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ENERGY AND CLIMATE CHANGE IN CHINA

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SUMMARY The paper examines future energy and emissions scenarios in China, presenting historical data and scenarios generated using the Integrated Assessment Model WITCH. A Business-as-Usual scenario is compared with four scenarios in which Greenhouse Gases emissions are taxed, at different levels. Key insights are provided to evaluate the Chinese pledge to reduce the emissions intensity of Gross Domestic Product by 40/45 percent in 2020 contained in the Copenhagen Accord. Marginal and total abatement costs are discussed using the OECD economies as a term of comparison. Cost estimates for different emissions reduction targets are used to assess the political feasibility of the 50 percent global reduction target set by the G8 and Major Economies Forum in July 2009.

Keywords: Climate Change, China, Energy Efficiency, Energy and Development

JEL: Q4

1. Introduction

The economic growth of China has been impressive in recent years. This growth has been fuelled by a rapid industrial expansion and it causes an ever growing appetite for natural resources in general and energy in particular, with worldwide implications. China's share of global Gross Domestic Product (GDP) in 2005 was roughly 5%. Its share of global Total Primary Energy Supply (TPES) was much higher: 17%. Its share of global emissions of carbon dioxide (CO_2), the most important among all Greenhouse Gases (GHGs), was 22% in 2005. This indicates that China has high energy intensity of input and even higher carbon intensity of energy with respect to the world average. This combination of forces – high economic growth with high energy and carbon intensity – has turned China into the world leading carbon dioxide emitter in 2006, five to nine years earlier than what forecasted as recently as in 2004.

Future prospects for the Chinese economy look bright. Home to one-fifth of the world population, China has the potentiality to become a global economic giant. The road to prosperity is however still very long because China's GDP per capita is only one-fourth of the world average. Such a prolonged period of high economic growth has the potential to multiply China's carbon emissions by a factor of two or three, even if we account for massive improvements of energy efficiency.

For its present and future share of global carbon dioxide emissions China must therefore be a key player of action against global warming. However – understandably – China is not willing to accept any absolute target, as many other developing and developed economies. In the United Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) held at Copenhagen on December 2009, China has made a step forward pledging to reduce the GHGs emissions intensity of its economy by 40/45 percent with respect to 2005 in 2020. This target leaves broad flexibility to Chinese authorities and it fits well into a renewed domestic plan of action to increase energy efficiency: domestic motivations seem still to prevail on the concerns for the protection of the global public good.

This study presents long-term scenarios of energy demand, emissions, energy intensity of output and carbon intensity of energy produced using the Hybrid Integrated Assessment Model WITCH (www.witchmodel.org). WITCH is a Ramsey-type neoclassical optimal growth model with a detailed description of the energy sector. A game-theoretic structure governs the interaction of thirteen regions of the world.

A first set of scenarios of energy demand and composition is derived under the assumption that no action is taken to reduce GHGs emissions. We refer to this scenario as the Business-as-Usual (BaU). A second set of scenarios studies the transformations induced by a tax on GHGs emissions. Four scenarios will explore the implications of carbon pricing on carbon intensity of energy and energy intensity of GDP, on total GHGs emissions and on the marginal and macroeconomic cost of the climate policy.

The rest of the paper is structured as follows: Section 2 introduces the reader to historic data and to the BaU scenario. Section 2 also contains a brief overview of the WITCH model. Section 3 presents the four climate policy scenarios. Conclusions follow with several remarks on a realistic climate policy pattern for China. The Appendix displays detailed information of the optimal energy mix in the BaU and in the four policy scenarios.

2. Historic data and the BaU Scenario

Table 1 synthetically displays key data on the economy, on the energy system, on CO_2 emissions and on key efficiency indicators from 1960 to 2050, at intervals of fifteen years. Historic data (1960-2005) has been gathered from a variety of sources by the World Bank in its Development Indicators series. Future scenarios are produced using the WITCH model (Bosetti et al 2006; Bosetti, Massetti and Tavoni, 2007; Bosetti et al 2009; witchmodel.org).

WITCH (World Induced Technical Change Hybrid model) is an Integrated Assessment Model (IAM) with endogenous technical change in the energy sector at its core. The economy evolves along the lines of a Ramsey-Cass-Koopmans optimal growth framework. Thanks to a synthetic description of end-use and energy sector technologies it is possible to reduce the degree of complexity and to focus on key technological transformations: fuels switching, energy efficiency, cost reductions in existing technologies and R&D investments to foster innovation.

	1960	1975	1990	2005	2020	2035	2050
The Economy							
GDP (trillions constant 2000 US$)							
China	0.07	0.13	0.44	1.91	7.38	17.00	28.00
OECD	6.07	12.00	19.49	27.75	46.98	63.00	79.82
World	7.28	14.70	24.22	36.71	69.70	110.27	159.47
GDP per capita (constant 2000 US$)							
China	105	146	392	1464	5164	11587	19741
OECD	8523	14501	21403	27743	41069	53792	68047
World	2400	3611	4587	5676	9094	12846	17356
GDP Growth rate (percentage, average over fiftheen years interval)							
China	--	2.2	6.8	9.2	8.8	5.5	3.6
OECD	--	3.6	2.6	1.7	2.6	1.8	1.6
World	--	2.8	1.6	1.4	3.2	2.3	2.0
The Energy System							
Energy use (Mt of oil equivalent)							
China	--	484	863	1690	2698	4008	4951
OECD	1884	3529	4322	5239	5991	6619	7152
World	--	6094	8556	11090	13391	16936	20167
Energy use (kg of oil equivalent per capita)							
China	--	528	760	1296	1887	2731	3491
OECD	2763	4266	4746	5238	5237	5652	6098
World	--	1366	1666	1769	1747	1973	2195
Fossil fuel energy consumption (% of total)							
China	--	64	75	85	89	91	92
OECD	94	93	84	82	92	90	89
World	94	83	81	81	88	89	89

	1960	1975	1990	2005	2020	2035	2050
CO2 Emissions							
CO2 emissions (Gt)							
China	0.78	1.14	2.46	5.61	9.32	13.91	17.44
OECD	5.70	9.85	10.94	12.40	17.06	19.35	21.85
World	9.44	16.91	22.53	29.21	38.49	50.41	62.54
CO2 emissions (metric tons per capita)							
China	1.17	1.25	2.17	4.30	6.52	9.48	12.30
OECD	8.01	11.90	12.01	12.40	14.91	16.52	18.63
World	3.11	4.15	4.27	4.52	5.02	5.87	6.81
Population, total (billions)							
China	0.667	0.916	1.135	1.304	1.430	1.468	1.418
OECD	0.712	0.828	0.911	1.000	1.144	1.171	1.173
World	3.032	4.071	5.279	6.467	7.664	8.584	9.188
Efficiency Indicators							
Carbon Intensity of Energy (t of CO2 per Mt of oil equivalent)							
China	--	2.4	2.8	3.3	3.5	3.5	3.5
OECD	3.0	2.8	2.5	2.4	2.8	2.9	3.1
World	--	2.8	2.6	2.6	2.9	3.0	3.1
Energy Intensity of GDP (t of oil eq. per 1,000 constant 2000 US$)							
China	--	3.63	1.94	0.89	0.37	0.24	0.18
OECD	0.31	0.29	0.22	0.19	0.13	0.11	0.09
World	--	0.41	0.35	0.30	0.19	0.15	0.13
Carbon Intensity of GDP (t of CO2 eq. per 1,000 constant 2000 US$)							
China	--	8.58	5.53	2.94	1.26	0.82	0.62
OECD	0.94	0.82	0.56	0.45	0.36	0.31	0.27
World	--	1.15	0.93	0.80	0.55	0.46	0.39

