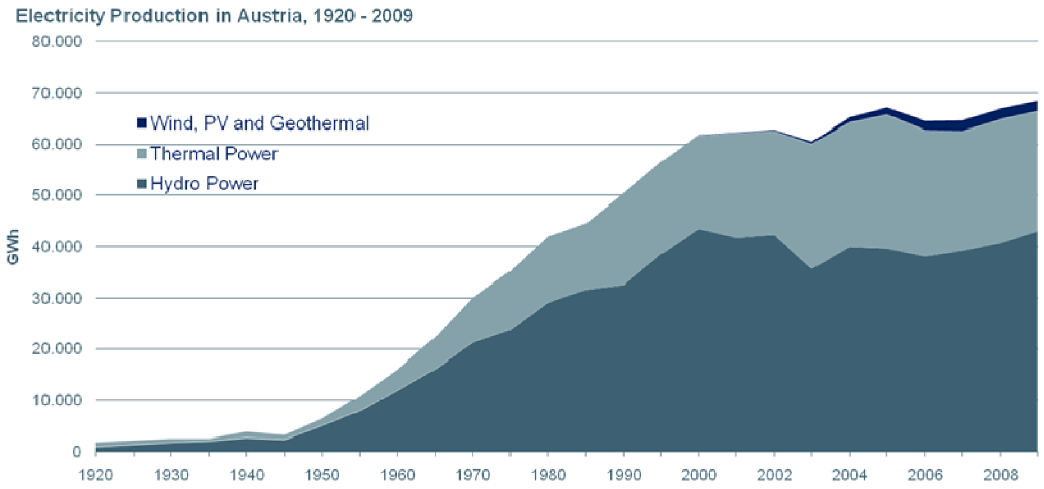
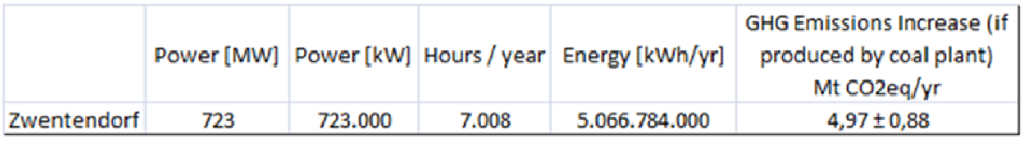


Figure 6: Electricity Production in Austria 1920 – 2009; based on data from (E-control 2011)

Another particular feature of the Austrian electricity generation mix is the non-production of nuclear power based electricity. Even though in 1971 it was decided to build an atomic power plant in Zwentendorf, Austria, the outcome of a 1978 popular referendum meant that the already constructed nuclear power plant would not go into operation (EVN 2011). Since then, Austria does not use nuclear energy in its electricity production mix, which of course has practical implications on the projections of electricity generation in the following chapters, as electricity not produced by nuclear power has to be produced by other technologies.

With this in mind, it has to be noted that in response to the decision not to produce electricity at the nuclear power plant in Zwentendorf, there was a need to find a replacement for the lost electricity production capacity. Hence a coal power plant has been built in the close vicinity of the nuclear plant. Zwentendorf had 723 MW gross power, and the replacement coal power plant 775 MW (EVN 2011). Due to the higher life-cycle GHG emissions of coal plants compared to nuclear power plants, this could also have resulted in an increased amount of GHG emissions. In fact, applying the model and data of this thesis as described in Chapter 3, the amount of GHG emissions arising from the substitution of electricity produced from nuclear power by electricity produced from coal power is as follows (for simplification, a load factor of 0.8 for the nuclear plant has been assumed, as well as the fact that all electricity not produced by the nuclear power plant has been produced by a substituting coal fired power plant):



	Power [MW]	Power [kW]	Hours / year	Energy [kWh/yr]	GHG Emissions Increase (if produced by coal plant) Mt CO2eq/yr
Zwentendorf	723	723.000	7.008	5.066.784.000	4,97 ± 0,88

Table 2: Increased GHG emissions [Mt CO2eq/yr] due to coal-based electricity production replacing nuclear production; Data based on (EVN 2011) and (Weisser 2007); a load factor of 0.8 has been assumed

Based on emissions data from (Weisser 2007), which do not account for the specific emissions of the particular coal power plant designed to replace the nuclear power plant Zwentendorf, Table 2 shows that the decision to produce coal-based electricity as a substitute for nuclear-based electricity potentially may have resulted in a significant increase in GHG emissions (4,97±0,88 Mt CO2eq/yr). In a world with active carbon pricing (i.e. within the framework of the UNFCCC or the EU) this adds to the complexity of deciding on the electricity production mix, as coal-fueled power plants cause significantly higher life-cycle GHG emissions than many other electricity producing technologies like gas, nuclear, hydro, wind or biomass (based on Weisser 2007).

China

In contrast to Austria, China primarily depends on thermal electric power plants. As illustrated in Figure 7, ever since the 1980s thermal power occupies the by far largest share in national electricity production (U.S. Energy Information Administration 2008). Coal accounts for the by far largest share in thermal power and total electricity production: In 2007, coal accounted for 80% of total electricity (Q. Wang & Y. Chen 2010, p.1025).

Accordingly, in 2002 the generation of electricity contributed nearly 43% of China's total GHG emissions (Steenhof & Fulton 2007, p.664).

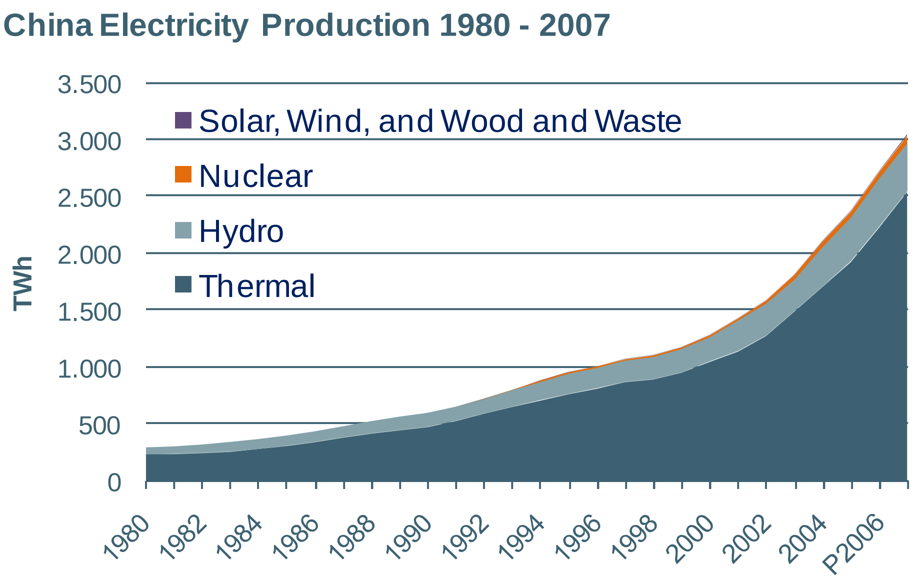


Figure 7: Electricity Production in China 1980 – 2007; based on data and projections (for 2006 and 2007) from (U.S. Energy Information Administration 2008)

Total installed capacity in China has witnessed significant growth levels recently, particularly since around the year 2000. Between 2001 and 2005, for example, total installed capacity has more than doubled (cf. Figure 7). Hydro-power has continuously been the second most important source of electricity, while nuclear power has been gaining momentum recently. Hydro-power and Nuclear-power are both expected to grow; in fact the actual scale of Chinese nuclear power development is expected to even exceed the present growth plan (Q. Wang & Y. Chen 2010, p.1024). Nonetheless, at the one hand, the electric power sector is expected to contribute almost 55% of China's total GHG emissions by 2020, which would correspond to approximately 20% of the world's total emissions (Steenhof & Fulton 2007, p.664). At the same time, however, China is also expected to have plenty of low-carbon electricity resources, allowing it to potentially revolutionize its electricity structure towards a low-carbon electricity system (Q. Wang & Y. Chen 2010, p.1025).

In all, Austria and China have very different electricity systems. While Austria currently depends largely on low-carbon hydro power, China depends on carbon-intensive thermal power. While Austria has a no-nuclear policy in place, China plans to increase electricity production from nuclear power. This thesis aims to assess the mitigation potential and carbon trading impact of different electric supply technologies for 2020 and 2030 for both countries in the following chapters.

3 Model Methodology

3.1 Research questions and purpose

The mitigation potential of carbon emissions is a main area of interest for climate research today. However, results of carbon mitigation scenarios from international research are often presented at aggregated sector levels (such as industry, transport or energy) and aggregated geographic levels (such as global, OECD or Annex I countries), without further disaggregation (e.g. in the IPCC 4 AR). In their effort to compare greenhouse gas mitigation potentials from different approaches and models, Hoogwijk et al. (Hoogwijk et al. 2010) hence conclude in the Energy Policy journal that, “analysts interested in particular technologies [...] require more detailed information to understand specific mitigation options in relation to business-as-usual trends. Unfortunately, none of the modelling efforts provide detailed results per sub-sectors and per region.”

This thesis thus aims to take one step towards the solution to this problem, by projecting the mitigation potential for *specific* electricity generating technologies for two *specific* regional entities (China and Austria) by employing a transparent and reproducible model. The carbon mitigation potential for 2020 and 2030 for the implementation of particular electricity generating technologies in China and Austria will be assessed. Furthermore, the economic impact of such mitigation measures on carbon trading will be shown under an assumed international carbon trading regime, converting carbon emissions avoided into potential earnings made.

This paper thus aims to answer the following research questions:

- What is the GHG mitigation potential for currently available electricity generation technologies compared to baseline emissions in China and Austria in 2020 and 2030?
- What is the economic impact of these mitigation potentials on the respective national carbon trading accounts in 2020 and 2030?

3.2 Building the model

The following subchapters will outline the details of the model as well as the data used in it.

3.2.1 Model Boundaries

Geographic boundary

The mitigation potential of the electricity generation sector will be assessed for Austria and China individually. The model is structured in a transparent way so that further countries can readily be analysed as well through future research (given that energy projections are available).

Sector boundary

The carbon mitigation potential for these two countries is to be shown for the electricity generation sector. In accordance with data availability, the carbon emissions and mitigation potential will be shown for the following technologies:

- China: Coal (baseline emissions), oil, gas, nuclear, hydro, wind;
- Austria: Coal (baseline emissions), oil, gas, nuclear, hydro, wind, biomass;

Temporal boundary

Projections are to be made for the years 2020 and 2030.

3.2.2 Emission Scenarios

For each country, two different emission scenarios are considered. The scenarios are based (i) for China on the IEA's electricity generation projections for China (OECD/IEA 2009) and (ii) for Austria on the European Commission's electricity generation projections for Austria (European Commission & Directorate-General for Energy 2010). Generally speaking, the first scenario for each country assumes "business as usual" with only limited efforts to combat climate change, while the second scenario takes into account more dedicated policies that aim to reduce climate change.

The **China.1 Scenario** is based on the IEA's World Energy Outlook 2009 reference scenario, which takes into account the recent economic downturn that hit the entire world; measures that governments have already adopted in pursue of energy and environmental policies; as well as changes in expectations about energy prices in the near term. However, the Reference Scenario does not attempt to guess at future government policies, and does not take into account intentions or targets that may have been expressed by governments but which are not backed up by specific implementing measures. (OECD/IEA 2009, p.53)

The **China.2 Scenario** is based on the IEA's World Energy Outlook 2009 450 ppm scenario. This scenario assumes that governments adopt commitments to limit the long-term concentration of greenhouse gasses in the atmosphere to 450 parts per million of CO2 equivalent (ppm CO2-eq), an objective gaining widespread support globally. The 450 Scenario reflects a realistic combination of policies that could emerge: a cap-and-trade system, sectoral agreements and national polices tailored to each country's circumstances. (OECD/IEA 2009, pp.53 - 54)

The **Austria.1 Scenario** is based on the EU Energy Baseline 2009 Scenario, which considers the development of the EU energy system under current trends and policies. It is based on current trends on population and economic development, including the recent economic downturn. It assumes that economic decisions and technological progress are driven by market forces in the context of concrete national and EU policies and measures implemented until April 2009. This includes the ETS and several energy efficiency measures; however it does not include the renewable energy target and the non-ETS targets. For the EU this scenario also is a benchmark for scenarios on alternative policy approaches or framework conditions (e.g. higher energy import prices, renewable and climate policies). (European Commission & Directorate-General for Energy 2010, p.10)

The **Austria.2 Scenario** is based on the EU Energy Reference 2009 Scenario, which is based on the same macroeconomic, price, technology and policy assumptions as the 2009 baseline scenario. However, it also considers policies adopted between April 2009 and December 2009 and as such assumes that national targets under the Renewables directive 2009/28/EC and the GHG effort sharing decision 2009/406/EC are achieved in 2020 (European Commission & Directorate-General for Energy 2010, p.10). Among others, directive 2009/28/EC calculates a target for each Member State according to the share of energy from renewable sources in its gross final consumption for 2020 (Europaserver 2010). For Austria, this means the target for the share of energy from renewable sources in gross final consumption of energy for 2020 is 34%, compared to 23.3% in 2005 (Decision 2009/406/EC 2009, p.46). Furthermore, decision 2009/406/EC sets out the efforts of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. For Austria, this means that it has to reduce its greenhouse gas emissions in 2020 by 16% compared to 2005 greenhouse gas emission levels (Decision 2009/406/EC 2009, p.147). Consequently, this scenario includes Austria's mandatory emission and energy targets set for 2020.

3.2.3 Projections of electricity generation

The model employs exogenous energy projections provided by the IEA's World Energy Outlook 2009 (for China) and by the European Commission's Electricity Generation Projections 2009 (for Austria). Exogenous energy projections are also used in the literature, i.e. in IIASA's bottom-up GAINS model, which also employs exogenous World Energy Outlook data (Amann et al. 2009, p.3). Furthermore, (Sims et al. 2003) use the IEA's energy projections as well.

China Electricity Generation [TWh]						
			2020		2030	
	1990	2007	China.1 Scenario	China.2 Scenario	China.1 Scenario	China.2 Scenario
Coal	471	2.685	5.119	4.208	6.639	3.521
Oil	49	34	41	35	32	28
Gas	3	41	156	130	253	195
Nuclear	0	62	322	501	487	956
Hydro	127	485	848	889	1.046	1.232
Wind	0	9	168	365	225	629
Other renewables	0	2	38	93	165	461
Total Generation	**650**	**3.318**	**6.692**	**6.221**	**8.847**	**7.022**

Table 3: China Electricity Generation [TWh]; based on (OECD/IEA 2009, p.352)

Table 3 is based on the IEA’s World Energy Outlook 2009 and shows China’s electricity generation capacity in [TWh] for 1990, 2007, 2020 and 2030 by technology: coal-fired capacity, oil-powered capacity, gas-fired capacity, nuclear power, hydropower (including small and large), wind power (including onshore and offshore), and other renewables (biomass, geothermal, solar, and tide and wave power). For 2020 and 2030, two scenarios are considered: The China.1 Scenario (corresponding to the Reference Scenario) and the China.2 Scenario (corresponding to the 450 Scenario).

