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China in the anthropocene: Culprit, victim or last best hope for a global ecological civilisation?

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Abstract

The anthropocene is the age where human influences are determining the development of the planet's ecosystems and thus the bio-physical basis of future human civilisations. Today China has become the world's largest economy and its worst polluter with per capita greenhouse gas emissions surpassing the EU average, the world's largest consumer of all kinds of resources. Even regarding the aggregate contribution to climate change (historical emission residues included), called the climate debt, China has not yet, but will be most probably climbing the top position rather soon.

At the same time China is the world's largest victim of environmental change, including air and soil pollution, water and land scarcity, biodiversity loss and climate change.

Thus not only slowing down the increase but reducing emissions should be a top priority for China, and it is: the government has taken some bold steps. China is the world's largest investor in renewable energies, has the largest afforestation program, and leads the world in reducing carbon dioxide emission reduction. As the largest polluter it has extraordinary opportunities to improve the global state of the environment – is it the world's last best hope for establishing a global ecological civilisation? Some implications regarding the Chinese environmental policy are discussed, some strengths highlighted and some weaknesses identified.

However, despite their magnitude, the efforts–and in particular their implementation–are not yet sufficient. We suggest three additional steps which could help China to begin reducing its climate debt within a couple of decades, define a long term perspective for policy planning and adjust its growth model to the challenges of the anthropocene.

Keywords

China, pollution, climate change, land use, HANPP, biodiversity, ecological debt/climate debt, CO2, methane, politics, Common but differentiated responsibility, Earth System Science, environmental justice

Introduction

Naming a new epoch signals earth system change, i.e. a point in time when (ubiquitous) local change in aggregate has begun changing the global system, ending the previous period in which human civilisation emerged, the Holocene. If the term anthropocene was originally proposed as "a strategy for getting the public to appreciate the extent to which humans were destroying the world" (B. Smith according to Balter 2013), one might consider the beginning of the anthropocene as the time window when evolutionary adaptability of biodiversity and ecosystems could no longer keep up with human alterations of the environment(s).

Such a threshold would coincide with escalating anthropogenic energy consumption, a peak in the human appropriation of net primary production (Erb et al. 2013, Krausmann et al. 2012), with a quantity of materials mobilised by humans, the anthropogenic material flows, exceeding natural flows (Schmidt-Bleek 1994, Peduzzi 2014), and with other drastic alterations in ecosystems mainly caused by land use intensification, including in agro-ecosystems. As a result, humanity as a whole is exceeding the planetary boundaries, leaving the safe operating space of humankind (Rockström et al. 2009).

Contemporary changes are very fast, often abrupt, as compared to earlier transformations by agricultural practices which have evolved over centuries or even longer periods, and thus have offered opportunities for species and species interactions to co-evolve in cultural landscapes (Settele and Spangenberg 2013). The resulting in managed equilibrium-type systems were mostly of high value for conservation, sustainable production and/or cultural ecosystem services. Consequently, the speed and scale of change destabilise the dynamic equilibria characterising the Holocene, and the Earth system threatens to flip into a new (more or less) stable state less accommodating to human civilisations (Rees 1999). Biodiversity loss and climate change are but the most obvious and pressing symptoms of this process of global environmental change. Thus deceleration of change to gain time for evolution (Settele and Kühn 2009) and preventing breakdowns in ecosystem services (Heong 2009) would be key objectives for future-proofing human civilizations and their biological and agricultural basis in the anthropocene (Settele and Spangenberg 2013).

Section 2 describes in some detail the challenges of the transition to the anthropocene, and the driving forces behind it. Section 3 identifies the most relevant nations, and China as a key driver of the process. However, China is not only a driver, but also a major victim of the process, as illustrated in section 4. This insight is growing rapidly in China itself, and the world's most populous country and largest economy rather naturally has not only a moral obligation, but also the capabilities to take decisive action, beyond the existing policy measures and the ambitious policy goals already formulated. Thus section 5 asks whether China is our last best hope for stabilising humankind's survival conditions before crossing severe tipping points of the global ecosystem. Section 6 suggests three strategic options how to turn China, on top of its current efforts, from a climate villain into a climate hero. Section 7 offers a brief outlook.