Notes: 1960-2005 historic data aggregated by the World Bank Development Indicators. Fossil fuel comprises coal, oil, petroleum, and natural gas products (source: International Energy Agency). Energy use refers to use of primary energy before transformation to other end-use fuels (source: International Energy Agency). Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement (source: CDIAC). GDP at purchaser's prices data are in constant 2000 U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2000 official exchange rates (Source: World Bank national accounts data, and OECD National Accounts data files). Population data is from a variety of sources, midyear estimates. 2020-2050 data are from the WITCH model Business-as-Usual scenario.

Table 1. Historic data and future scenario on the economy, energy system and emissions.

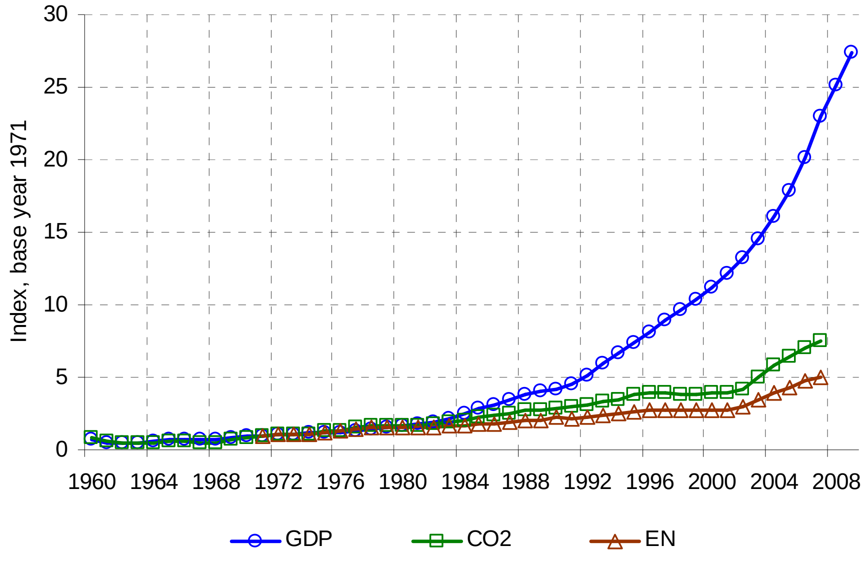
A second peculiarity of WITCH is a characterization of the non-cooperative interaction of world regions – on global climate, technology and natural resources – by means of an open-loop Nash game, as in the Rice model (Nordhaus and Yang 1996, Nordhaus and Boyer 2000). International R&D spillovers and global learning connect the technological frontier of all regions in this non-cooperative framework (Bosetti et al 2008). In an enhanced versions of the WITCH model technical change can be directed towards the capital-labour aggregate and knowledge spillovers are modelled at both domestic and international level (Carraro, Massetti and Nicita 2009; Massetti and Nicita 2010).

The Chinese economy has expanded at remarkably high rates during the past thirty years. From 1975 to 1990 China’s GDP has grown at an average rate of 6.8 percent per year. From 1990 to 2005 the expansion of the economy has been even faster, with an average growth rate of 9.2 percent per year. In our BaU scenario we expect a modest contraction of economic growth between 2005 and 2020 and a gradual decline over the next decades. Despite the slow-down of economic expansion, China's economy grows at an average yearly rate of 3.6 percent in 2050, as fast as the OECD economies in the Sixties (90 years earlier). Economic growth has fuelled and unprecedented improvement in the standard of life in China during the past thirty years. Average GDP per capita increased fourteen-fold from 1960 to 2005. During the same period GDP per capita in OECD economies has only increased three-fold. Despite this remarkable difference the average OECD citizen was nineteen times richer than the average Chinese in 2005. We expect moderate convergence in income per capita between Chinese and OECD economies and a wide gap is likely to persist for still many years: in 2050 GDP per capita is 3.5 times higher in OECD economies than in China in our BaU scenario.

The persistence of the income gap between the richest economies and China has – and will have – important repercussions in all international negotiations to share the global cost of containing global warming. However, China will likely surpass the world average per capita GDP around 2035, in our scenarios. Thus, China will emerge as a peculiar actor in future climate negotiations. From one side, there are factors that will push towards a limited involvement: China will not be as affluent as the major world economies for most of the century and Chinese emissions per capita will still be 50 percent lower than in OECD economies. On the other side, there are factors that will push towards a higher commitment: China is and will likely remain the major emitter of GHGs during the whole century – capable of nullifying the efforts of other economies to control global warming – with a growing responsibility towards all poorer economies that will bear heavy negative climate change impacts (China will surpass global average GDP around 2040 in our BaU Scenario).

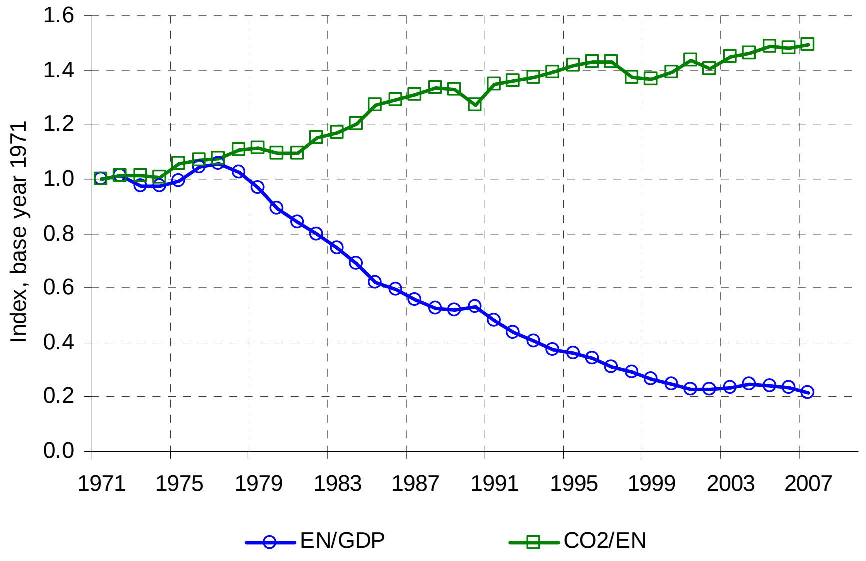
The rise of energy consumption during the past thirty years has been much less impressive than the rise of the economy in China. While the GDP has increased 14.7 times between 1975 and 2005 total energy use has increased only 3.5 times (see Table 1 and Figure 1), making it possible to produce in 2005 the same level of aggregate output than in 1975 with only one-fourth of energy inputs (see Figure 2).