Austria Electricity Generation [GWh]						
			2020		2030	
	2000	2010	Austria.1 Scenario	Austria.2 Scenario	Austria.1 Scenario	Austria.2 Scenario
Coal	5.924	5.899	5.371	5.270	4.659	5.359
Oil	1.096	805	563	891	842	671
Gas	9.407	13.534	18.423	9.977	18.139	13.236
Nuclear	0	0	0	0	0	0
Hydro	41.832	37.651	41.538	41.769	45.033	45.033
Wind	67	2.538	3.812	5.246	6.608	6.680
Biomass	1.524	3.056	6.600	9.575	6.948	10.317
Other renewables	3	60	307	338	680	821
Total Generation	**59.853**	**63.543**	**76.614**	**73.066**	**82.909**	**82.117**

Table 4: Austria Electricity Generation [GWh]; based on (European Commission & Directorate-General for Energy 2010, pp.69 and 127)

Table 4 is based on the European Commission’s Electricity Generation Projections 2009 and shows Austria’s electricity generation capacity in [GWh] for 2000, 2010, 2020 and 2030 by technology: Coal-fired capacity, oil-powered capacity (i.e. petroleum products), gas-fired capacity, nuclear power, hydropower, wind power, biomass (and waste) power, and other renewables (i.e. solar, tidal, geothermal and others). For 2020 and 2030, two scenarios are considered: The Austria.1 Scenario (corresponding to the Baseline Scenario) and the Austria.2 Scenario (corresponding to the Reference Scenario).

It has to be noted that the category “Other renewables” for both Austria and China will not be considered in the model, as life-cycle GHG emissions as well as costs from the different technologies within the group “other renewables” naturally vary significantly due to technical differences.

3.2.4 Life-cycle GHG emissions from electric supply technologies

All energy systems emit GHGs and contribute to anthropogenic climate change (Weisser 2007, p.1543). They do so in different stages: **Upstream emissions** occur before actual plant operation and result from e.g. mining, fuel exploration and transport. **Downstream emissions** occur after plant operation and are a consequence of e.g. decommissioning and waste management. Emissions from power plant operation are referred to as **direct emissions** (Weisser 2007, p.1544). For fossil fuel technology options, upstream emissions can be up to 25% of direct emissions. On the other hand, for most renewable energy technologies and nuclear power, upstream and downstream emissions can account for over 90% of cumulative emissions (Weisser 2007, p.1543). In a model where carbon is being priced under an international mitigation regime, it is hence important to consider GHG emissions over the entire life-cycle of the energy system.

In his 2007 paper “A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies” Daniel Weisser reviewed and compared the results of GHG emission life-cycle analysis of various electricity generation chains, based on LCA studies and reports published mainly between 2000 and 2006. He also provided the author of this paper with his data, so that the mean and SD values of his comparative analysis can be used for calculations in this model. The results of Daniel Weisser's analysis (Weisser 2007, p.1549) are illustrated in Figure 5.

3.2.5 Electricity Generating costs

Investments into power plants have both upfront costs as well as ongoing operational expenses over the life cycle of the facility. In order to compare the cost of electricity across different technologies, the levelized cost of energy (LCOE) is used. One of the most succinct definition of how to calculate the LCOE is from the IEA's Projected Costs of Electricity 2010 Edition (OECD/IEA 2010, p.33): "The calculation of the LCOE is based on the equivalence of the present value of the sum of discounted revenues and the present value of the sum of discounted costs." The calculation of the LCOE thus considers:

- The investment costs in year t
- Operations and Maintenance costs in year t
- Fuel costs in year t
- Decommissioning costs in year t
- The amount of electricity produced in year t
- The constant price of electricity
- The discount factor for year t

The LCOE aims to capture the full lifetime costs of an electricity generation plant, and allocates these costs over the lifetime electrical output, with both future costs and outputs discounted to present values (Heptonstall 2007, p.9). However, in reality there are a number of limitations to this method, which have to be kept in mind. One is that in practice the availability of "real numbers" appears to be very poor (Heptonstall 2007, p.2): In liberalised markets, the real numbers reside with electricity generating companies, who may have a commercial incentive to keep this information out of the public domain. Also, those numbers which are available may be subject to a range of imbedded assumptions within the generating companies operating and accounting systems (e.g. the approach adopted to allocate corporate level costs to individual power plants).

Furthermore, one of the most influential factors in levelized cost calculations is the discount rate. The impact of the discount rate on the LCOE depends on the characteristics of the technology. Capital intensive technologies with high upfront investment costs but lower operating and fuel costs (e.g. nuclear, wind, hydro) will be more sensitive to discount rates. Let alone the problem of deciding on an appropriate discount rate, when comparing the LCOE of different electricity generating technologies, it is thus paramount to compare LCOE which used the same discount rate. Considering these limitations, levelised costs may hence be only one of the indicators that companies may consider when assessing investment options (Heptonstall 2007, p.11). Nonetheless, LCOE remains the most transparent consensus measure of generating costs (OECD/IEA 2010, p.33).

In the context of this model, it also needs to be stressed that the LCOE varies greatly for different regions and countries. In the latest 2010 edition of its traditional Projected Costs of Generating Electricity report, the IEA observes that the LCOE varies widely from region to region and even from country to country and concludes that *country-specific circumstances determine the LCOE*. These differences in LCOE highlight the need to look at the region or country level, as illustrated in Figure 8.

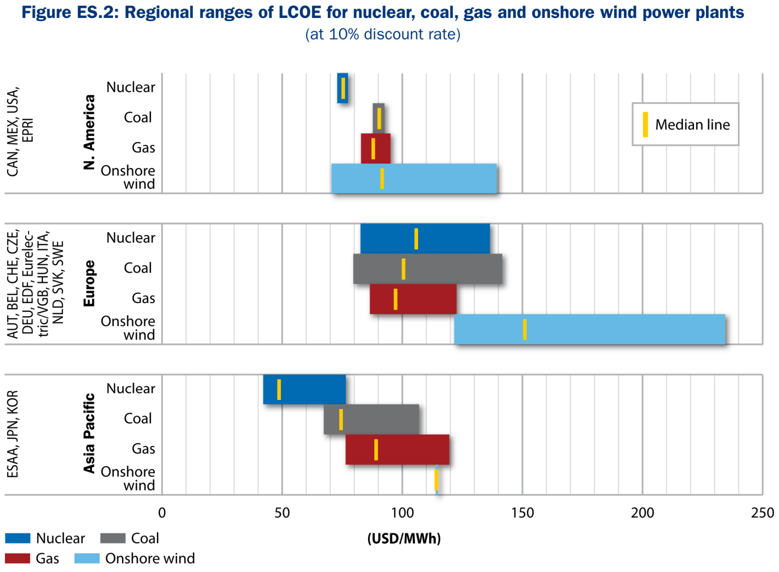


Figure 8: Regional ranges of LCOE for nuclear, coal, gas and onshore wind plants at a 10% discount rate (OECD/IEA 2010, p.19)

This model will thus take the following steps to address the above limitations of the LCOE:

- Different LCOE for Austria and China will be integrated into the model in order to account for the variations in electricity generation costs between these two individual countries
- Only LCOE data from authoritative sources (i.e. the IEA for China and the European Commission for Austria) which apply transparent methods will be considered
- Sources with the same discount rate across all LCOE will be used (i.e. 10%, for which data from the above sources is both available for China and Austria).

Consequently, the LCOE used within the framework of this model are illustrated in Table 5 and Table 6. As a general methodology for both tables, values reported in USD were converted to EUR based on the Eurostat exchange rates for the reference year of the data given in the publication (i.e. USD2008 were converted to EUR2008 by using the annual average exchange rate in 2008 of 1.4708). All values have been converted to

EUR2008 values using the annual average inflation rates for the Euro area as reported by Eurostat (i.e. EUR2005 values to EUR2008 values).

China Levelised Cost of Electricity LCOE				
Country	Electricity Generation Technology	**LCOE Min. EUR$_{2008}$cent/kWh**	**LCOE Max. EUR$_{2008}$cent/kWh**	Data Source
China	Coal	2,26	2,34	OECD/IEA (2010) p. 59ff
China	Oil	10,24	13,47	EC (2008) p. 4
China	Gas	2,65	2,71	OECD/IEA (2010) p. 59ff
China	Nuclear	2,97	3,71	OECD/IEA (2010) p. 59ff
China	Hydro	1,58	3,50	OECD/IEA (2010) p. 59ff
China	Wind	4,90	8,55	OECD/IEA (2010) p. 59ff

Table 5: Levelised Cost of Electricty LCOE for China in EUR$_{2008}$cent/kWh.

Table 5 depicts the LCOE for different electricity generation technologies in China. All values are in Eur$_{2008}$cent/kWh. (OECD/IEA 2010) data for coal, gas, nuclear, hydro and wind power is specifically from China. (European Commission 2008) data represents European values, as no LCOE data on oil was available for China from the (OECD/IEA 2010) report. Table 5 illustrates that in China, coal is among the cheapest electricity generation technologies, with a very narrow price range (2,26 – 2,34). Hydro power has an even lower minimum LCOE; its maximum LCOE however is considerably bigger than coal's (1,58 – 3,50). Nuclear and Gas are in the middle range(2,97 – 3,71 resp. 2,65 – 2,71), while wind is generally considerably more expensive, particularly in the maximum price range (4,90 – 8,55). Oil is a special case in this instance, as European price levels are depicted. However, oil's share in total electricity production in China is negligible (cf. Table 3), therefore this is not expected to have a considerable impact on the model results.

Austria Levelised Cost of Electricity LCOE				
Country	Electricity Generation Technology	**LCOE Min. EUR$_{2008}$cent/kWh**	**LCOE Max. EUR$_{2008}$cent/kWh**	Data Source
Austria	Coal	4,31	5,93	EC (2008) p. 4
Austria	Oil	10,24	13,47	EC (2008) p. 4
Austria	Gas	5,39	8,08	EC (2008) p. 4
Austria	Nuclear			EC (2008) p. 4
Austria	Hydro	3,77	19,94	EC (2008) p. 4
Austria	Wind	8,08	11,86	EC (2008) p. 4
Austria	Biomass	8,62	21,02	EC (2008) p. 4

Table 6: Levelised Cost of Electricty LCOE for Austria in EUR$_{2008}$cent/kWh.

Table 6 depicts the LCOE for different electricity generation technologies in Austria. All values are in Eur_{2008}cent/kWh. LCOE data for all electricity generation technologies represent European values and have been prepared by the (European Commission 2008) for use in the Second Strategic EU Energy Review. No nuclear values are given as Austria does not produce nuclear energy. Like in China, coal is among the cheapest sources of electricity, with again a rather narrow range (4,31 – 5,93). Gas-powered electricity production follows with a similar narrow range of comparatively low-cost electricity production (5,39 – 8,08). Hydro power can be very competitive as well; however, its cost range may vary widely (3,77 – 19,94). Oil-power production is considerably more expensive than coal or gas production, however it does have a relatively narrow cost range (10,24 – 13,47). Wind power is generally already more competitive than oil-production (8,08 – 11,86). Biomass can be more competitive as well, however its costs range is significant (8,62 – 21,02).

3.3 Model Overview and Calculations

In order to answer the research questions posed in the beginning of this chapter, this paper employs a simple model based on the combination of similar models and assumptions, particularly from (Sims et al. 2003), (Cai et al. 2010), and (Pearson 2000, p.155 ff.). The following figure gives an overview of how the model works:

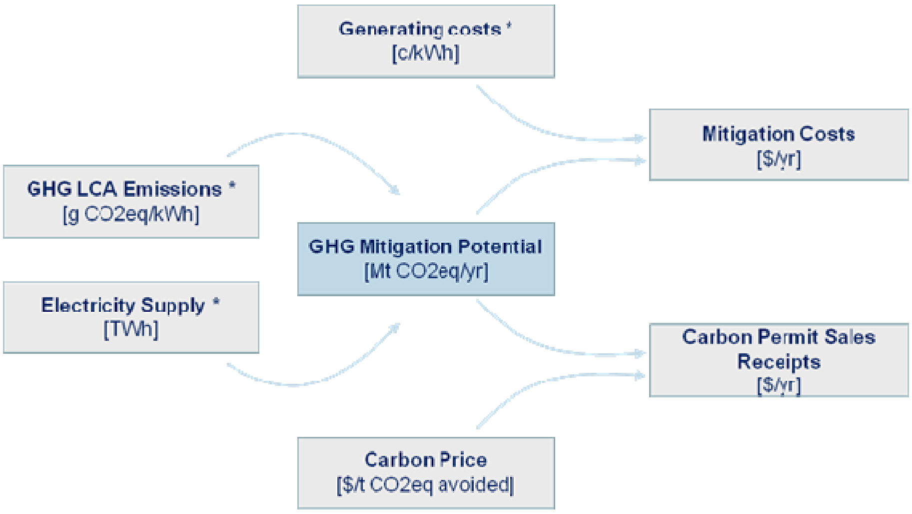


Figure 9: The model used in this thesis. The asterisk (*) denotes exogenic data.

Figure 9 illustrates the model which is being used in this thesis. The model is based on exogenic data (denoted by an asterisk). Electricity Supply refers to the electricity generation projections of various technologies for 2020 and 2030 for China and Austria respectively (cf. Chapter 3.2.3). GHG LCA Emissions refer to life-cycle greenhouse gas emissions originating from the various electricity generation technologies (cf. Chapter 3.2.4). Together, GHG LCA Emissions and Electricity Supply Projections form the basis of the model and result in the **GHG Mitigation Potential** for 2020 resp. 2030 by applying the following formula:

$$[(gCO2eq/kWh)_{coal} - (gCO2eq/kWh)_{re}]xEGx10^{-12}$$

The CO2 emissions from coal [in gCO2eq/kWh] are taken as baseline emissions. Mitigation potential from a certain electricity generating technology (denoted by $_{re}$, however also referring to nuclear and gas) is calculated by multiplying the reduced CO2eq emissions from this technology in comparison to coal with the projected amount of electricity produced by this technology in 2020 resp. 2030 (denoted by *EG*).