The challenge of the Anthropocene

Driving Forces

The 1950s mark the beginning of the *modern international era*, the decade in which the modern internationalised world emerged. This is not only testified by the founding of global institutions like the United Nations Organisation UNO (1947) and the World Bank (1946), but–at least as important–also by the beginning of official bilateral development aid programs following the liberation of many so-called Third World countries from colonisation. Even more important in our context, it was the time of the emergence of modern communication and transport, providing for the first time mass access to telecommunication, television, cars and air transport (for the 19th century globalisation of communication and trade see Standage 1998). Both communication and transportation were conditions for outsourcing and globalising supply chains; together with development aid and foreign direct investment FDI they induced a rapid global spread of information and innovation replication (Fischer-Kowalski and Amman 2001). Globally, industrial and labour cultures began to converge towards a standard developed in the early industrialised countries.

Regarding resource consumption, the 1950s have been described as the *great acceleration*; a phenomenon that started 20 years earlier in the USA and took hold throughout the industrialised countries, capitalist or socialist, before being transferred to the rest of the world. Economic growth reached unprecedented levels and became the leitmotif not only for the industrialised countries and a yardstick in their competition, but also for their former colonies gaining independence in the 1950s and 1960s. A de-colonising global economy, the East-West competition for more economic growth (in which the socilist block was leading in the 1950s - remember the 'Sputink Shock'), escalating consumption in the West in the 1960s, a shift from coal to oil in the affluent countries, and the Green Revolution coincided, accelerating the global biological and cultural homogenisation. While the outpacing of evolution followed with a certain delay, its reasons are to be found in this decade and the economic changes it saw emerging in most of the world.

The increasing human impact due to ever faster change had two driving forces–technological progress, increasing wealth and population growth amplified resource consumption, and the internationalisation of exchange, both communication and trade, led to the rapid spread of innovations regardless where in the world they had been developed. In their interplay, they enhanced the speed as much as the scale of change to levels unprecedented in earth history–except for the few global catastrophes caused by massive asteroids hitting the planet. Physically this development was based on the massive expansion of energy consumption and the transition from biomass to fossil fuels, first coal and in the 1950s shifting to oil and later complementing gas. In the early industrialising countries different patterns of fossil fuel use coincide with certain stages of the transformation to an industrial society and with changing trajectories of societal development (Fischer-Kowalski and Amman 2001, Wiedenhofer et al. 2013). Other drivers of change growing simultaneously with fossil fuel use include the exponentially increasing consumption of metallic and mineral resources (Schmidt-Bleek 2008). In particular the extent of and the changing patterns and growing intensity of land use (Bringezu et al. 2012, Haberl et al. 2009, Spangenberg 2007) played an important role, not least promoted by the green (grain), the blue (fish) and the white (milk) revolution (Spangenberg 1991). It was in particular the combination of escalating resource use and these revolutions and their positive feedback loops which caused, with a time lag, the destabilisation of ecosystems by overburdening their evolutionary and adaptive capabilities. Thus it was not one big decisive change but the confluence of globally dispersed, ubiquitous accelerated local changes, synchronised through ideology, technology, power and finance, that caused a massive qualitative change of the global socio-economic-environmental system as a whole.

Today 15% of the world's population have successfully completed the transition from an agrarian to an industrial (and now post-industrial) society, in the course exhausting if not destroying the capacity of global CO_2 sinks, overburdening the global nitrogen and phosphorous cycles and–worst of all–accelerating the loss of biodiversity by a factor 100 and more (Rockström et al. 2009). On top of this, 60% of the world's current population are undergoing the same transition from agricultural to industrial societies, so far mainly following the Northern development trajectory. The globalisation of this "normal development paradigm", from agricultural societies assumed to be poor to presumably affluent industrial societies, was propelled by national elites and international financial institutions. As a result, the number of people in absolute poverty has decreased significantly (while the number of people in plain poverty increased), the majority of them now living in middle income countries. Poverty has become a social group problem rather than a developing country problem, making established development concepts obsolete. The solution can no longer be increasing the wealth of a country, but must include redistribution within countries, usually not only of income but also of assets, depending on the national situation.