Levine, Zhou and Price (2009) distinguish among three different eras in China's energy story. The first is the "Soviet Model" and goes from 1949 to 1980. In these early years of the communist regime China followed the Russian model with low energy prices, predominance of heavy industries and no concern for environmental effects. This lead to very high inefficiencies both on the demand and supply side. The "Classic" period goes from 1980 through 2002. In 1980 Deng Xiaoping stated the goal to quadruple GDP while only doubling energy consumption between 1980 and 2000. New institutions were created to promote energy conservation, among them the most important was the Bureau of Energy-Saving and Comprehensive Energy Utilization in the State Planning Commission. Energy conservation centres were spread throughout the country, employing more than 7,000 people at their peak. All these efforts – together with a long-term shift of the economy towards less energy intensive industries – explain the success of Chinese energy demand management, well beyond Deng Xiaoping's expectations. Finally, from 2002 trough 2005 China lived a phase of "Out-of-control Growth" in energy demand (see Figure 1 and Figure 2). Levine, Zhou and Price (2009) believe that the sharp increase in energy use and the reversal of the long-term energy intensity trend is explained by more lenient policies to manage energy demand and by a fast expansion of energy intensive industries, stimulated by exports (China enters the WTO in 1995) and by domestic demand (cement and steel to build infrastructures). Emissions of CO_2 skyrocketed from 2002 to 2005, surpassing U.S. emissions in 2006 (Levine and Aden 2008), between nine and fourteen years earlier than what estimated in 2004.



Source: see notes to Table 1. Base year 1971.

Figure 1. Long-term time series of GDP, CO_2 emissions and energy use.



Source: see notes to Table 1. Base year 1971.

Figure 2. The indices of energy intensity of GDP and of carbon intensity of energy.

The share of fossil fuels in total energy consumption has increased during the past thirty years. Fossil fuels covered 64% of energy demand in 1975, 75% in 1990 and 85% in 2005 (Table 1). Coal – the fossil fuel with the highest content of carbon per unit of energy – has played a major role in satisfying the growing appetite for energy in China. Between 2003 and 2005 the power sector has seen the fastest expansion ever recorded in world history: 66GW of new capacity were installed each year, with a dominant role of coal-fired power plants (Zhou, Levine and Price 2010). About 200GW of new capacity translate into more than one large coal power plant of 1GW per week. Since the expected lifetime of coal-fired power plants is about forty years, three years of “Out-of-Control Growth” of energy will have repercussions on global CO_2 emission for many decades.

Energy use triples between 2005 and 2050 in our BaU scenario, from 1,690 to 4,951 Mt of oil equivalent (Mtoe). At global level an extra 9,077 Mtoe of energy will be needed in 2050 with respect to 2005, 55% of this incremental demand will go to China. Strong efficiency gains are able to slow down the growing appetite for energy but are not able to stop it: in 2005 China used 0.89 tonnes of oil equivalent (toe) per 1,000 US$ of output, in 2050 0.18 toe/’000. Compared to OECD economies China reduces its energy intensity of output twice as faster from 2005 to 2050 (Table 1). The average annual optimal contraction of energy intensity in our BaU scenario is equal to 3.5 percent from 2005 to 2050, lower than the average 4.6 percent per year decline from 1975 to 2005, but it represents a net reversal compared to the “Out-of-Control” years in which energy intensity increased an average 3.8 percent per year.

There are reasons to expect that a fourth era in the Chinese story of energy efficiency is about to begin. Levine, Zhou and Price (2009) call this a “modern re-enactment of the early days.” A key role will be played by governmental regulation. In November 2005 the Politburo mandated a 20 percent reduction by 2010 in energy intensity, compared to 2005 (an average 4.3 percent per year). Chinese officials perceive all the threats that an out-of-control expansion of energy demand will pose to future economic growth and have put energy efficiency again at the top of their agenda. “Ten Key Projects” were incorporated in the 11th Five Year Plan. The most important actions include: the renovation of coal-fired industrial boilers; district-level combined heat and power projects; oil conservation and substitution; and energy efficiency and conservation in buildings (Levine, Zhou and Price 2009; Zhou, Levine and Price 2010). A decisive contribution to higher energy efficiency will come from market forces: energy prices are currently reflecting their actual costs in China (IEA 2007); The electricity prices were increased from 0.43 RMB/kWh in May 2004 to 0.51 RMB/kWh in July 2006

(Moskovitz et al 2007).[1]

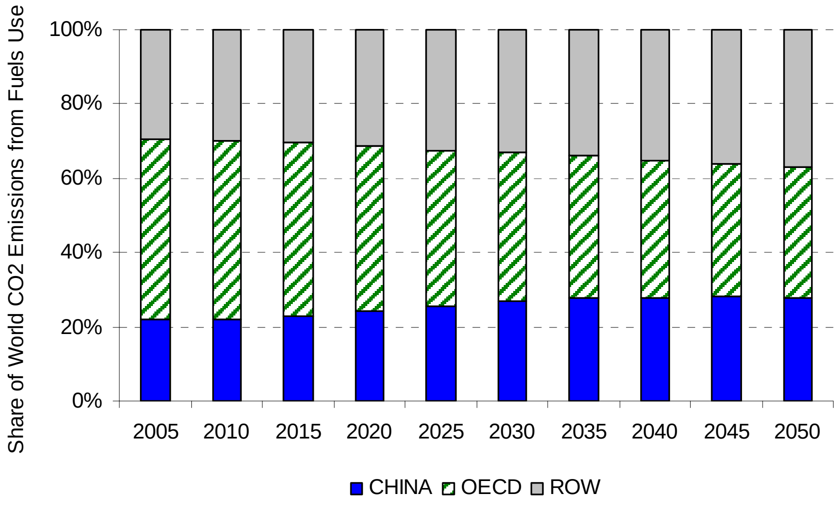
It is not possible to assess to what degree current policies to contain energy efficiency have been successful, but preliminary data show that energy intensity declined by 3.7 percent in 2007 and by 4.6 percent in 2008. The global economic crisis of 2007-2009 has probably had a major impact in reducing international demand for energy intensive goods, but the commitment of the Chinese government to put energy management on top of the agenda cannot be denied. China seems therefore in track to achieve its mandated 20 percent reduction target in 2010.