The **Mitigation Costs** for using a certain technology are calculated by the following formula:

$$[(c/kWh)_{re} - (c/kWh)_{coal}]xEGx10^{-2}$$

The cost of electricity generation for the alternative technology less the cost of electricity generated from coal is multiplied with the electricity produced by this technology in 2020 resp. 2030. Generating costs refer to levelised costs of electricity generation of the different technologies analysed (cf. Chapter 3.2.5). This denotes the costs of mitigation.

This model assumes a fully functioning carbon permit trading market to which both Austria and China are parties. The mitigation potential is thus combined with a hypothetical carbon price (under various assumptions) in order to calculate potential **Carbon Permit Sales Receipts** with the following formula:

$$(MitigationPotential) * (CarbonPrice)$$

The potential carbon permit sales receipts determine the impact of the mitigation option on the national carbon trading accounts.

4 Experimental Modelling

The experimental modelling part of this thesis will apply the model presented in Chapter 3 in order to assess the GHG mitigation potential [kt CO2eq/yr], Mitigation Costs [EUR2008/yr], Carbon Permit Sales Receipts [EUR2008/yr], and Net Welfare [EUR2008/yr] for the following cases:

- Austria 2020
    - Scenario 1 (Austria.2020.1)
    - Scenario 2 (Austria.2020.2)
- Austria 2030
    - Scenario 1 (Austria.2030.1)
    - Scenario 2(Austria.2030.2)
- China 2020
    - Scenario 1 (China.2020.1)
    - Scenario 2 (China.2020.2)
- China 2030
    - Scenario 1 (China.2030.1)
    - Scenario 2 (China.2030.2)

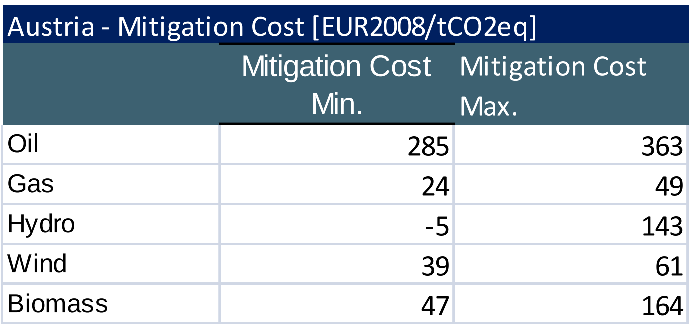
The subsequent chapters will individually analyse the above scenarios. All calculations have been carried out using standard spreadsheet software and pivot tables & charts.

4.1 Austria 2020

The Austria 2020 case analyses two scenarios, the second one generally assuming more stringent efforts to curb CO2 emissions than the first (cf. Chapter 3.2.2).

4.1.1 GHG Mitigation Costs per tCO2eq avoided

For all scenarios, including the 2030 scenarios, the following mitigation costs per tCO2eq avoided occur:



Austria - Mitigation Cost [EUR2008/tCO2eq]		
	Mitigation Cost Min.	Mitigation Cost Max.
Oil	285	363
Gas	24	49
Hydro	-5	143
Wind	39	61
Biomass	47	164

Table 7: Austria – GHG Mitigation Costs per tCO2eq avoided

Table 7 illustrates the mitigation costs for the different technologies in Austria (ranges from minimum to maximum in accordance with data). All values are in EUR2008/tCO2eq. Oil is clearly the most expensive mitigation option (285-363), while gas and wind are much cheaper and show a relatively narrow range between minimum and maximum values. Hydro has the potential to be even a cheaper provider of electricity than coal; however, its costs exhibit a wide range (-5 to 143). Biomass (47 – 164) has the highest minimum and maximum values apart from oil.

4.1.2 Electricity Generation Projections

The following graph depicts the electricity generation projections in the two Austria.2020 Scenarios:

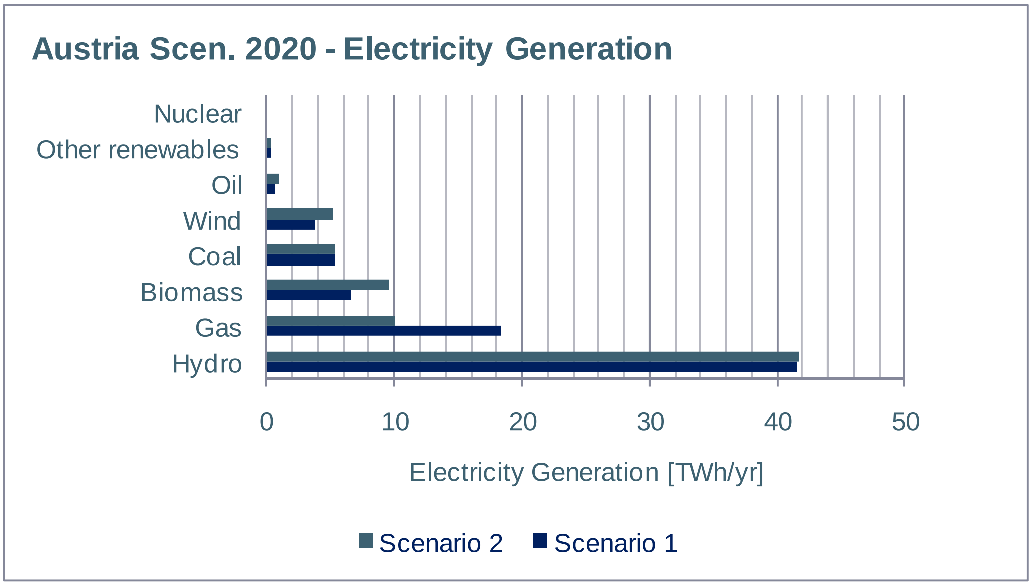


Figure 10: Austria.2020 – Electricity Generation Projection for Scenarios 1 and 2

In Figure 10, electricity generation is projected for Austria in the year 2020, for both Scenarios. In both scenarios, nuclear plays no role, while oil and other renewables play a minor part. Hydro is in both cases the leading electricity generation technology, with only small difference between the two scenarios. Gas occupies the second largest share in both scenarios, though it is considerably more significant in Scenario 1. Biomass and wind, on the other hand, occupy a bigger share in the electricity generation mix in Scenario 2 than in Scenario 1. Production from Coal is in both cases similar to production from wind.

4.1.3 GHG Mitigation Potential

The following figure displays the GHG Mitigation Potential for Austria in 2020 according to Scenario 1 and Scenario 2:

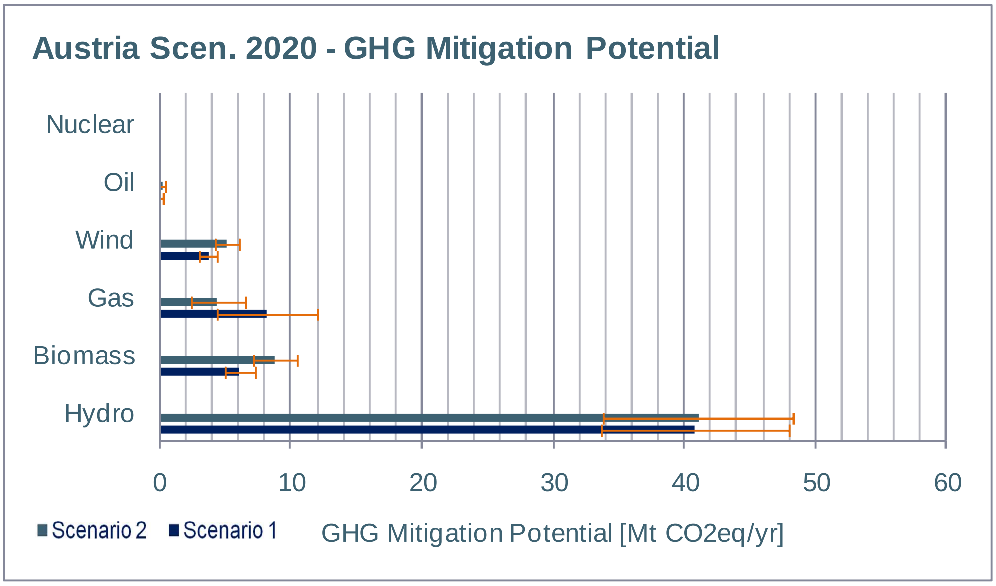


Figure 11: Austria.2020 – GHG Mitigation Potential; error bars represent the standard deviation

In Scenario 1, hydro Power has the by far largest potential for GHG mitigation (40,8±7,2 Mt CO2eq/yr). Gas comes second with considerably lower potential for GHG mitigation and it exhibits a relatively large spread of measurements. Biomass and Wind have a lower spread and values of 6,1±1,2 Mt CO2eq/yr respectively 3,7±0,7 Mt CO2eq/yr. Oil is projected to occupy a negligible share in electricity production. In Scenario 2, the image looks similar, with hydro providing the biggest mitigation potential. Biomass and Wind provide more mitigation potential in Scenario 2 compared to Scenario 1, while potential of gas is being reduced. Oil again plays a negligible role.

4.1.4 Total Mitigation Costs and Carbon Permit Sales Receipts

The following section will compare mitigation costs of the different technologies with potential carbon permit sales receipts. The subsequent tables will introduce carbon permit sales receipts at different carbon price levels (20EUR2008, 40EUR2008, and 60EUR2008 per tCO2eq), allowing for the direct comparison of mitigation costs and carbon permit sales receipts. Figure 12 illustrates the graphic representation of carbon mitigation costs and benefits for a carbon price of 20EUR2007/tCO2eq for the Austrian 2020 Scenario 1. However, for clarity reasons the remaining results for the different carbon prices and scenarios will be presented in the form of tables.

Illustrative Figure (Assumption: Carbon price = 20EUR2008/tCO2eq)

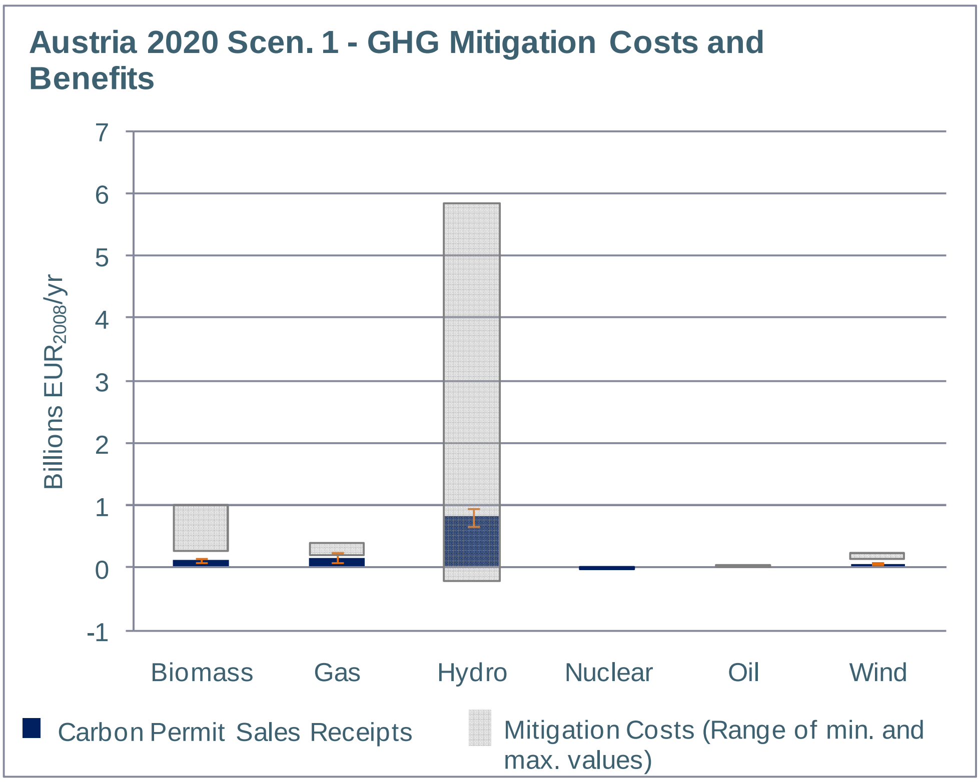


Figure 12: Austria.2020.1 – GHG Mitigation Costs and Carbon Permit Sales Receipts. Assumption: Carbon Price = 20EUR2008/tCO2eq

Figure 12 illustrates the mitigation costs and potential carbon permit sales receipts for Austria in 2020 under Scenario 1, assuming a carbon price of 20EUR2008/tCO2eq. The grey area depicts the minimum and maximum mitigation costs. The dark blue area represents potential carbon permit sales receipts, with the orange error bars representing the standard deviation.

Austria 2020 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 20EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	284,6 - 996	121,5 ± 23	412,83 - 1444,92	176,3 ± 33,4
Gas	198,58 - 397,16	162,8 ± 75,9	107,54 - 215,08	88,2 ± 41,1
Hydro	-223,87 - 5820,58	816,6 ± 144	-225,11 - 5852,94	821,2 ± 144,8
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	33,38 - 42,48	2,3 ± 3,1	52,82 - 67,23	3,7 ± 4,8
Wind	143,81 - 225,99	74,5 ± 13,2	197,91 - 311,01	102,5 ± 18,2

Austria 2020 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 40EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	284,6 - 996	243,1 ± 46	412,83 - 1444,92	352,6 ± 66,8
Gas	198,58 - 397,16	325,6 ± 151,8	107,54 - 215,08	176,3 ± 82,2
Hydro	-223,87 - 5820,58	1633,3 ± 288	-225,11 - 5852,94	1642,4 ± 289,6
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	33,38 - 42,48	4,7 ± 6,1	52,82 - 67,23	7,4 ± 9,7
Wind	143,81 - 225,99	148,9 ± 26,4	197,91 - 311,01	205 ± 36,4

Austria 2020 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 60EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	284,6 - 996	364,6 ± 69,1	412,83 - 1444,92	528,9 ± 100,2
Gas	198,58 - 397,16	488,3 ± 227,7	107,54 - 215,08	264,5 ± 123,3
Hydro	-223,87 - 5820,58	2449,9 ± 432	-225,11 - 5852,94	2463,6 ± 434,4
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	33,38 - 42,48	7 ± 9,2	52,82 - 67,23	11,1 ± 14,5
Wind	143,81 - 225,99	223,4 ± 39,6	197,91 - 311,01	307,5 ± 54,5

Table 8: Austria.2020 – GHG Mitigation Costs and Carbon Permit Sales Receipts for different carbon price assumptions

Conclusions and Results from Table 8 will follow in the Results Chapter.