Pressures: Biodiversity loss, climate change and the ecological debt

The agricultural revolutions, by increasing growth in line with extraction (harvest) did not significantly change the share of natural primary production appropriated by humankind. Although correlations between HANPP and biodiversity loss have been described at smaller scales (Haberl et al. 2004), increased human appropriation was probably not the cause of the disruptions in ecosystem functioning: species loss has accelerated throughout the globe, while the level of HANPP declined in the industrialised countries and remained rather steady in South East Asia (see Erb et al. 2009 for the global distribution of HANPP and Krausmann et al. 2012 for data from the Philippines). Nonetheless the steady but very high levels of HANPP can be read as indicating a high level of anthropogenic pressures on ecosystems (Haberl 2013).

Avoiding an increase in HANPP by increasing external input, however, came at a cost: the global nitrogen and phosphorus cycles were expanded beyond the planetary boundaries (Rockstöm et al. 2009, Krausmann et al. 2012). Intensive, often irrigated agriculture in particular in Asia (Figure 1), together with urbanisation and industriali-

Figure 1. Agriculture on the Chinese Loess Plateau, 2013.

sation, sent water, energy and mineral consumption skyrocketing, undermined water availability and quality and turned agriculture from a net energy provider into an energy consuming industrial sector. This links the agricultural revolutions to the second major threat to ecosystem stability and sustained ecosystem service provision besides biodiversity loss, which is of course climate change (Rockström et al. 2009). Besides industrialisation and growing consumption, logging, irrigation agriculture, aquaculture and intensive animal husbandry significantly increased the emission of potent greenhouse gases like methane (CH_4), laughing gas (nitrous oxide N_2O) and carbon dioxide CO_2.

The most important greenhouse gas is CO_2, responsible for about half of the warming effect, followed by CH_4, causing about 20% of global warming and N_2O with about 6%. Their dynamics are quite different: while CO_2 has an average atmospheric residence time of about 120 years, methane's residence time is 9-15 years, while its radiative forcing (RF) is 25 times higher than that of CO_2, but less than that of N_2O (298 times, 114 years). As a result of these differences, the contribution of individual gases (and thus of their emitters) to what has been called the climate debt differs significantly in and between countries. This debt has been defined as the remaining climate change effect of the accumulated historical emissions of a country, taking both the RF and the residence time into account (Martinez Alier 2002, Smith et al. 2013). The climate debt is strongly influenced by recent emissions as they are least subject to the residence limit effect, and is a key component of the broader ecological debt.

Methane concentrations in the atmosphere have reached three times the pre-industrial level of about 600 ppb, and continue to rise. Globally, more than 35% are directly or indirectly caused by cattle breeding and some 15% by other biomass use.

About half is caused by leakages in extraction, transport and processing of natural gas, including incomplete combustion during flaring of technically not recoverable gas; data for methane emissions from hydraulic fracturing are not yet available.

2013 is the year in which atmospheric CO_2 concentrations crossed the 400 ppm threshold–up from 349 ppm in 1987, the year the Brundtland report was published (and the last year when the annual average CO_2 level was less than 350 ppm, the level recommended for stabilizing the Holocene climate) and from 356 ppm 1992, at the time of the Earth Summit in Rio de Janeiro. At the Cancun climate negotiations 2011, the countries of the world agreed to commit to a maximum temperature rise of 2°C above pre-industrial levels, and to consider lowering that maximum to 1.5° in the near future. To give a relatively high certainty of not exceeding 2°C, scientists tend to recommend stabilising greenhouse gas concentrations at about 350 ppm CO_{2eq} by 2050 (IPCC 2014). To achieve this, global GHG emissions have to decline by about 2/3 until 2050, with industrialised countries' greenhouse gas emissions declining by 4/5 or more to about 2 t/cap*yr. Fossil fuel consumption would have to be reduced accordingly. Even remaining below 2°C does not guarantee avoidance of all significant adverse impacts, but if exceed, they are projected to become much more severe, widespread, and irreversible (for current impacts see EEA 2012); if the current global trend of increasing CO_2 emissions continues, cumulative emissions will surpass the 2°C limit within the next couple of decades. The climate system would then be likely to cross more dangerous thresholds that could trigger large-scale catastrophic events (IPCC 2014).