Understanding the future trend of energy intensity is crucial to derive sensible scenarios of CO_2 emissions from fuels use in China. The carbon content of energy is in fact expected to change only marginally. Coal is a cheap and abundant source of energy for China. It plays and it will continue to play a major role in the next decades if aggressive policies to reduce global warming are not implemented. Although renewables and nuclear are by far the energy sources with the fastest growth rate in our BaU scenario (see Table 2), they remain marginal for many decades. In our scenario the share of fossil fuels in energy use increases from 85 to 92 percent, in line with the historic trend (Figure 1 and Figure 2); the carbon content of energy increases from 3.3 to 3.5 ton of CO_2 per Mtoe, but it roughly remains the same from 2020 until 2050. Total emissions will therefore be driven by population, economic growth and energy use.

A moderate growth of population, a fast expansion of economic activity and a marginal increase of carbon intensity of energy translate into a three-fold expansion of CO_2 emissions from fuels use from 2005 to 2050 in the BaU scenario. China will be the largest emitter in the world, with a share of 27 percent of global emissions (Figure 3). Emissions per capita will increase to 12.3 tons, 80 percent higher than the world average but still 35 percent lower than in OECD economies. Higher energy use is responsible for 90 percent of the incremental carbon emissions in 2050 with respect to 2005; increased carbon intensity of energy for the remaining 10 percent.

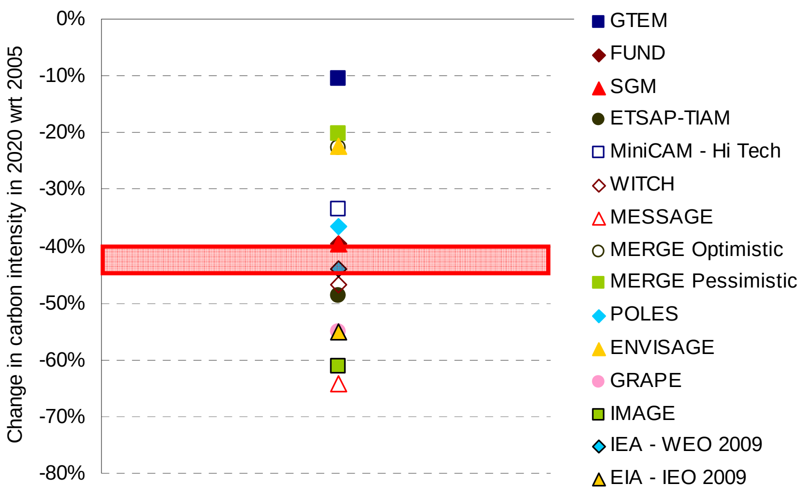
An intense debate on the future pattern of energy efficiency in China has spurred after China pledged in the Copenhagen Accord to reduce the

[1] IEA (2007) and Moskovitz et al (2007) cited in Zhou, Levine and Price (2010).



Source: WITCH model Business-as-Usual Scenario.

Figure 3. Share of global CO_2 emissions from fuels use.



Notes: Carbon intensity reductions for China as predicted in the reference scenarios of the EMF22 participating models, the International Energy Agency (IEA) World Energy Outlook 2009, the Energy Information Administration (EIA) International Energy Outlook 2009. The shadowed box marks the -40/-45 percent target of China pledged in the Copenhagen Accord. *Source*: adapted from Tavoni (2010).

Figure 4. Carbon intensity reductions for China in 2020.

GHGs emissions content of GDP by 40-45 percent in 2020 compared to 2005.

Although not biding, this target reflects the present commitment of Chinese authorities to reduce GHGs gases and researchers have tried to estimate by what degree the proposed plan of action would differ from the reference scenarios.[2]

We find that China achieves a 57 percent contraction of carbon intensity of output already in our BaU scenario. Since other GHGs emissions decline at a slower pace, the overall emissions intensity of the economy would decline by 47 percent. Well above the Chinese pledge. How do our results compare with the historical trend and with analogous studies in the literature?

If we use the 5 percent annual rate of energy intensity decline experienced from 1980-2002 (the "classic" period), and we leave unchanged the carbon intensity of energy, the carbon intensity of GDP would decline by 53 percent in 2020 with respect to 2005. Our scenarios thus seem optimistic when compared to historic data.

Tavoni (2010) gathered energy and emissions scenarios from the Energy Modeling Forum 22 (EMF 22), the International Energy Agency (IEA) World Energy Outlook 2009 and the Energy Information Administration (EIA) International Energy Outlook 2009, to compare China's pledge to scenarios in the literature. The result is shown in Figure 4. Nine out of fifteen models expect that China will achieve the -40 percent target in the reference scenario, with the median exactly at -40 percent. WITCH's emissions intensity of the economy lies below the median but well within a 50 percent confidence interval around the median.

The renewed commitment of the Chinese government to reduce the energy dependency of their economy is a sign that the international pledge fits well into the domestic framework of action to guarantee stable economic growth in the next decades. For this reason it should not be a surprise if China meets its Copenhagen pledge in many models' reference scenarios. Energy efficiency improvements will come at a cost, but direct and side-benefits motivate action in China without making any specific reference

[2] China also committed to increase the share of non-fossil fuels in primary energy consumption to around 15% by 2020 and to increase forest coverage by 40 million hectares and forest stock volume by 1.3 billion cubic meters by 2020 from the 2005 levels.

to climate change, which is exactly what the reference scenario reflects.

3. Climate Policy

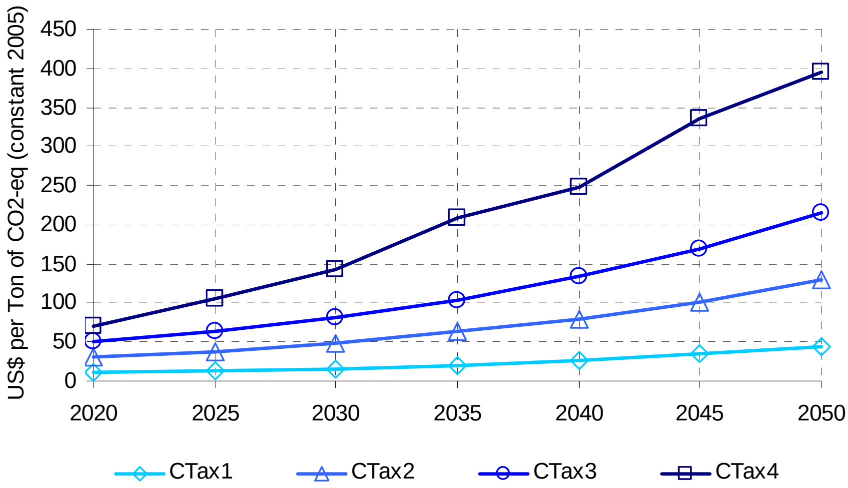
In this Section we explore scenarios in which explicit policy measures are taken to reduce the level of GHGs emissions in China. We focus here on four emissions tax scenarios which span a plausible range of emissions reductions targets in the next fifty years. We assume that the same tax applies to all world regions, therefore including spillovers on natural resources use and on technological progress triggered by climate policy. The four tax scenarios all start from 2020, beyond the horizon of the Copenhagen Accord. The CTax1 scenario starts with a tax on all GHGs emissions fixed at 10 US$ per ton of CO_2-eq; the CTax2 scenario starts from 30 US$ per ton; the CTax3 from 50 US$. In all three scenarios the tax then increases at 5% per year. We include a fourth scenario (CTax4) which induces emissions reductions in line with a global GHGs concentrations target of 535 ppm at the end of the century.[3] Figure 5 displays the time path of the four carbon taxes.