4.2 Austria 2030

4.2.1 Electricity Generation Projections

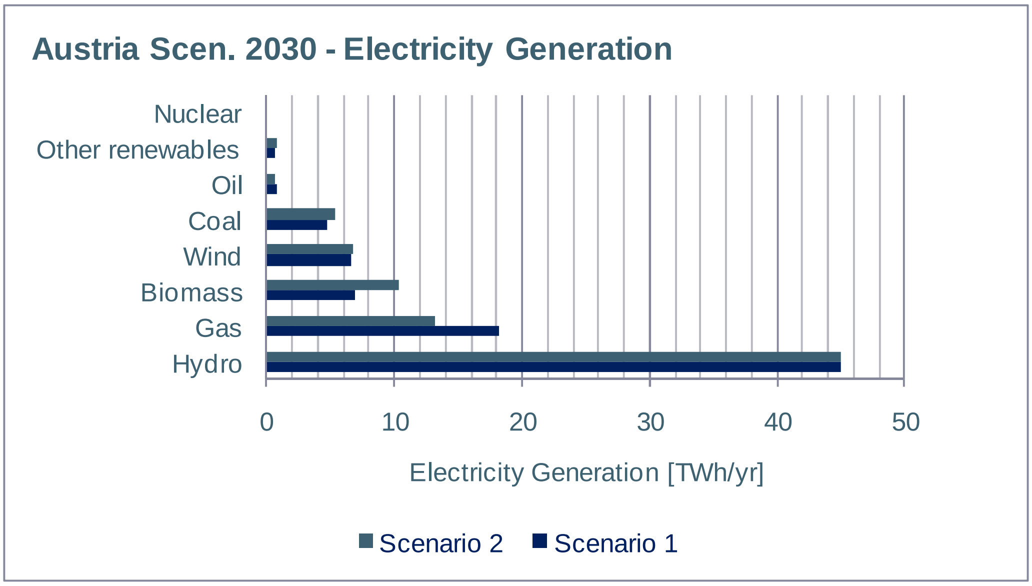


Figure 13: Austria.2030 –Electricity Generation for Scenarios 1 and 2

Figure 12 illustrates the electricity generation projections for Austria in 2030, for both Scenarios 1 and 2. In both scenarios, hydro power is the main source of electricity. Gas follows second, with a larger share in the total electricity mix in Scenario 1. Biomass and Wind come third respectively fourth, with biomass in this case having a larger share in the second scenario. Coal follows, and oil and other renewables play a minor role in electricity generation.

4.2.2 GHG Mitigation Potential

Figure 13 portrays the GHG mitigation potential for Austria in 2030 for Scenarios 1 and 2. In both cases hydro power bears the largest potential (in line with its importance in the electricity generation mix). In scenario 1, gas bears the second biggest potential, with biomass and wind following closely. In scenario 2, however, biomass represents the second most important technology in terms of mitigation potential in the electricity generation mix. Oil’s share is again negligible.

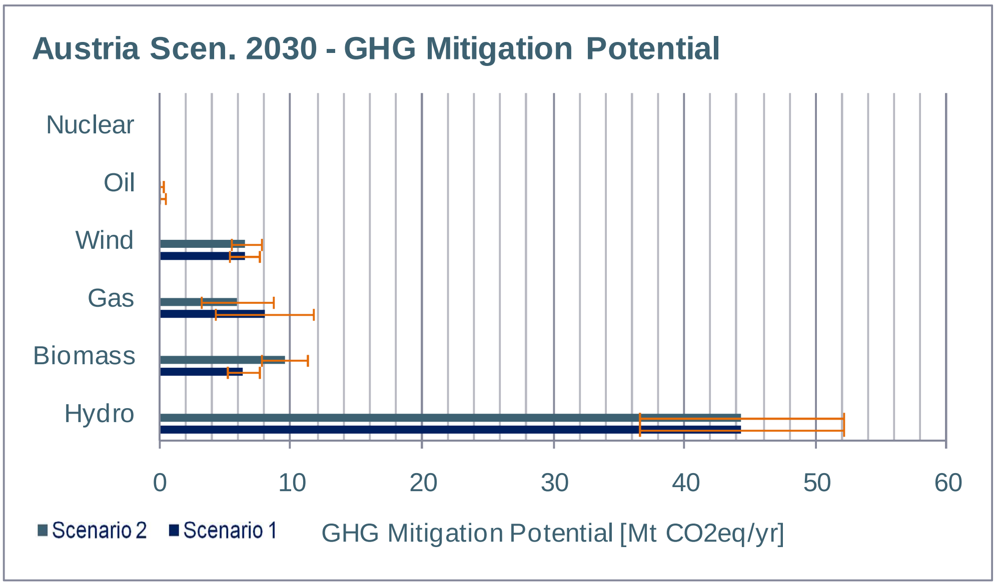


Figure 14: Austria.2030 – GHG Mitigation Potential; error bars represent the standard deviation

4.2.3 Mitigation Costs and Carbon Permit Sales Receipts

The following figure depicts the GHG mitigation costs and benefits for Austria in 2030 for Scenario 1 for an assumed carbon price of 20EUR2008/tCO2eq:

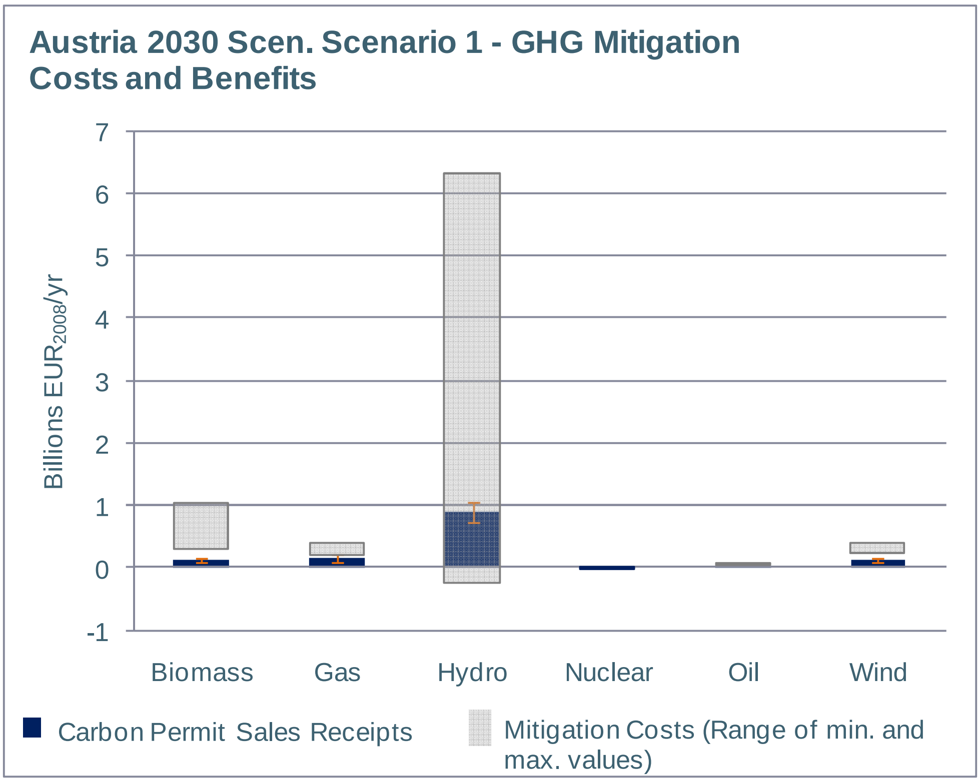


Figure 15: Austria.2030 Scenario 1 – GHG Mitigation Costs and Benefits; error bars represent the standard deviation; Carbon Price Assumption of 20EUR2008/tCO2eq

The following table assesss the mitigation costs and beneifts under a number of scenarios and carbon price assumptions:

Austria 2030 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 20EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	299,6 - 1048,5	127,9 ± 24,2	444,83 - 1556,89	190 ± 36
Gas	195,52 - 391,04	160,3 ± 74,7	142,67 - 285,34	116,9 ± 54,5
Hydro	-242,7 - 6310,32	885,4 ± 156,1	-242,7 - 6310,32	885,4 ± 156,1
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	49,92 - 63,53	3,5 ± 4,6	39,78 - 50,63	2,8 ± 3,6
Wind	249,3 - 391,75	129,1 ± 22,9	252,01 - 396,02	130,5 ± 23,1

Austria 2030 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 40EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	299,6 - 1048,5	255,9 ± 48,5	444,83 - 1556,89	379,9 ± 72
Gas	195,52 - 391,04	320,5 ± 149,5	142,67 - 285,34	233,9 ± 109,1
Hydro	-242,7 - 6310,32	1770,7 ± 312,2	-242,7 - 6310,32	1770,7 ± 312,2
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	49,92 - 63,53	7 ± 9,2	39,78 - 50,63	5,6 ± 7,3
Wind	249,3 - 391,75	258,2 ± 45,8	252,01 - 396,02	261 ± 46,3

Austria 2030 - Mitigation Costs and Potential Benefits [Million EUR2008/yr]				
Carbon Price = 60EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Biomass	299,6 - 1048,5	383,8 ± 72,7	444,83 - 1556,89	569,9 ± 108
Gas	195,52 - 391,04	480,8 ± 224,2	142,67 - 285,34	350,8 ± 163,6
Hydro	-242,7 - 6310,32	2656,1 ± 468,3	-242,7 - 6310,32	2656,1 ± 468,3
Nuclear	0 - 0	0 ± 0	0 - 0	0 ± 0
Oil	49,92 - 63,53	10,5 ± 13,7	39,78 - 50,63	8,4 ± 10,9
Wind	249,3 - 391,75	387,3 ± 68,7	252,01 - 396,02	391,5 ± 69,4

Table 9: Austria.2030 – GHG Mitigation Costs and Carbon Permit Sales Receipts for different carbon price assumptions

4.3 China 2020

The China 2020 case analyses two scenarios, the second one generally assuming more stringent efforts to curb CO2 emissions than the first (cf. Chapter 3.2.2).

4.3.1 GHG Mitigation Costs per tCO2eq avoided

For all China scenarios, including the 2030 scenarios, the following mitigation costs per tCO2eq avoided occur:

China - Mitigation Cost [EUR2008/tCO2eq]		
	Mitigation Cost Min.	Mitigation Cost Max.
Oil	383,38	534,95
Gas	8,85	8,43
Nuclear	7,25	13,99
Hydro	-6,90	11,81
Wind	26,97	63,60

Table 10: China – GHG Mitigation Costs

Table 10 illustrates the mitigation costs for the different technologies in China (ranges from minimum to maximum in accordance with data). It has to be pointed out that for arithmetic reasons, for gas in China the “minimum” value is bigger than the “maximum” value (due to the min. and max. levelized cost of electricity for both coal and gas being very similar in China). It is thus not a miscalculation (the same formulas as described in 3.3 were applied across all technologies). This has to be kept in mind when interpreting the subsequent graphs and tables.

Oil is clearly the most expensive mitigation option (383 – 534; all values are in EUR2008/tCO2eq.). Wind is the second most expensive option, with costs ranging from 27 to 64. Hydro power has the potential of being even cheaper than electricity from coal (-6,90), however its cost can go up to 11,81. Gas has a very narrow range of costs (8,43 – 8,85). Unlike in Austria, nuclear power is an option in China, and its costs are comparable to gas, with a lower minimum as well as a higher maximum value (7,25 – 13,99).

4.3.2 Electricity Generation Projections

The following figure illustrates the electricity generation projections for China in 2020 for Scenarios 1 and 2:

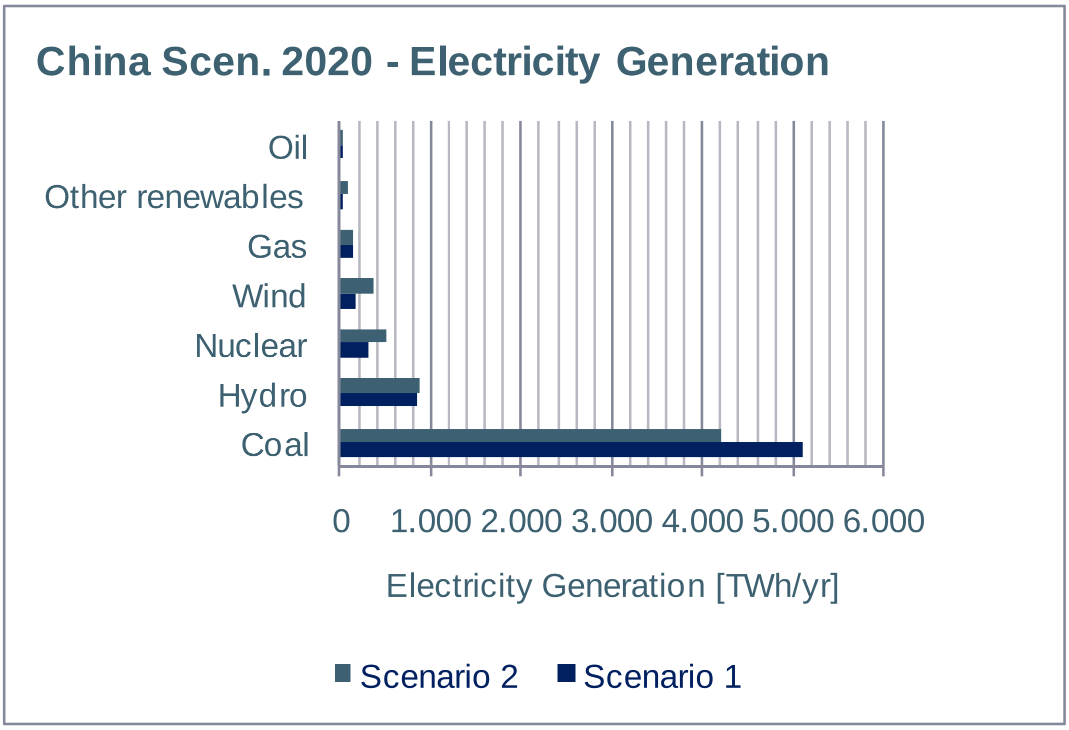


Figure 16: China.2020 – Electricity Generation for Scenarios 1 and 2

Figure 16 illustrates that in both scenarios, coal is clearly the by far most important source of electricity in China. In Scenario 2, however, less electricity is produced from coal than in Scenario 1. Hydro power is the second most important source of electricity in both Scenarios, with a slightly higher production in Scenario 2. Nuclear power is the third most important technology, with a significantly higher share in Scenario 2.