Pursuing a 2:1 chance of limiting global warming to, or below, 2°C above pre-industrial levels, limits the world's "carbon budget" (the maximum permissible emissions) to no more than 1.000 Gt (Giga tonnes, 10^9 metric tonnes) of carbon to be released into the atmosphere from the beginning of the industrial era to the end of this century, of which 531 Gt had been emitted by 2011. Factoring in other climate pollutants than carbon dioxide brings the overall cumulative budget 200 Gt down from the 10^{12} tonnes of carbon, leaving just 269 Gt of carbon as the remaining budget–the result of two lost decades (IPCC 2013). The total proven international fossil fuel reserves, 2,860 Gt CO_{2eq} according to the International Energy Agency's *World Energy Outlook* (IEA 2013), are a multiple of the permissible extraction. Consequently, to stabilise the environmental conditions of the Holocene, 2/3 to 9/10 of the proven reserves will have to be left in the ground, as "unburnable carbon" (Meinshausen et al. 2009) or "unburnable fuel" (The Economist 2013a). Burning all proven reserves would result in an atmospheric CO_2 concentration exceeding 550 ppm (and more if unconventional and so far not economically viable resources were extracted, or new fossil fuels discovered), and to dire consequences. Thus Peak Oil, although threatening, will come too late to rescue us from climate change.

Thus, if governments are determined to implement their climate policies, a focus on efficiency, although important, will not be enough, but capping resource use and subsequently decreasing it will be required. However, this urgent turnaround is hampered by the fact that most of the fossil fuel reserves are owned by governments or state energy firms like Gazprom und Rosneft (Russia), Petrobras (Brazil), Pemex (Mexico), Saudi Aramco (Saudi Arabia), or Sinopec, CNPC und CNOOC (China); they contribute significantly to public revenues, about $2*10^{11}$ US$ in the OECD countries and unknown amounts in the emerging economies (Haas 2014). Thus while reserves would be left in the ground if governments took their own policy objectives seriously (The Economist 2013a), economic interests dominate. A similar bias is detectable for private energy companies, representing about a quarter of the world's fossil reserves: their shareholders and investors expect a return. Markets are valuing companies as if all their reserves would be burned, and investors treat reserves as an indicator of future revenues. They therefore require companies to replace reserves depleted by production, even though this runs afoul of emission-reduction policies. If the reserve replacement ratio of fossil-fuel firms falls below 100%, their shares tumble down: an analysis by the UK HSBC bank found that effective climate policy targeted at a maximum of 2° warming would cut the stock exchange value of Australian mining companies by half. As a consequence, although companies already have far more oil, gas and coal than they need (again, assuming temperatures are not to rise by more than 2°C), the 200 largest listed oil, gas and coal companies, with a market capitalisation of $4*10^{12}$ US$ at the end of 2012, spent $6.74*10^{11}$ US$ on developing new reserves; ExxonMobil alone planned to spend $\$3.7*10^{10}$ a year on exploration each year 2014-2016 (The Economist 2013a). This is a squandering of financial resources for securing those fossil reserves necessary to propel CO_2 emissions above 550 ppm–an intention nobody admits to have, despite investing billions of dollars for it (Haas 2014).

China the culprit–in a global context

Past economic growth in China has been lifting hundreds of millions of people out of absolute poverty, and was the main contribution to reaching the UN Millennium Development Goals MDG at least in some respect. It will make China the world's largest economy already next year, in terms of purchasing power adjusted GDP. Purchasing power parity PPP is calculated by the International Comparison Programme to make national GDPs comparable despite exchange rate fluctuations and diverging domestic prices, by counting a hair cut or a bus ride as equivalents in all countries. It's latest report, issued April 30th, 2014, but based on 2011 data, suggests that China will be surpassing the USA by 2015 (The Economist 2014a).