Figure 6 displays the pattern of emissions in the four policy scenarios compared to the BaU in China and in OECD economies. The CTax4 scenario is the most demanding in terms of emissions reductions, followed closely by the CTax3 scenario and the Ctax2 scenario. The lowest tax achieves only "moderate" emissions reductions.[4]

Figure 7 displays the percentage deviation of emissions in each tax scenario with respect to the BaU and with respect to the level of emissions in 2005. It is useful to check what is the level of taxation that is coherent with the emissions reduction pledges of Annex I countries in the Copenhagen Accord. The US have pledged to reduce GHGs emissions by 17% in 2020 with respect to 2005. The EU has an internal binding target to reduce emissions by 20% with respect to 1990 (-13% wrt 2005) and has pledged to reduce

[3] The emissions tax is obtained by solving the model imposing a global pattern of emissions that is consistent with the 2100 concentration target and allowing countries to trade emissions allowances internationally to equate marginal abatement costs. We then run the model imposing the carbon price as a tax, thus avoiding complex distribution issues. This concentration target is equivalent to a temperature increase of 2.5°C above the pre-industrial level with median probability in 2100, well above the stated objective of keeping temperature increase below the 2°C.

[4] WITCH is a perfect foresight model. The level of future taxation influences present decisions. Therefore it is optimal to smooth the transition to a regime of emissions taxes in WITCH. This explains why emissions decline with respect to the BaU before 2020 in Figure 6 and Figure 7. Equivalently, the high level of taxes in 2050 affects investment decisions in earlier years.

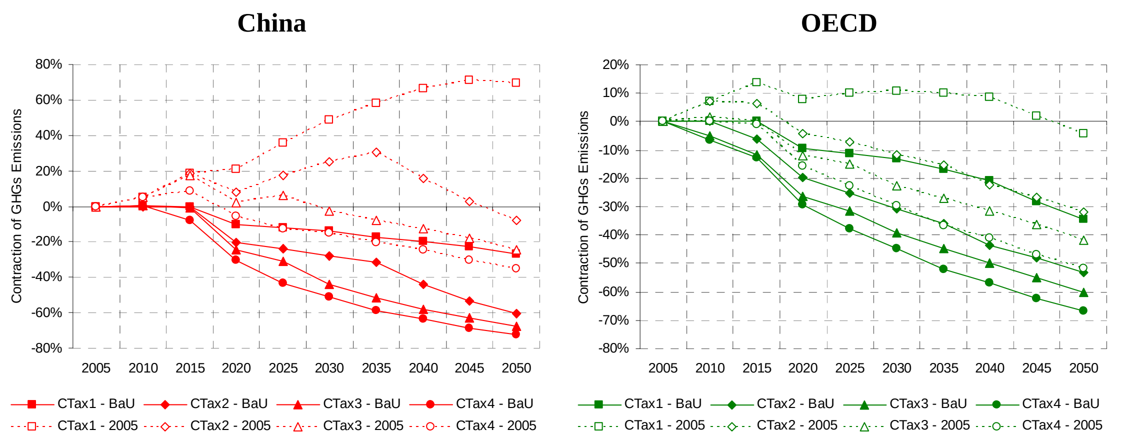


Notes: All GHGs emissions included. Source: WITCH model.

Figure 5. The emissions tax scenarios.

Source: WITCH model.

Figure 6. The time pattern of Greenhouse Gases (GHGs) emissions in China and OECD economies, in the BaU and in the tax scenarios.



Notes: Solid lines mark the change of GHGs emissions with respect to the BaU level. Dashed lines mark the change of GHGs emissions with respect to the level in 2005. Source: WITCH model.

Figure 7. Change in Greenhouse Gases (GHGs) emissions trajectories in China and OECD economies, in the tax scenarios.

emissions by 30% with respect to 1990 (-24% wrt 2005), if a global ambitious climate treaty is signed. Japan has pledged to reduce emissions by 25 percent with respect to 1990 (-29% wrt 2005).[5] Our analysis reveals that the level of emissions reductions promised in Copenhagen implies a tax greater than 50 US$ per ton of CO_2-eq in 2020 (right panel of Figure 7).

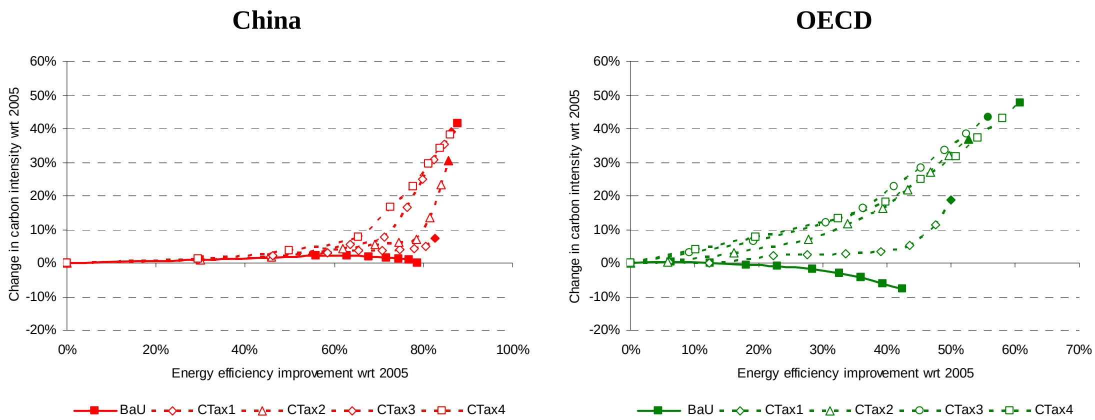
A second useful check is to assess if the taxation level in 2050 is coherent with the long-term 80 percent emissions reductions target set by the Group of eight (G8) for high income economies. The highest price of emissions in 2050 that we consider (400 US$ per ton of CO_2-eq) is not able to meet the 80 percent reduction target (right panel of Figure 7)[6] Therefore, our scenarios are quite conservative and do not cover the case of aggressive climate policies.

The left panel of Figure 7 focuses on China. In order for emissions to be lower than the 2005 level the tax must be higher than 130 US$ per ton of CO_2-eq in 2050. In OECD economies 40 US$ per ton of CO_2-eq in 2050 are sufficient to keep the emissions at 2005 level. However China's emissions are very reactive to the price of the tax if we use the BaU as a term of comparison. Even a modest 40 US$ per ton of CO_2-eq in 2050 would deliver a contraction of emissions greater than 20 percent with respect to the BaU (left panel of Figure 6 and Figure 7). This implies 4 less Gton of CO_2-eq in the atmosphere in 2050, equivalent to 80 percent of emissions of the EU27 in 2005. This explains how important is that China puts in place even a modest climate policy.