4.3.3 GHG Mitigation Potential

The GHG Mitigation Potential for Scenarios 1 and 2 is graphed in the following figure:

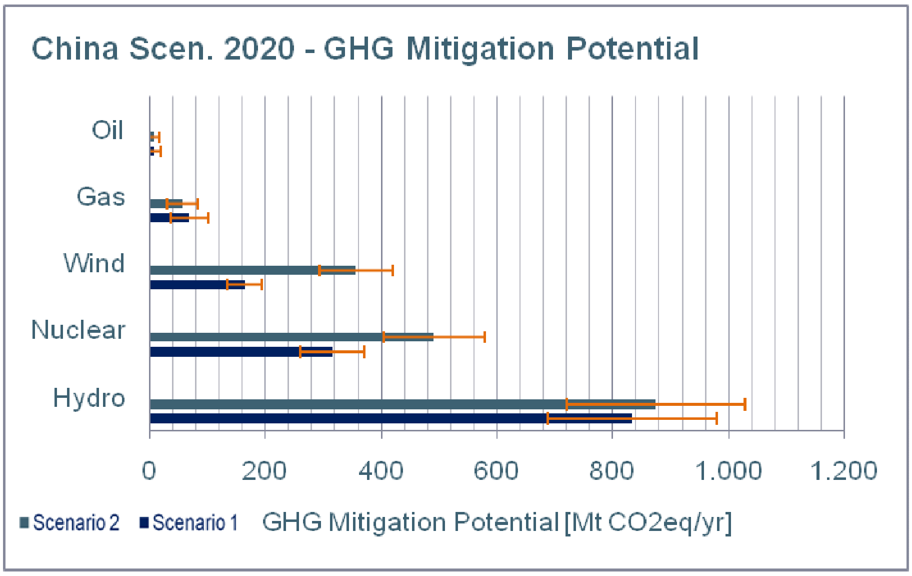


Figure 17: China.2020 – GHG Mitigation Potential; error bars represent the standard deviation

Hydro-power has the greatest potential for GHG mitigation in both Scenarios, with a slightly bigger potential in Scenario 2. Nuclear power is the second mosti important technology in terms of GHG mitigation potential, with significantly greater potential in Scenario 2. Wind exhibits significatn potential as well, particularly in Scenario 2. Gas plays a minor role, while oil is negligible.

4.3.4 Total Mitigation Costs and Carbon Permit Sales Receipts

Figure 18 is an illustrative example of total mitigation costs per technology and. potential carbon permit sales receipts for China in 2020, Scenario 1 and an assumed carbon price of 20EUR2008/tCO2eq.

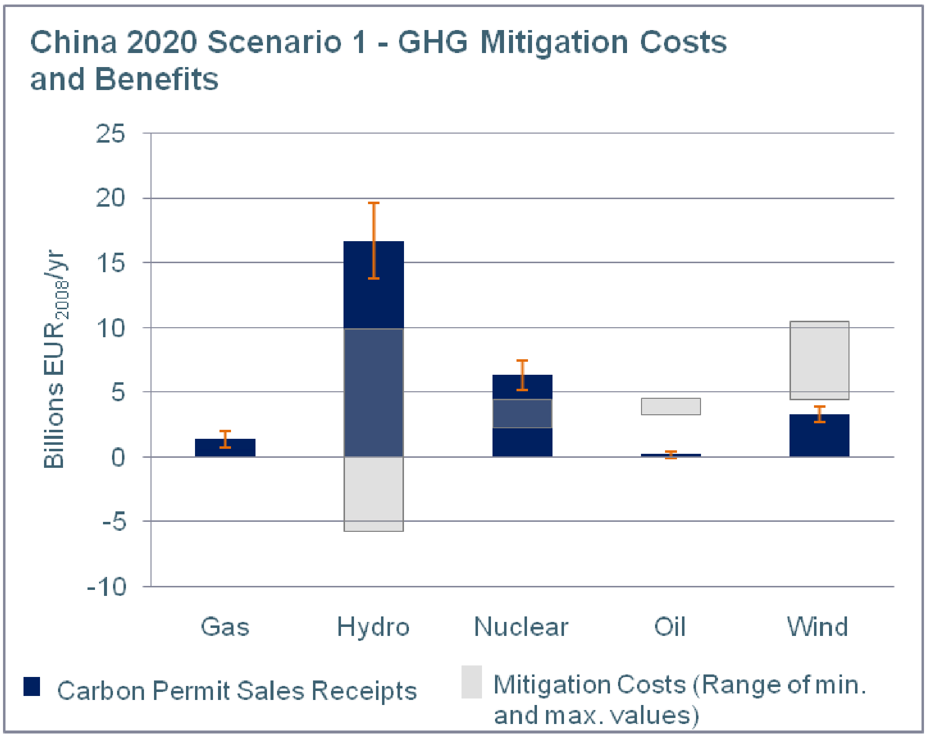


Figure 18: China.2020 Scenario 1 – GHG Mitigation Costs and Benefits; error bars represent the standard deviation; Carbon Price Assumption of 20EUR2008/tCO2eq

At a carbon price of 20EUR2008/tCO2eq the two most important technologies for GHG mitigation in China, hydro and nuclear, are already competitive and even in the maximum price ranges may result in higher carbon permit sales receipts than costs. At this carbon price level, wind is not competitive yet. The following table gives the exact results for Scenarios 1 and 2 for a number of carbon prive level assumptions (20, 40, and 60 EUR2008/tCO2eq). An interpretation will follow in the discussions section.

China 2020 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 20EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	0,6 - 0,6	1,4 ± 0,6	0,51 - 0,48	1,1 ± 0,5
Hydro	-5,75 - 9,84	16,7 ± 2,9	-6,03 - 10,32	17,5 ± 3,1
Nuclear	2,29 - 4,42	6,3 ± 1,1	3,56 - 6,87	9,8 ± 1,7
Oil	3,27 - 4,56	0,2 ± 0,2	2,79 - 3,9	0,1 ± 0,2
Wind	4,43 - 10,44	3,3 ± 0,6	9,62 - 22,67	7,1 ± 1,3

China 2020 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 40EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	0,6 - 0,6	2,8 ± 1,3	0,51 - 0,48	2,3 ± 1,1
Hydro	-5,75 - 9,84	33,3 ± 5,9	-6,03 - 10,32	35 ± 6,2
Nuclear	2,29 - 4,42	12,6 ± 2,2	3,56 - 6,87	19,7 ± 3,5
Oil	3,27 - 4,56	0,3 ± 0,4	2,79 - 3,9	0,3 ± 0,4
Wind	4,43 - 10,44	6,6 ± 1,2	9,62 - 22,67	14,3 ± 2,5

China 2020 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 60EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	0,6 - 0,6	4,1 ± 1,9	0,51 - 0,48	3,4 ± 1,6
Hydro	-5,75 - 9,84	50 ± 8,8	-6,03 - 10,32	52,4 ± 9,2
Nuclear	2,29 - 4,42	18,9 ± 3,3	3,56 - 6,87	29,5 ± 5,2
Oil	3,27 - 4,56	0,5 ± 0,7	2,79 - 3,9	0,4 ± 0,6
Wind	4,43 - 10,44	9,8 ± 1,7	9,62 - 22,67	21,4 ± 3,8

Table 11: China.2020 – GHG Mitigation Costs and Carbon Permit Sales Receipts for different carbon price assumptions

4.4 China 2030

4.4.1 Electricity Generation Projections

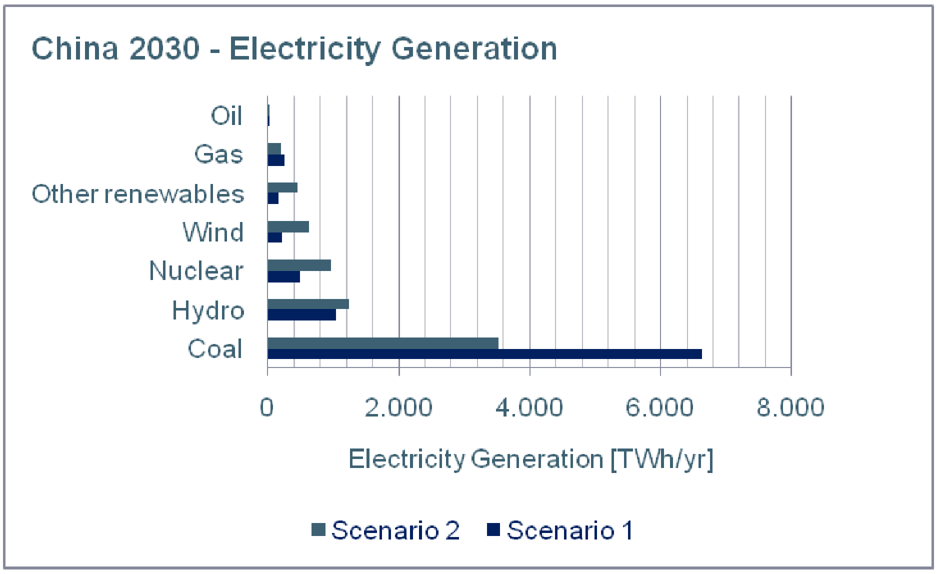


Figure 19: China.2030 – Electricity Generation for Scenarios 1 and 2

Like in 2020, coal is the by far most important source of electricity, particularly in Scenario 1. In Scenario 2, however, the amount of electricity coming from coal is drastically reduced. Hydro and nuclear power are the second respectively third most important electricity sources. Nuclear also has a significantly higher output in Scenario 2 than in Scenario 1, like in 2020. Wind will play a significant role in Scenario 2, while Scenario 2 also indicates the rising importance of other renewables. The output from gas is being reduced in Scenario 2, while oil is negligible in both Scenarios.

4.4.2 GHG Mitigation Potential

The following figure illustrates the GHG mitigation potential for the various technologies for China in 2030 (Scenarios 1 and 2).

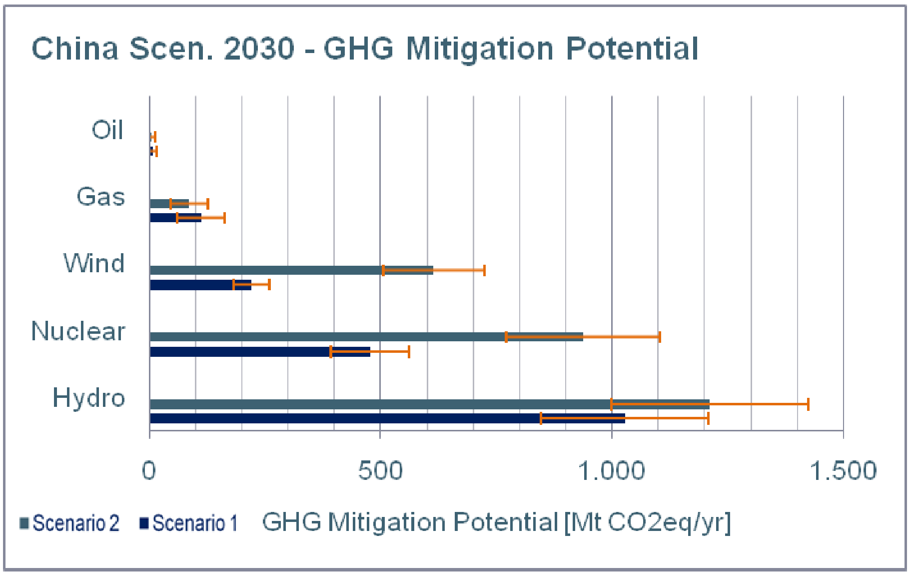


Figure 20: China.2030 – GHG Mitigation Potential; error bars represent the standard deviation

In Scenario 1, Hydro's mitigation potential is by far the greatest, with nuclear being the second and wind the third most important technologies. Hydro power still bearts the greatest potential in Scenario 2. However, it is being closely followed by nuclear and, with some distance, wind power.Gas power is relatively less important for GHG mitigation in both Scenarios, and oil negligible.

4.4.3 Total Mitigation Costs and Carbon Permit Sales Receipt

Figure 21 illustrates mitigation costs and potential carbon permit sales receipts for China in 2030 (Scenario 1) for a carbon price of 20EUR2008/tCO2eq. Hydro and Nuclear power clearly have the potential to be profitable, with higher carbon permit sales receipt than maximum costs. At a price level of 20EUR2008/tCO2eq, wind power is not competitive yet.

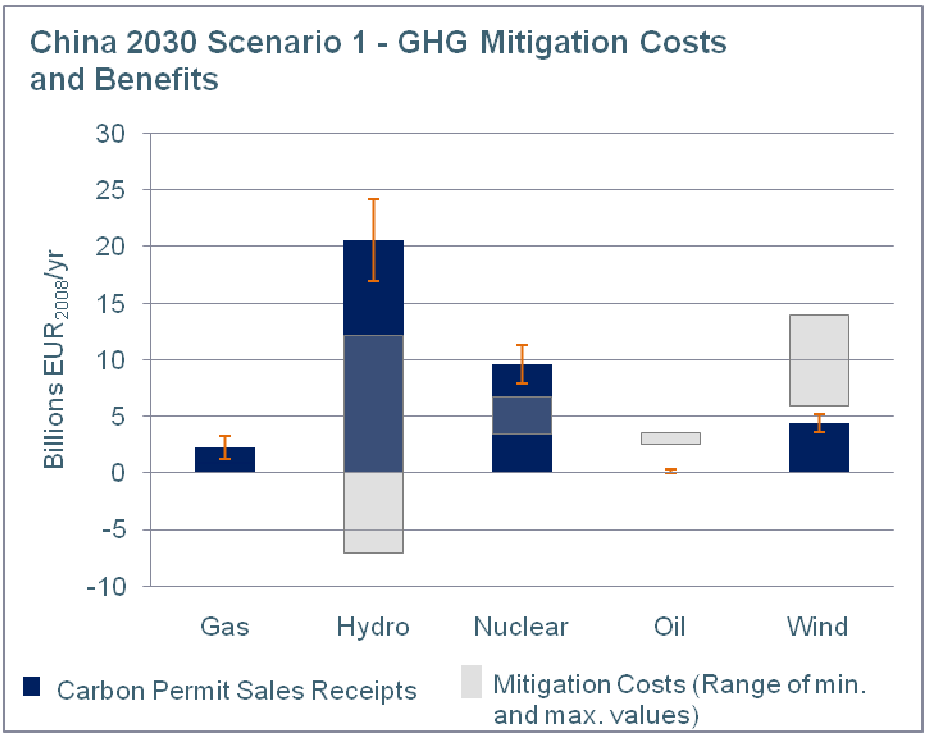


Figure 21: China.2030 Scenario 1 – GHG Mitigation Costs and Benefits; error bars represent the standard deviation; Carbon Price Assumption of 20EUR2008/tCO2eq

Table 12 illustrates detailed mitigation costs and carbon permit sales receipts for all China 2030 scenarios for a different carbon price assumptions (20, 40 and 60 EUR2008/tCO2eq).