This enormous success has led to a massive increase in resource consumption; China's industries are consuming 40-45% of the world production of copper, steel, nickel, aluminium and zinc. China today imports half the planet's tropical logs and raises half of its pigs (The Economist 2013b), with significant environmental and social impacts in China and in the countries of origin. At the same time, the massive growth fuelled an accumulation of wealth not only lifting the poorest out of poverty but also establishing a new class of super-rich, swelling the ranks of the world's billionaires. Today 358 US$-billionaires, 1/5 of the global total are situated in China (The Economist 2014b).

Air pollution–the most frequent reason of premature death–and water security are amongst the best known environmental pressures in China, together with land devastation by mining and the impacts of intensive agriculture. This, and the logging of forests from the 1970s to the 1990s, contributed to a massive threat to biodiversity in China, a megadiverse biodiversity hotspot. However, as these factors, despite their global relevance, primarily affect China itself, they are discussed in section 3, while in this section the focus is on global effects, in particular climate change.

In total, global emissions of carbon dioxide (CO_2)–the main cause of global warming–increased by 3% in 2011 and 1.4% in 2012. According to the 2013 report "Trends in global CO_2 emissions", released by the EU Joint Research Centre JRC and the Netherlands Environmental Assessment Agency (PBL), the top emitters contributing to the global 34.5 billion tonnes of CO_2 in 2012 are: China (29% - only a quarter of the emissions is for export production, making China still the biggest emitter if embodied emissions in global trade are factored in), the United States (16%), the European Union (11%), India (6%), the Russian Federation (5%) and Japan (4%). However, in the European Union CO_2 emissions dropped by 1.6% in 2012 to 7.4 tonnes per capita (t/cap) while in China (without Taiwan) average emissions of CO_2 increased by 3% to 7.3 t/cap. The increase in China, although low by historical standards, was equivalent to two-thirds of the net global CO_2 increase in 2012. Between 2000 and 2012, China has accounted for about two thirds of the increase in global CO_2 emissions, living through the coal and oil phase of development simultaneously; modern energy sources have surpassed traditional bio-based ones (Haberl et al. 2009, Erb et al. 2009).

As a result, China's CO_2 *emissions per capita* were comparable to those in the EU and by 2014 most probably have surpassed them, making a reduction of about 70% per capita a necessary longer term objective for both, China and the EU. China's CO_2 *emissions per USD Gross Domestic Product* (GDP) are almost double those of the EU and United States and similar to those of the Russian Federation (Olivier et al. 2013). The United States remain the second largest emitter of CO_2, with 16.4 t/cap, despite a significant decline due to the recession in 2008–2009, high oil prices and an increased share of natural gas from fracking (the methane balance of fracking is so far unknown). Only a few Near East countries such as Saudi Arabia, United Arab Emirates, and Qatar, and isolated islands like the Falklands/Malvinas have higher emissions per capita (Olivier et al. 2013). Coal is the most important fuel, in China and globally, and the most important source of CO_2 (Figure 2).

The strongest short-term economic effects of effective climate policies phasing out hard coal use would be felt by the world's major coal exporters, which in 2012 were Indonesia with 383 Mt = 32.8%, Australia with 302 Mt = 25.9%, the United States (106 Mt = 9.1%), Russia (103 Mt = 9.1%), Colombia (7.0%) and South Africa (6.2%) (IEA 2013). The longer term impacts on producers would arise due to the foregone income opportunities from mobilising and marketing reserves of hard coal (anthracite, bituminous and sub-bituminous); here China itself would be affected economically, holding the world's 3rd largest coal reserves. Globally, reserves in 2011 were: USA 207.1 Gt (30.0%), Russia 146.6 Mt (21.2%), China 95.9 Gt (13.9%), India 56.1 Gt (8.1%),

Figure 2. City power plants contribute to global warming and to local air pollution: Harbin, Heilongjiang province (left, 2010) and Taiyuan, Shanxi province (right, 2013).

Australia 39.2 Gt (7%), and Ukraine 3.9 Gt (4.6%)(end-2011 data, WEC 2013). On the other hand, coal (besides oil) is a major factor in the balance of payments and a burden for the major importers, all of them in Asia (2012: China Mainland 278 Mt and 65 Mt Taiwan, Japan 184 Mt, India 158 Mt, South Korea 126 Mt, and Germany 44 Mt)(IEA 2013). Their national economies including the consumption capabilities of consumers would benefit significantly from saving the money spent on these imports.