The transformations induced by climate policy can be grouped into two major categories: those increasing energy efficiency and those decreasing the carbon content of energy. WITCH produces scenarios with the optimal mix of action along these two trajectories (Figure 8). The sufficiently high detail of the energy sector allow to study also the optimal mix of alternative energy technologies (for details see the Appendix).

Figure 8 gives a synthetic description of optimal movements along the dimension of energy efficiency and of de-carbonization of energy. The solid lines in both the right (OECD) and left (China) panels refer to the BaU scenario. In both China and OECD economies energy efficiency increases substantially

[5] See Carraro and Massetti (2010) for a detailed analysis of the Copenhagen Accord.
[6] It is not clear the reference year for the emissions cuts. We consider here 2005.



Notes: Each data point marks the combination of decarbonization of energy and energy efficiency improvements with respect to 2005. Negative values of decarbonization improvements mean that the carbon content of energy is increasing. Source: WITCH model.

Figure 8. The time pattern of carbon intensity of energy and energy intensity of GDP in China and OECD economies, in the BaU and in the tax scenarios.

		COAL (NO CCS)	GAS	OIL	NUCLEAR	HYDRO	BIOMASS	WIND and SOLAR	TPES
2030-2005 (average per year)									
	BaU	2.5%	3.9%	3.9%	4.6%	3.5%	0.0%	7.9%	2.7%
	CTax1	1.8%	4.0%	3.9%	5.7%	3.5%	0.0%	9.3%	2.3%
	CTax2	0.8%	3.9%	3.6%	7.4%	3.5%	0.0%	11.4%	1.7%
	CTax3	-0.8%	4.0%	3.6%	8.6%	3.5%	0.0%	12.8%	1.3%
	CTax4	-1.6%	3.4%	3.1%	9.0%	3.5%	0.0%	13.3%	1.1%
2050-2005 (average per year)									
	BaU	2.2%	2.8%	2.9%	3.8%	2.2%	0.1%	7.8%	2.2%
	CTax1	1.3%	3.0%	2.7%	5.2%	2.2%	0.1%	9.6%	1.7%
	CTax2	-0.5%	2.7%	2.2%	6.7%	2.2%	0.1%	11.6%	1.2%
	CTax3	-1.2%	2.8%	1.8%	7.1%	2.2%	0.1%	12.2%	1.1%
	CTax4	-1.4%	2.1%	1.2%	7.5%	2.2%	0.1%	12.8%	0.9%

Notes: Coal with Carbon Capture and Storage (CCS) and backstop carbon-free technologies not included because not used in 2005.

Table 2. Average growth rate of different components of Total Primary Energy Supply.

in the BaU. As already discussed, the energy content of output declines in China at twice faster than in OECD economies. While carbon intensity of energy remains rather stable in China, in our BaU scenario it is optimal to increase slightly carbon intensity in OECD economies. It is easy to understand why there are no reductions in the carbon intensity of energy in the BaU scenario: without any concern for global warming world countries continue to rely for many decades on abundant and relatively cheap fossil fuels.

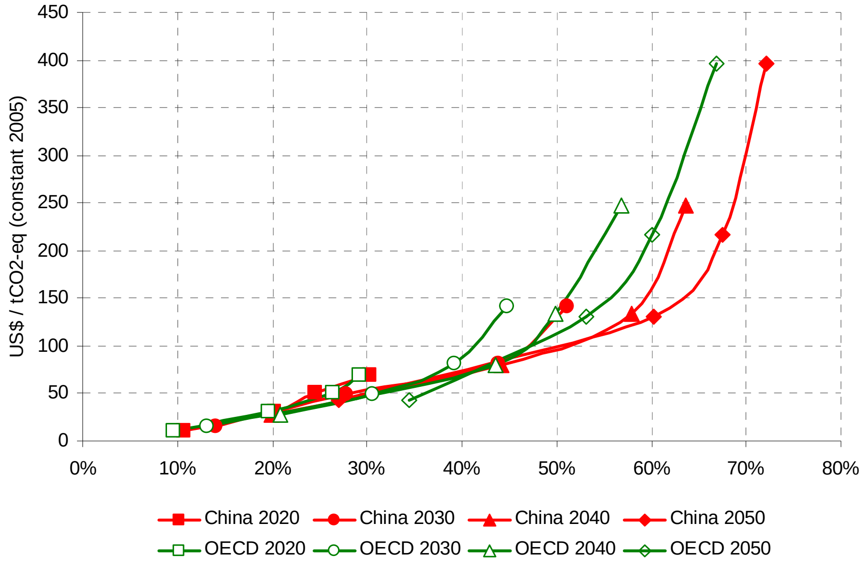
The introduction of emissions taxes reinforces the trend of energy efficiency improvements (especially in OECD economies) and tilts up-ward all curves, indicating a substantial de-carbonization of energy in all scenarios. The optimal contraction of the carbon content of energy with the lowest tax scenarios is twice as high in OECD economies than in China. With high taxes both China and OECD economies converge to a 40/50 percent reduction of carbon intensity of energy in 2050.

What are the transformations needed in the power sector and in the energy system as a whole to reduce substantially the carbon content of energy in China? Table 2 presents synthetic information on major energy technologies that are used both in the BaU and in the climate policy scenarios. For a more detailed description of the contribution of each energy source to total primary energy supply (TPES) we refer to the Appendix.

The fastest growing components of TPES in the BaU are Wind and Solar and Nuclear. In all climate policy scenarios Wind and Solar and Nuclear receive further momentum. Coal that is not burnt using CCS is the biggest loser in a climate policy scenario, although in the CTax1 scenario coal loses only shares of TPES but grows from 2005 level at both the 2030 and 2050 time horizons. With the CTax2 scenario Coal grows in absolute terms at least until 2030. The growth of TPES will decline substantially, especially from 2030 until 2050, but TPES will be higher in 2050 than in 2030. With the most stringent climate policy scenario TPES grows 43 percent from 2005 to 2050 and oil demand will increase by 70 percent in the same period.