China 2030 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 20EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	1 - 0,9	2,2 ± 1	0,76 - 0,73	1,7 ± 0,8
Hydro	-7,1 - 12,14	20,6 ± 3,6	-8,36 - 14,3	24,2 ± 4,3
Nuclear	3,46 - 6,68	9,6 ± 1,7	6,8 - 13,12	18,7 ± 3,3
Oil	2,55 - 3,56	0,1 ± 0,2	2,23 - 3,12	0,1 ± 0,2
Wind	5,93 - 13,98	4,4 ± 0,8	16,57 - 39,08	12,3 ± 2,2

China 2030 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 40EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	1 - 0,9	4,5 ± 2,1	0,76 - 0,73	3,4 ± 1,6
Hydro	-7,1 - 12,14	41,1 ± 7,3	-8,36 - 14,3	48,4 ± 8,5
Nuclear	3,46 - 6,68	19,1 ± 3,4	6,8 - 13,12	37,5 ± 6,6
Oil	2,55 - 3,56	0,3 ± 0,3	2,23 - 3,12	0,2 ± 0,3
Wind	5,93 - 13,98	8,8 ± 1,6	16,57 - 39,08	24,6 ± 4,4

China 2030 - Mitigation Costs and Potential Benefits [Billion EUR2008/yr]				
Carbon Price = 60EUR2008/tCO2eq				
	Scenario 1		Scenario 2	
	Mitigation Cost	Carbon Permit Sales Receipt	Mitigation Cost	Carbon Permit Sales Receipt
Gas	1 - 0,9	6,7 ± 3,1	0,76 - 0,73	5,2 ± 2,4
Hydro	-7,1 - 12,14	61,7 ± 10,9	-8,36 - 14,3	72,7 ± 12,8
Nuclear	3,46 - 6,68	28,7 ± 5,1	6,8 - 13,12	56,2 ± 9,9
Oil	2,55 - 3,56	0,4 ± 0,5	2,23 - 3,12	0,3 ± 0,5
Wind	5,93 - 13,98	13,2 ± 2,3	16,57 - 39,08	36,9 ± 6,5

Table 12: China.2030 – GHG Mitigation Costs and Carbon Permit Sales Receipts for different carbon price assumptions

5 Results and Discussion

This chapter presents the consolidated results. The first part will focus on Austria; the second part on China. For each country, a table with all consolidated results is presented, followed by a graphical representation and discussion of the calculated fields.

5.1 Austria

The following table illustrates the results for Austria for all calculated fields, years and Scenarios.

Austria	**Oil**	**Gas**	**Hydro**	**Wind**	**Biomass**
Per-t GHG Mitigation Cost [EUR2008/tCO2eq]	284,87 - 362,56	24,4 - 48,8	-5,48 - 142,55	38,62 - 60,69	46,83 - 163,91
Mitigation Potential [Mt CO2eq/yr] - 2020.1	0,12 ± 0,15	8,14 ± 3,79	40,83 ± 7,2	3,72 ± 0,66	6,08 ± 1,15
Mitigation Potential [Mt CO2eq/yr] - 2020.2	0,19 ± 0,24	4,41 ± 2,06	41,06 ± 7,24	5,12 ± 0,91	8,82 ± 1,67
Mitigation Potential [Mt CO2eq/yr] - 2030.1	0,18 ± 0,23	8,01 ± 3,74	44,27 ± 7,81	6,45 ± 1,14	6,4 ± 1,21
Mitigation Potential [Mt CO2eq/yr] - 2030.2	0,14 ± 0,18	5,85 ± 2,73	44,27 ± 7,81	6,53 ± 1,16	9,5 ± 1,8
Mitigation Cost [Mio. EUR2008/yr] - 2020.1	33,4 - 42,5	198,6 - 397,2	-223,9 - 5820,6	143,8 - 226	284,6 - 996
Mitigation Cost [Mio. EUR2008/yr] - 2020.2	52,8 - 67,2	107,5 - 215,1	-225,1 - 5852,9	197,9 - 311	412,8 - 1444,9
Mitigation Cost [Mio. EUR2008/yr] - 2030.1	49,9 - 63,5	195,5 - 391	-242,7 - 6310,3	249,3 - 391,8	299,6 - 1048,5
Mitigation Cost [Mio. EUR2008/yr] - 2030.2	39,8 - 50,6	142,7 - 285,3	-242,7 - 6310,3	252 - 396	444,8 - 1556,9
Carbon Price = 20EUR2008/tCO2eq					
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.1	2,34 ± 3,06	162,78 ± 75,9	816,64 ± 144	74,47 ± 13,21	121,53 ± 23,02
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.2	3,71 ± 4,84	88,15 ± 41,1	821,18 ± 144,8	102,49 ± 18,18	176,31 ± 33,4
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.1	3,5 ± 4,58	160,27 ± 74,73	885,36 ± 156,11	129,1 ± 22,89	127,94 ± 24,23
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.2	2,79 ± 3,65	116,95 ± 54,53	885,36 ± 156,11	130,5 ± 23,14	189,97 ± 35,98
Carbon Price = 40EUR2008/tCO2eq					
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.1	4,69 ± 6,12	325,55 ± 151,79	1633,29 ± 288	148,95 ± 26,41	243,06 ± 46,04
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.2	7,42 ± 9,69	176,3 ± 82,2	1642,37 ± 289,6	204,98 ± 36,35	352,62 ± 66,79
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.1	7,01 ± 9,16	320,54 ± 149,45	1770,71 ± 312,23	258,2 ± 45,79	255,88 ± 48,47
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.2	5,59 ± 7,3	233,89 ± 109,06	1770,71 ± 312,23	261,01 ± 46,29	379,95 ± 71,97
Carbon Price = 60EUR2008/tCO2eq					
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.1	7,03 ± 9,18	488,33 ± 227,69	2449,93 ± 431,99	223,42 ± 39,62	364,59 ± 69,06
Carbon Trading Impact [Mio. EUR2008/yr] - 2020.2	11,13 ± 14,53	264,46 ± 123,31	2463,55 ± 434,4	307,47 ± 54,53	528,93 ± 100,19
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.1	10,51 ± 13,73	480,8 ± 224,18	2656,07 ± 468,34	387,29 ± 68,68	383,81 ± 72,7
Carbon Trading Impact [Mio. EUR2008/yr] - 2030.2	8,38 ± 10,94	350,84 ± 163,58	2656,07 ± 468,34	391,51 ± 69,43	569,92 ± 107,95

Table 13: Austria – Consolidated Results: Mitigation Potential, Mitigation Cost, and National Carbon Trading Impact (considering various carbon price scenarios)

5.1.1 Mitigation Cost per tCO2eq

As illustrated in Figure 22, most mitigation options (oils, hydro and biomass) depict relatively wide ranges of mitigation costs. Oil is clearly the most expensive one. Hydro’s mitigation costs could potentially be negative; however they may as well go up significantly due to its wide range. Gas and Wind have a rather narrow range.

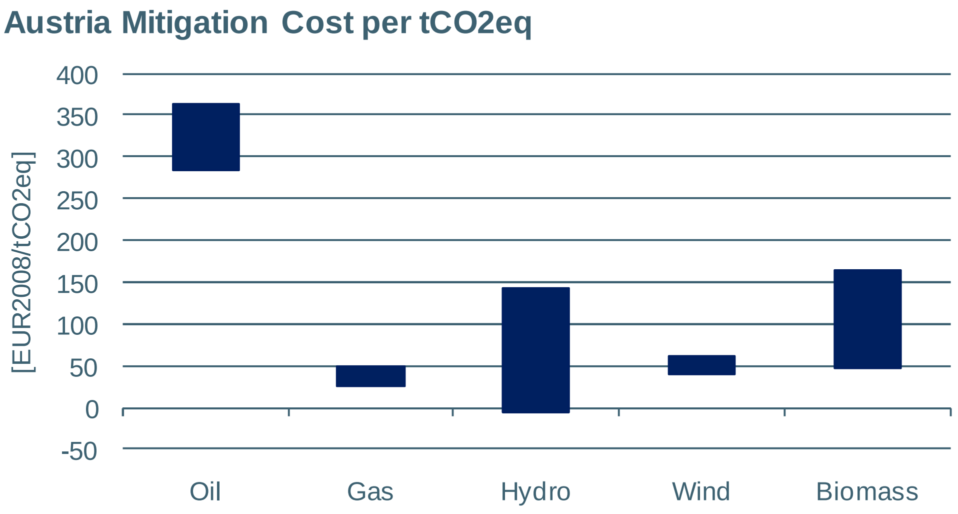


Figure 22: Mitigation Cost per tCO2eq in Austria

5.1.2 GHG Mitigation Potential for 2020 and 2030

Figure 23 illustrates the mitigation potential for 2020 and 2030 for the main electricity generation technologies in Austria. Hydro-power clearly shows the greatest mitigation potential in both years, with similar values for Scenarios 1 and 2. While gas exhibits significant mitigation potential as well in both years, its potential is generally lower in Scenario 2 than in Scenario 1. Biomass generally shows greater mitigation potential than wind, though both are comparable in size. The fact that the mitigation potential for hydro, wind and biomass is comparable in size in Scenarios 1 and 2 both in 2020 and in 2030 does indicate that the extent to which these technologies can be used seems to be limited.

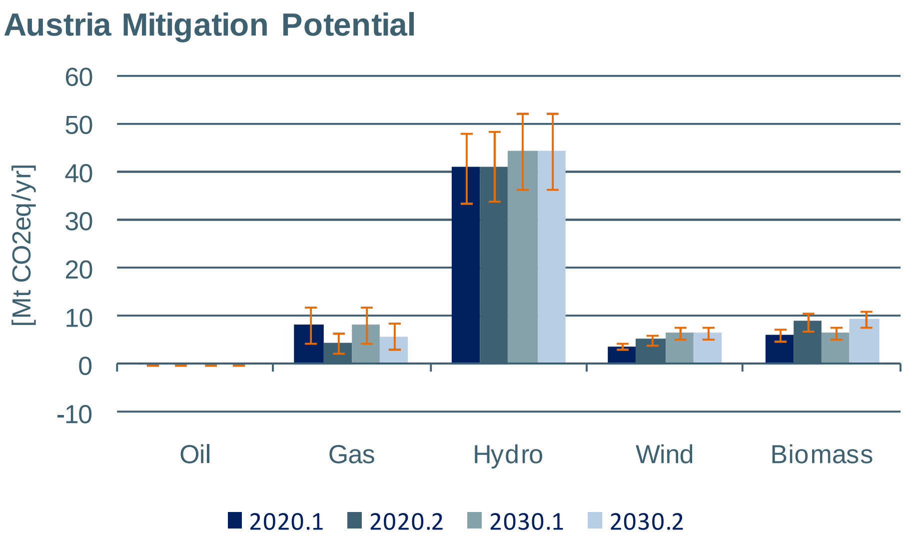


Figure 23: Mitigation Potential in Austria for 2020 and 2030

5.1.3 Mitigation Costs and National Carbon Trading Impact

For technical and clarity reasons, not all mitigation costs and carbon trading impact scenarios for the various technologies and years can be illustrated in one or two catchy graphs. The details and results for each combination can be found in Table 13. In the following, one example is depicted in order to illustrate the case for Austria, with reference also to other examples.

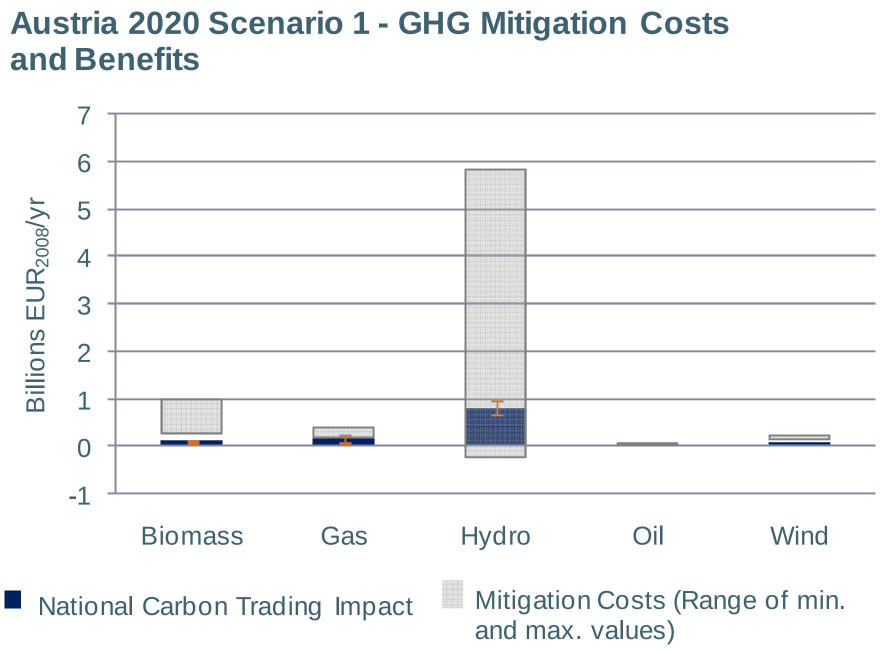


Figure 24: Mitigation Costs and Carbon Trading impacts, Austria, 2020, Scenario 1. A carbon price of 20EUR2008/tCO2eq is assumed.

In general, Figure 22 shows the ranges of the mitigation cost in EUR2008/tCO2eq for the different electricity generation options. At the same time, it can be said that these ranges represent the minimum carbon price in EUR2008/tCO2eq at which these technologies would become economic, i.e. where mitigation costs and national carbon trading impact for the respective technology would balance.

As such, Figure 24 and Figure 25 illustrate the case for Austria rather well. At a carbon price of 20EUR2008, almost all mitigation technologies are still more expensive than potential carbon permit sales receipts (= national carbon trading impact). Only Hydro at its lowest cost ranges may have the potential to reap net benefits. However, the problem with hydro power is its wide range of costs. This means that at a carbon price of 20 or even 60EUR2008/tCO2eq, hydro power’s mitigation costs may still be significantly higher than the carbon permit sales receipts it would yield. This creates a significant amount of uncertainty for Austria, as according to Figure 23 Hydro power seems to be Austria’s by far most important electricity generation technology for mitigating climate change. Uneconomic at 20EUR2008/tCO2eq, wind power seems to become economic at a carbon price of around 60EUR2008/tCO2eq (cf. Figure 25). Gas is economic at a carbon price of approximately 50EUR2008/tCO2eq or a little lower, while biomass requires a carbon price of approximately 50 – 150EUR2008/tCO2eq to become economic.