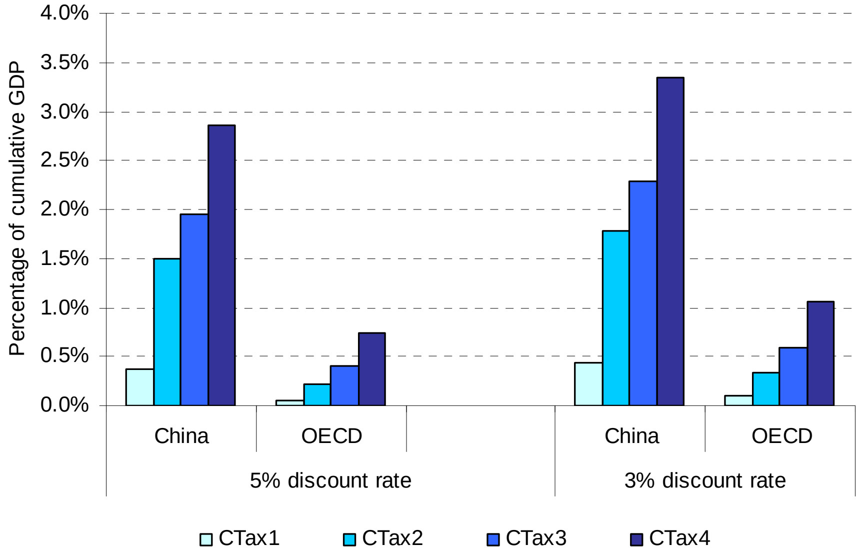
What are the marginal and total costs of reducing emissions in China and how do they compare with costs in OECD economies? Figure 9 and Figure 10 present information on these important aspects.

The first message is that marginal abatement cost curves (MACCs) are time specific in long-term IAMs. The economy, the technology, the cost of fuels change as time goes by and influence the cost of reducing emissions. Technical progress in carbon-free technologies is a major driver of MACCs. Learning-by-doing and learning-by-researching will reduce the cost of installing and operating wind mills, for example.



Notes: Marginal abatement cost curves include all GHGs. Abatement potential at different GHGs emissions values. Abatement potential expressed in percentage of emissions reductions in the BaU for comparability. Source: WITCH model.

Figure 9. Marginal abatement cost curves.



Notes: Costs are expressed as the ratio between the discounted sum of GDP losses with respect to the BaU scenario and cumulative discounted GDP in the BaU scenario. Two alternative discount rates are used. The interest rate is endogenous and region specific in WITCH. In China, in 2005 the interest rate is equal to 7 percent, in 2050 is equal to 4.3 percent. Source: WITCH model.

Figure 10. The cost of reducing GHGs emissions.

For this reason Figure 9 displays MACCs from 2020 to 2050 at ten years intervals, using data from the four tax scenarios.

A first analysis of Figure 9 clearly shows that MACCs are highly non-linear, in each given year. Increasing the rate of emissions abatement beyond a given threshold increases costs beyond what might be economically and politically acceptable.

The second key message that emerges from Figure 9 is that OECD economies have steeper MACCs than China. An emissions tax equal to 216 US$ per ton of CO_2-eq induces a contraction of emissions equal to 60 percent in OECD economies and equal to 67 percent in China. In all tax scenarios there is therefore space for a more efficient allocation of abatement effort: Clean Development Mechanisms and other co-operation schemes offer important opportunities.

Total costs of emissions reductions are displayed in Figure 10. Costs are measured as the ratio between discounted GDP losses and BaU discounted GDP. A 3 percent and 5 percent discount rates are used. Costs are much higher in China than in OECD economies. This is explained by the larger area under the MACCs displayed in Figure 9 for any level of taxation – i.e. China's contribution to the global public good is higher than in OECD countries. Climate policy widens, rather than narrowing the gap between OECD economies and China.

Figure 10 has important implications for future negotiations on climate change as countries will not accept excessively high policy costs. Bosetti and Frankel (2009) have examined an international climate architecture which is based on the postulate that countries will not cooperate to reduce emissions if – among other conditions – costs will exceed 1% of GDP in discounted terms. This implies that while OECD countries would participate to a global agreement in all four scenarios under exam, China would be willing to accept only the moderate CTax1 scenario. It is therefore evident that aggressive mitigation action in China will likely need substantial financial transfers from high income countries.

4. Conclusions

This paper uses historic data and scenarios on future economic development, energy use and emissions developed using the WITCH model to convey four key messages.

First, without specific climate policy measures China’s emissions are likely to grow substantially in the next decades. Energy efficiency improvements are expected to return to the fast pace that was recorded in the eighties and in the nineties. However, continued economic growth and a rather stable carbon content of energy do not allow to stabilize GHGs emissions.

Second, despite fast economic growth, China will have a relatively low level of GDP per capita for still many years. The gap between China and the OECD economies, in terms of GDP per capita, will narrow but will remain substantial even in 2050, according to our scenario. China will therefore be in the peculiar position of being the greatest emitter of GHGs but at the same time not rich enough to afford costly abatement measures.

Third, the pledged contraction of emissions intensity of GDP by 40/45 percent in 2020 with respect to 2005 will have highly beneficial effects in terms of emissions reductions. However, the Chinese goal seems already embedded in all reference scenarios that include strong energy efficiency improvements. The Chinese pledge for the Copenhagen Accord seems motivated more by domestic concerns over excessive energy use, than by the desire to control global warming.

Fourth, marginal abatement costs will be lower in China than in other economies. This implies that, for a given tax on emissions, China will suffer higher aggregate costs. It also implies that there are important efficiency gains from de-localizing emissions reductions in China.

Finally, a mild commitment to introduce some sort of emissions pricing in China is much needed in a post-2020 climate architecture. Even a modest contribution would be extremely important due to the scale of emissions from China. If discounted climate policy costs need to be lower than 1 percent of cumulative discounted GDP for political feasibility problems, we see that China would accept only the lowest tax scenario that we study: 10 US$ per ton of CO_2-eq in 2020, 43 US$ in 2050. With this tax scenario emissions decline by 25 percent with respect to the BaU scenario – which is a substantial result –

but still increase by 60 percent with respect to 2005. This scenario is clearly not compatible with the 25 percent reduction with respect to 2005 required by the G8 and MEF goal of reducing global emissions 50 percent below the 2005 level. A tax that starts from 50 US$ per ton of CO_2-eq in 2020 and increases up to 200 US$ in 2050 is sufficient to deliver the 25 percent reduction of emissions, but it clearly appears to be too costly for China (2.0/2.5 percent of GDP depending on the discount rate used).

It thus clearly appears that there is a political gap between the stated goals and what appears politically feasible. For the crucial role that China has and will have in determining global future climate it is of utmost importance that this gap is filled in the next ten years.

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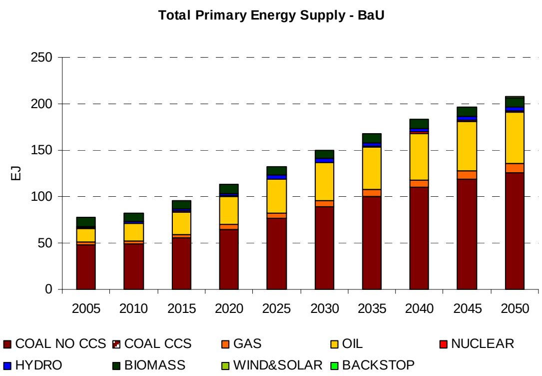
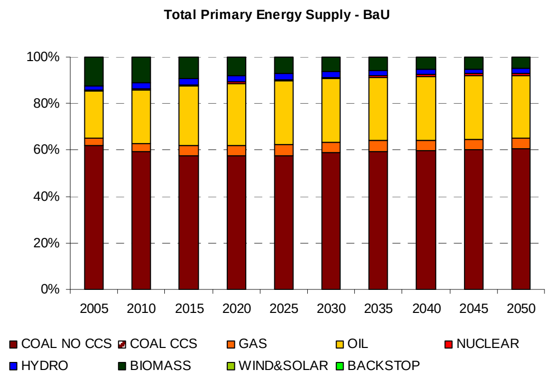
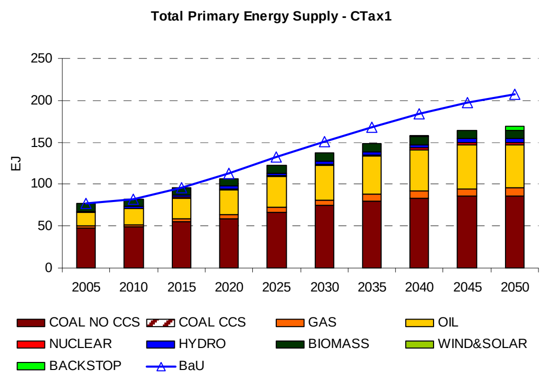
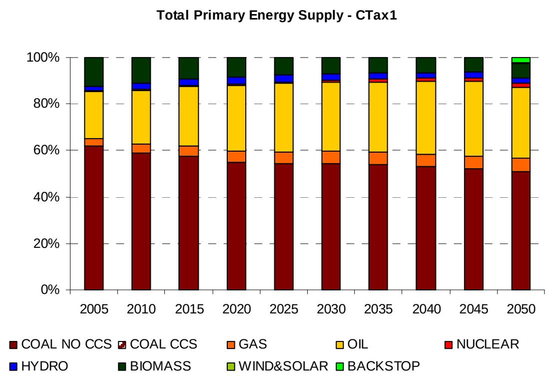
Appendix


Total Primary Energy Supply - BaU
EJ
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP


Total Primary Energy Supply - BaU
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP


Total Primary Energy Supply - CTax1
EJ
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP
BaU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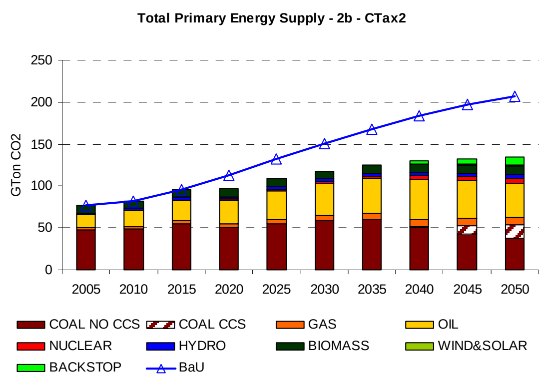
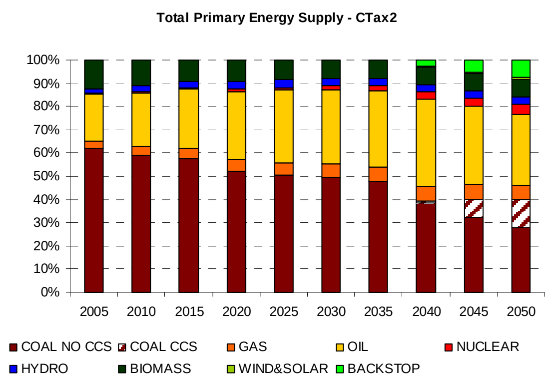
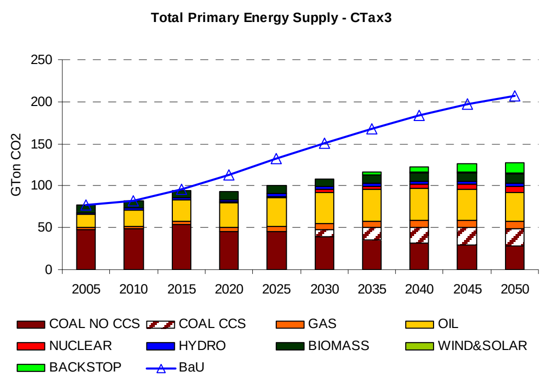
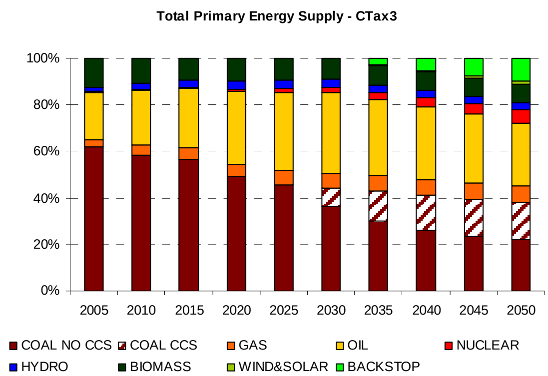
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP


Total Primary Energy Supply - 2b - CTax2
GTon CO2
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP
BaU


Total Primary Energy Supply - CTax2
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP


Total Primary Energy Supply - CTax3
GTon CO2
COAL NO CCS
COAL CCS
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP
BaU


Total Primary Energy Supply - CTax3
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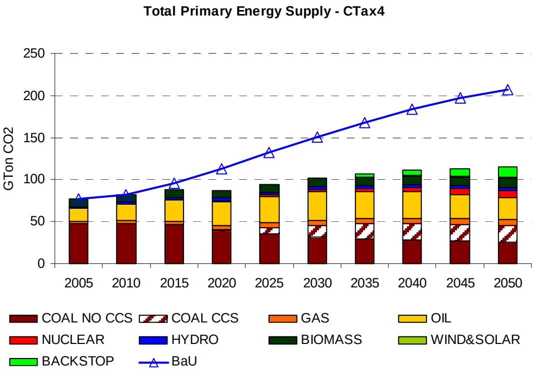
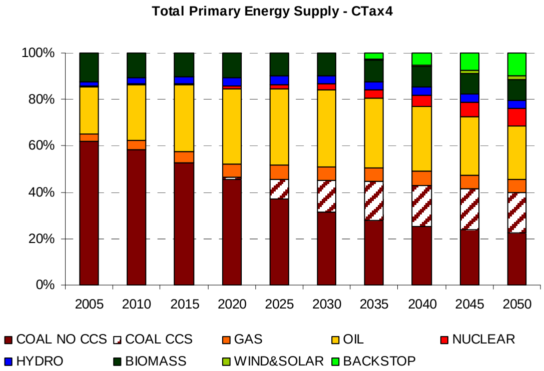
GAS
OIL
NUCLEAR
HYDRO
BIOMASS
WIND&SOLAR
BACKSTOP





Notes for all figures in the Appendix: Total primary energy supply under alternative tax scenarios. The backstop technology is a generic source of carbon-free energy which becomes available if sufficient resources are invested in a dedicated R&D fund. Source: WITCH model.