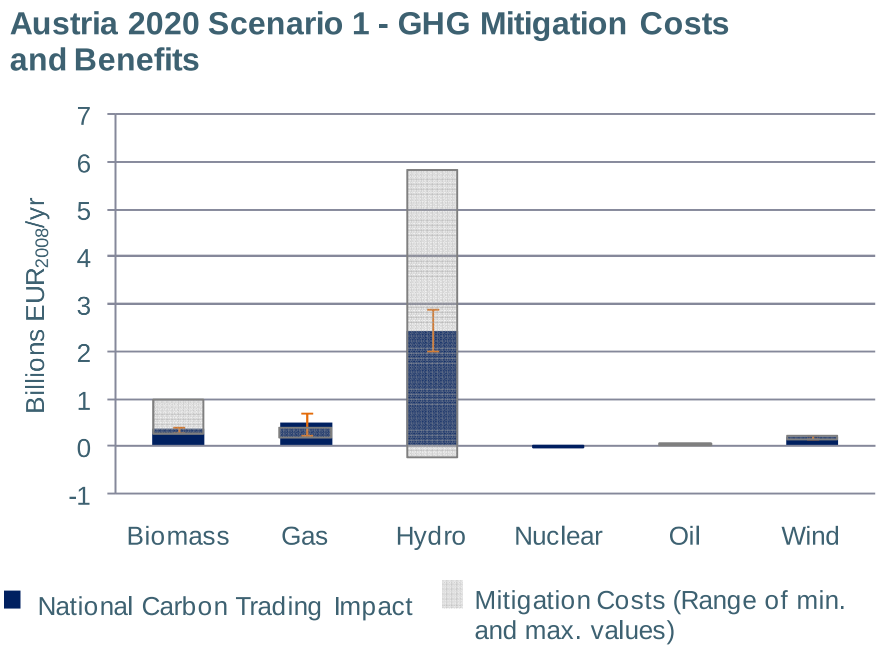


Figure 25: Mitigation Costs and Carbon Trading impacts, Austria, 2020, Scenario 1. A carbon price of 60EUR2008/tCO2eq is assumed.

5.2 China

The following table depicts the results for China for all calculated fields, years and Scenarios.

China	**Oil**	**Gas**	**Nuclear**	**Hydro**	**Wind**
Per-t GHG Mitigation Cost [EUR2008/tCO2eq]	383,38 - 534,95	8,85 - 8,43	7,25 - 13,99	-6,9 - 11,81	26,97 - 63,6
Mitigation Potential [Mt CO2eq/yr] - 2020.1	8,53 ± 11,15	68,92 ± 32,13	315,76 ± 55,79	833,59 ± 146,99	164,11 ± 29,1
Mitigation Potential [Mt CO2eq/yr] - 2020.2	7,28 ± 9,51	57,43 ± 26,78	491,29 ± 86,8	873,89 ± 154,09	356,54 ± 63,23
Mitigation Potential [Mt CO2eq/yr] - 2030.1	6,66 ± 8,7	111,77 ± 52,11	477,56 ± 84,37	1028,23 ± 181,31	219,79 ± 38,98
Mitigation Potential [Mt CO2eq/yr] - 2030.2	5,83 ± 7,61	86,15 ± 40,17	937,47 ± 165,63	1211,06 ± 213,55	614,43 ± 108,96
Mitigation Cost [Bio. EUR2008/yr] - 2020.1	3,3 - 4,6	0,6 - 0,6	2,3 - 4,4	-5,8 - 9,8	4,4 - 10,4
Mitigation Cost [Bio. EUR2008/yr] - 2020.2	2,8 - 3,9	0,5 - 0,5	3,6 - 6,9	-6 - 10,3	9,6 - 22,7
Mitigation Cost [Bio. EUR2008/yr] - 2030.1	2,6 - 3,6	1 - 0,9	3,5 - 6,7	-7,1 - 12,1	5,9 - 14
Mitigation Cost [Bio. EUR2008/yr] - 2030.2	2,2 - 3,1	0,8 - 0,7	6,8 - 13,1	-8,4 - 14,3	16,6 - 39,1
Carbon Price = 20EUR2008/tCO2eq					
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.1	0,17 ± 0,22	1,38 ± 0,64	6,32 ± 1,12	16,67 ± 2,94	3,28 ± 0,58
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.2	0,15 ± 0,19	1,15 ± 0,54	9,83 ± 1,74	17,48 ± 3,08	7,13 ± 1,26
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.1	0,13 ± 0,17	2,24 ± 1,04	9,55 ± 1,69	20,56 ± 3,63	4,4 ± 0,78
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.2	0,12 ± 0,15	1,72 ± 0,8	18,75 ± 3,31	24,22 ± 4,27	12,29 ± 2,18
Carbon Price = 40EUR2008/tCO2eq					
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.1	0,34 ± 0,45	2,76 ± 1,29	12,63 ± 2,23	33,34 ± 5,88	6,56 ± 1,16
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.2	0,29 ± 0,38	2,3 ± 1,07	19,65 ± 3,47	34,96 ± 6,16	14,26 ± 2,53
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.1	0,27 ± 0,35	4,47 ± 2,08	19,1 ± 3,37	41,13 ± 7,25	8,79 ± 1,56
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.2	0,23 ± 0,3	3,45 ± 1,61	37,5 ± 6,63	48,44 ± 8,54	24,58 ± 4,36
Carbon Price = 60EUR2008/tCO2eq					
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.1	0,51 ± 0,67	4,14 ± 1,93	18,95 ± 3,35	50,02 ± 8,82	9,85 ± 1,75
Carbon Trading Impact [Bio. EUR2008/yr] - 2020.2	0,44 ± 0,57	3,45 ± 1,61	29,48 ± 5,21	52,43 ± 9,25	21,39 ± 3,79
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.1	0,4 ± 0,52	6,71 ± 3,13	28,65 ± 5,06	61,69 ± 10,88	13,19 ± 2,34
Carbon Trading Impact [Bio. EUR2008/yr] - 2030.2	0,35 ± 0,46	5,17 ± 2,41	56,25 ± 9,94	72,66 ± 12,81	36,87 ± 6,54

Table 14: China – Aggregated Results: Mitigation Potential, Mitigation Cost, and National Carbon Trading Impact (considering various carbon price scenarios)

5.2.1 Mitigation Cost per tCO2eq

As illustrated in Figure 26, oil shows the by far greatest costs. Like in Austria, hydro power may in fact cause negative costs. Just like hydro, gas and nuclear are very competitive in China, while the mitigation cost of wind power is significantly higher.

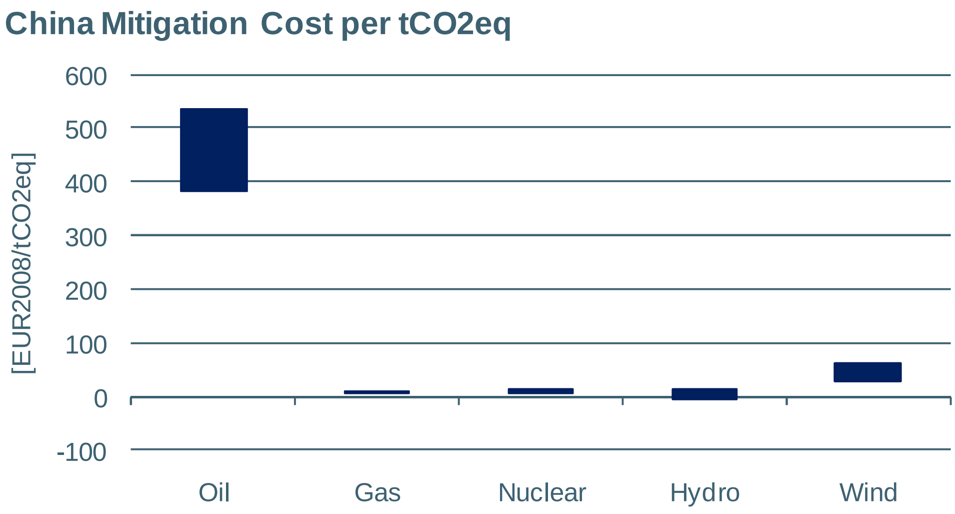


Figure 26: Mitigation Cost per tCO2eq in China

5.2.2 GHG Mitigation Potential for 2020 and 2030

Figure 27 illustrates the mitigation potential for 2020 and 2030 for the main electricity generation technologies in China. In all Scenarios, hydro shows the greatest mitigation potential, followed by nuclear. Wind is the third most important mitigation option, while gas does not show significant mitigation potential. Remarkably, in both years the mitigation potential for nuclear, hydro and wind power are significantly higher in Scenario 2 than in Scenario 1, indicating that these technologies do have a considerable potential for the mitigation of GHG. Particularly nuclear and wind power show much greater potential in the second scenarios than in the first ones, both in 2020 and in 2030.

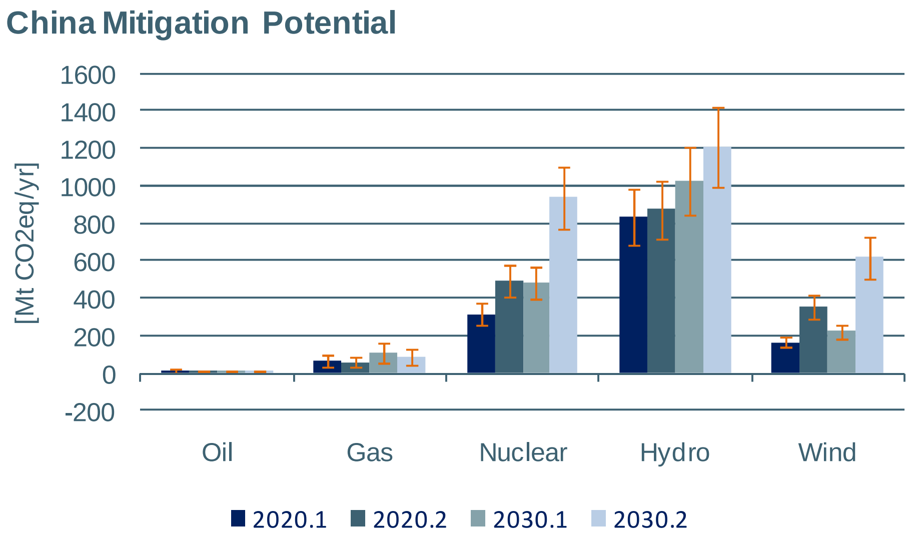


Figure 27: Mitigation Potential in China for 2020 and 2030

5.2.3 Mitigation Costs and National Carbon Trading Impact

For technical and clarity reasons, not all mitigation costs and carbon trading impact scenarios for the various technologies and years can be illustrated in one or two catchy graphs. The details and results for each combination can be found in Table 14. In the following, one example is depicted in order to illustrate the case for Austria, with reference also to other examples.

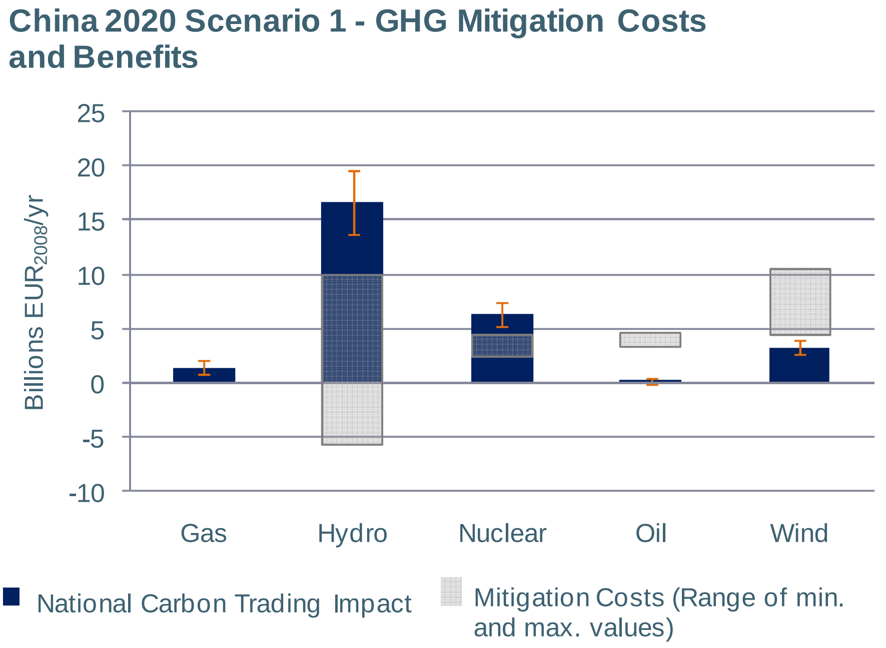


Figure 28: Mitigation Costs and Carbon Trading impacts, China, 2020, Scenario 1.
A carbon price of 20EUR2008/tCO2eq is assumed.

In general, Figure 26 shows the ranges of the mitigation cost in EUR2008/tCO2eq for the different electricity generation options. At the same time, it can be said that these ranges represent the minimum carbon price in EUR2008/tCO2eq at which these technologies would become economic, i.e. where mitigation costs and national carbon trading impact for the respective technology would balance.

With this in mind, Figure 28 and Figure 29 illustrate the case for China rather well. At a carbon price of 20EUR2008/tCO2eq, nuclear and hydro (China's two most important mitigation technologies) are even in the highest cost ranges competitive. In fact, they even appear to bring net benefits, as their impact on the national carbon trading account (through the sale of carbon permit sales receipts) outweighs the costs for employing hydro and nuclear power to produce electricity. This holds true at all scenarios, so hydro and nuclear really do have the potential to become profitable technologies already at a carbon price at the lower end of 20EUR2008/tCO2eq. Though less important in terms of mitigation potential, gas is profitable as well. Wind power, however, is not competitive at 20EUR2008/tCO2eq yet. Moving up the carbon price ladder, however, wind may become competitive at a carbon price of approximately 27EUR2008/tCO2eq, with its maximum range ending around 64EUR2008/tCO2eq. Thus at a carbon price of approximately 60EUR2008/tCO2eq, also wind power has significant potential to become an economic (or even profitable) mitigation option. In fact, Figure 29 makes apparent the significant benefits China could potentially gain from pursuing low-carbon electricity generation options (particularly hydro and nuclear) paired with membership to an international carbon trading regime.

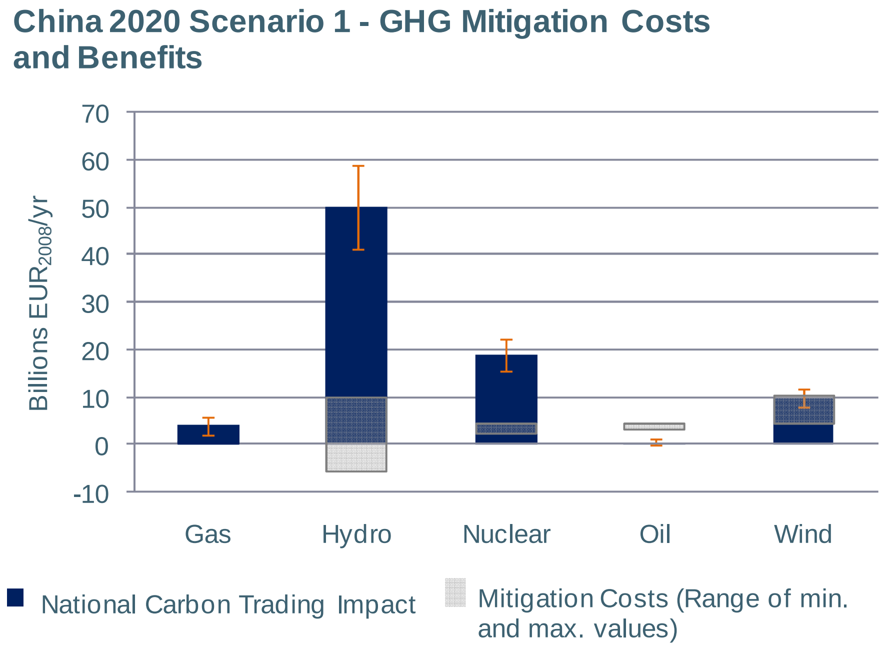


Figure 29: Mitigation Costs and Carbon Trading impacts, China, 2020, Scenario 1. A carbon price of 60EUR2008/tCO2eq is assumed.

6 Conclusion

Countries have a number of technologies at their disposal for the generation of electricity. Compared with coal-based power generation, some of these technologies offer lower carbon emissions, yet they are in most cases also more expensive in terms of levelized cost of electricity (LCOE). International carbon regimes may tackle the cost issue by putting a price on carbon emissions.

This paper has built and employed a transparent model based on exogenic data (electricity generation projections, LCOE, GHG emissions) in order to illustrate the carbon mitigation potential in China and Austria for the most significant electricity generation technologies in 2020 and 2030. Two Scenarios have been assessed for both years. Furthermore, the impact of realising these mitigation potentials on the respective national carbon trading accounts has been assessed as well. Different carbon pricing scenarios have been assumed within the framework of an international carbon trading regime to which both China and Austria are parties.

The results of this analysis show that both countries have a number of options for producing low-carbon electricity. In general, the costs for this are significantly higher in Austria. Hydro and nuclear power bear great GHG mitigation potential in China and are at the same time already profitable in the 20EUR2008/CO2eq carbon price scenario. In Austria (with nuclear being off the agenda), the single electricity generation technology bearing the greatest GHG mitigation potential is hydro power, which however is subject to a wide range in mitigation costs, resulting in significant uncertainty concerning the competitiveness of hydro power in Austria.

All in all, becoming a member of an international carbon trading regime, Austria would still need a significantly higher carbon price than China in order to render its low-carbon electricity generation sector competitive. A carbon price of 20EUR2008/tCO2eq is not enough for Austria to offset its carbon mitigation costs for any technology, except in the lowest range of hydro power costs. Increasing the carbon price to 60EUR2008/tCO2eq may make hydro, gas and wind more competitive and could even result in net gains from the sale of carbon permits, depending on exact LCOE and assuming that Austria fulfils its GHG emission obligations.

If China were to join an international carbon trading regime and at the same time would be able to fulfil its obligations therein, hydro and nuclear power appear to hold great potential for the realisation of significant profits through the sale of carbon permits on the international carbon market. Based on the data used in this model, this already holds true at a carbon price of around 20EUR2008/tCO2eq. While gas power is also competitive at this lower cost range, its mitigation potential is limited. A higher carbon price would also render wind power competitive or even profitable; hydro and nuclear power could become even more profitable. China’s electricity generation sector thus appears to be in a position to realize significant benefits from low-carbon technologies within the framework of an international carbon trading regime.

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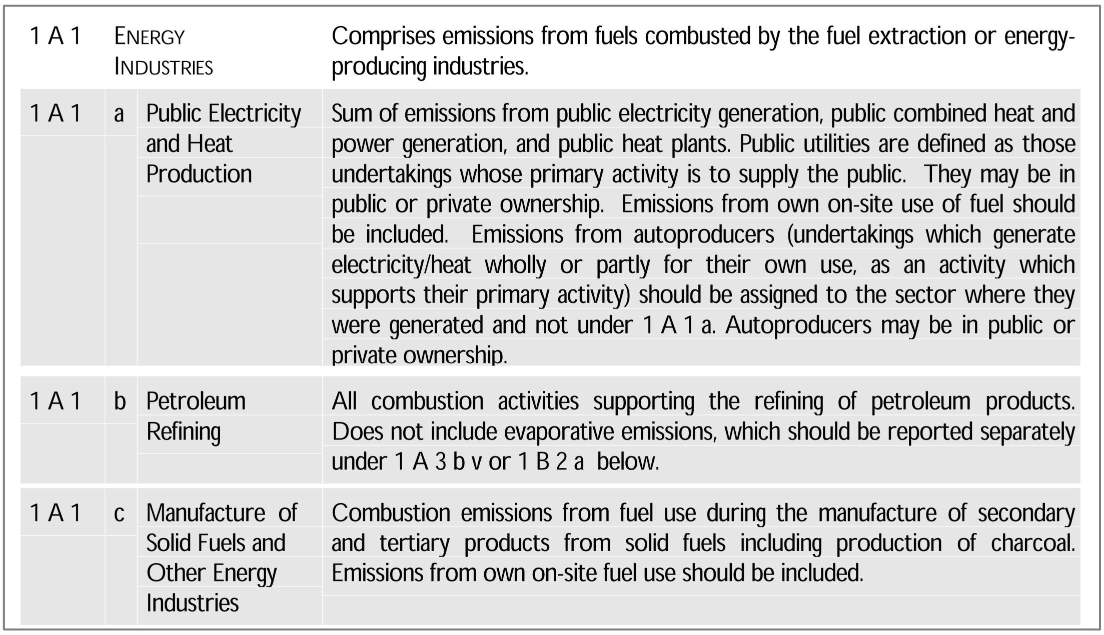
Annex

A.I The "Electricity & Heat" sector

Due to data availability, the "Electricity & Heat" sector, as used by the World Resource Institute's CAIT and in this thesis[1], does in fact correspond to IPCC Source category 1A1 "Energy Industries" (WRI 2010, p.15). IPCC Source category 1A1 is composed of (IPCC 1996, p.1.3):



1 A 1	ENERGY INDUSTRIES		Comprises emissions from fuels combusted by the fuel extraction or energy-producing industries.
1 A 1	a	Public Electricity and Heat Production	Sum of emissions from public electricity generation, public combined heat and power generation, and public heat plants. Public utilities are defined as those undertakings whose primary activity is to supply the public. They may be in public or private ownership. Emissions from own on-site use of fuel should be included. Emissions from autoproducers (undertakings which generate electricity/heat wholly or partly for their own use, as an activity which supports their primary activity) should be assigned to the sector where they were generated and not under 1 A 1 a. Autoproducers may be in public or private ownership.
1 A 1	b	Petroleum Refining	All combustion activities supporting the refining of petroleum products. Does not include evaporative emissions, which should be reported separately under 1 A 3 b v or 1 B 2 a below.
1 A 1	c	Manufacture of Solid Fuels and Other Energy Industries	Combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels including production of charcoal. Emissions from own on-site fuel use should be included.

Table 15: IPCC Source category 1A1 – Energy Industries (IPCC 1996, p.1.3)

Within the framework of this thesis, IPCC source category 1A1a "Public Electricity and Heat Production" would give the most accurate assessment of CO2 emissions from electricity generation. However, Table 16 shows that the CAIT's "Electricity & Heat" sector refers to the more aggregated IPCC 1A1 "Energy industries" category, consisting of categories 1A1a, 1A1b and 1A1c (WRI 2010, p.15):

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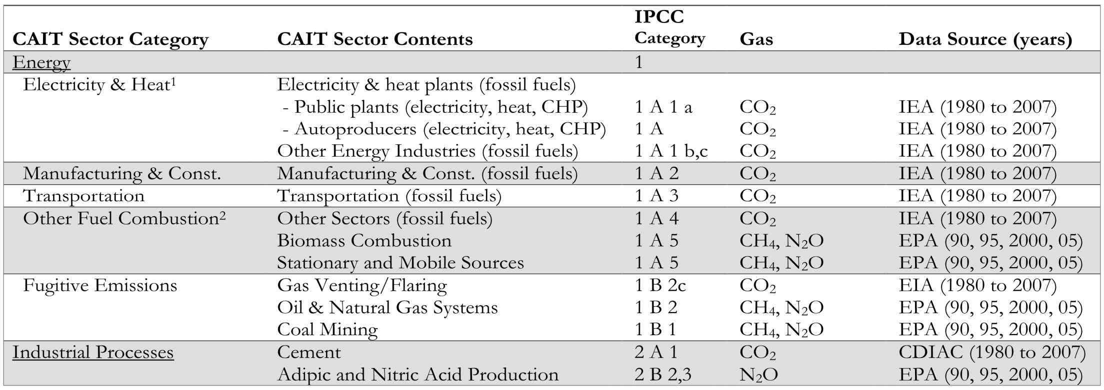
[1] Table 1: Global CO2 emissions by sector in 2005 (WRI 2011)



CAIT Sector Category	CAIT Sector Contents	IPCC Category	Gas	Data Source (years)
Energy		1		
Electricity & Heat[1]	Electricity & heat plants (fossil fuels)			
	- Public plants (electricity, heat, CHP)	1 A 1 a	CO_2	IEA (1980 to 2007)
	- Autoproducers (electricity, heat, CHP)	1 A	CO_2	IEA (1980 to 2007)
	Other Energy Industries (fossil fuels)	1 A 1 b,c	CO_2	IEA (1980 to 2007)
Manufacturing & Const.	Manufacturing & Const. (fossil fuels)	1 A 2	CO_2	IEA (1980 to 2007)
Transportation	Transportation (fossil fuels)	1 A 3	CO_2	IEA (1980 to 2007)
Other Fuel Combustion[2]	Other Sectors (fossil fuels)	1 A 4	CO_2	IEA (1980 to 2007)
	Biomass Combustion	1 A 5	CH_4, N_2O	EPA (90, 95, 2000, 05)
	Stationary and Mobile Sources	1 A 5	CH_4, N_2O	EPA (90, 95, 2000, 05)
Fugitive Emissions	Gas Venting/Flaring	1 B 2c	CO_2	EIA (1980 to 2007)
	Oil & Natural Gas Systems	1 B 2	CH_4, N_2O	EPA (90, 95, 2000, 05)
	Coal Mining	1 B 1	CH_4, N_2O	EPA (90, 95, 2000, 05)
Industrial Processes	Cement	2 A 1	CO_2	CDIAC (1980 to 2007)
	Adipic and Nitric Acid Production	2 B 2,3	N_2O	EPA (90, 95, 2000, 05)

Table 16: CAIT Sector Category “Electricity & Heat” (WRI 2010, p.15)

The CAIT’s data is itself based on a number of sources; data for the CAIT’s “Electricity & Heat” sector is based on IEA data (WRI 2010, p.15), which is available at *http://data.iea.org/ieastore/statslisting.asp* (accessed February 11, 2011). However, IEA data access is on a pay-per-view basis only, so a further disaggregation of the CAIT’s “Electricity & Heat” sector (IPCC category 1A1) into the more specific “Public Electricity and Heat Production” sector (IPCC category 1A1a) for the year 2005 is not feasible.

However, this inaccuracy is acceptable for the WRI (WRI 2010, p.15) as well as for the table it affects in this thesis (cf. footnote 1 above). This stems from the fact that the difference between IPCC category 1A1 and 1A1a does not appear to be substantial: An analysis of available IEA data from the year 2008 (IEA 2010a, p.II.81) shows that CO2 emissions from IPCC source category 1A1a (“Public Electricity and Heat Production”) are responsible for about 89% of total CO2 emissions from IPCC source category 1A1 (“Energy Industries”), as depicted in Figure 30.

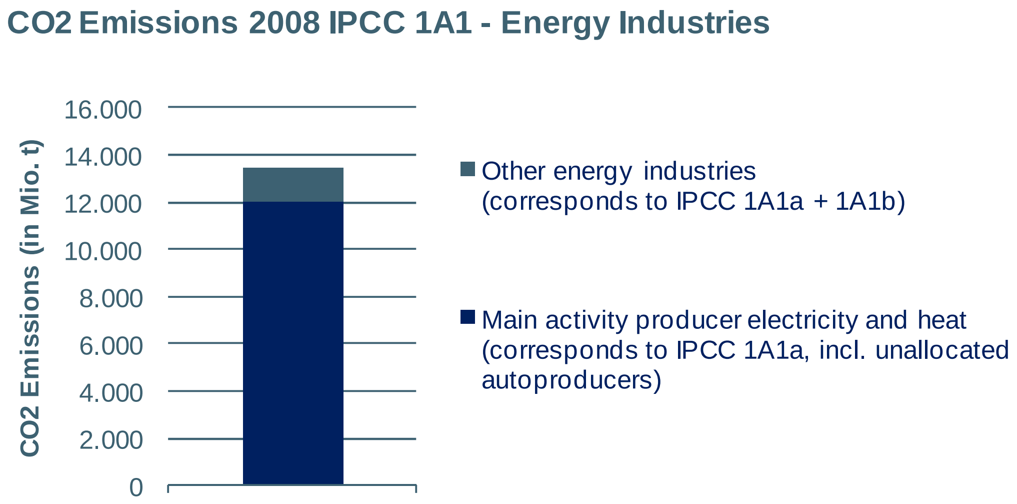


Figure 30: Global CO2 emissions in 2008 in IPCC source category 1A1 "Energy Industries". The primary source (89%) within this category is 1A1a "Public Electricity and Heat Production" (here: "Main activity producer electricity and heat"). Based on (IEA 2010, p.I.7 and II.81).

Alas, one may assume that approximately 90% of the year 2005 CO2 emissions in the CAIT's "Electricity & Heat" sector are, in fact, emitted by public electricity and heat production facilities. Likewise, this inaccuracy has no impact on the conclusion that "Electricity & Heat production is the main CO2 emitting human activity". At any rate, the model used in this thesis for projections of CO2 mitigation potential for electricity generation technologies is not affected by this.

A.II Other renewables

"Other renewables" generally is a rather heterogeneous group, with all different sorts of electricity production technologies (e.g. solar, geothermal, tidal). Costs of these technologies as well as CO2 emissions per kWh naturally vary significantly, and thus this group is not considered in the model (i.e. in mitigation potential projections, mitigation costs projections as well as projections of potential carbon permit sales receipts). However, electricity generation projections for both China and Austria in all Scenarios indicate that this group occupies only a comparatively small share in electricity production in 2020 and 2030, both Scenarios.