The Chinese climate debt looms even larger, and with it the responsibility and the future (at least moral) obligation for compensation, when methane emissions are added to the balance. More specifically, in 2005, the last year for which figures are available (Smith et al. 2013), the USA was responsible for 25.1% of the global climate debt from fossil fuel incineration (net anthropogenic emissions) and China only for 11.1% (Russia: 8.5%, Germany 5.1%, Japan 4.8%), but regarding methane already in 2005 the USA/China relation was the opposite. China's share in methane climate debt was the world's largest at 18.4%, while the USA was responsible for 9.6% of the global accumulated methane based climate debt, followed by India (8.2%), Russia (7.4%) and Brazil (5.5%). In total (CO_2 plus CH_4) the ranking changed little, but the distances between countries were shrinking (which most probably has changed the ranking to the disbenefit of China now, nine years on). The country shares of the global environmental debt were 18.4% for the USA and 13.8% for China, followed by Russia (8.0%), India 5.3% and Germany (3.5%).

Add to this the greenhouse gas emissions from land use change and forestry (LUCF), and the picture changes again: 16.3% of the total climate debt including all the factors (CO_2, CH_4 and LUCF) were allocated to the USA in 2005, 13.8% to Europe, 13.4% to China (including Taiwan), and 8.0% to the former Soviet Union (Smith et al. 2013). In the nine years since China has certainly surpassed Europe and most probably caught up with the USA's climate debt level, as the latest emissions are most effective. As a result, the argument that other countries with a long industrial history have higher aggregate impacts is no longer valid as in 2014 most probably the world's largest climate debt rests with China, and so does the responsibility for climate impacts around the world. Furthermore, despite its moral plausibility, the argument was not ethically valid from the outset as claiming the same right to pollution means justifying own misbehaviour with others' misconduct, which is no ethical or moral legitimation at all. Today, however, China is not playing catch-up anymore; it is by now doing more damage to the global ecosphere than any other country, with only 1/4 of its CO_2 and hardly any of its CH_4 and LUCF emissions resulting from export.

When China started its race to the top, the capacity of the atmosphere was already half consumed by nations which underwent the industrialisation process earlier, and by no means any longer available. This justifies a demand on the early industrialisers to set a precedent in emission reduction, but not for any other country to repeat their mistake and become, in a moral sense, at least as guilty as they are. Any effective international climate protection policy would have to respect the different situations (focus on different greenhouse gases and industrial sectors), but also acknowledge the need for support for countries and regions most affected by structural change due to the phasing out of fossil fuels. Also for a number of countries national climate adaptation and risk reduction strategies may need external support. Early polluters have a moral duty to provide such help as part of their wealthy has been built by exploiting the sources and sinks no longer available to the later arrivals.

China the Victim–glimpses on impacts the anthropocene has for China

Far from claiming to be comprehensive, this section highlights some of the key pollution and environmental degradation problems China is struggling with. The transition from the Holocene to the Anthropocene, of which China is a major driver, is causing significant challenges domestically. Besides being culprit, China is also a victim.

The burden created throughout the development process is rather unevenly distributed in the country; economic, social and environmental development are not in a balance. Provincial improvements in aggregate sustainability indices are in most cases due to the socio-economic development, most often with deterioration or stagnation in the environmental dimension (Hara et al. 2009). Those in between, inland but not distinct border regions, with limited resource endowments and semi-stable environments suffer most in environmental terms, without much economic compensation: they exhibit the highest NPP loss. Coastal areas build wealth from imported resources and technology, border regions generate limited wealth, in between regions have to (over-) exploit their own mineral, fossil and biological resources to generate intermediate levels of wealth (Zhao et al. 2011), not least by exporting them to wealthier, more industrialised provinces (Feng et al. 2013).

Air pollution

The urban air in China has long been known as the world's worst, but in the latest WHO list of most polluted cities there is no Chinese one amongst the top ten any more–Iran,

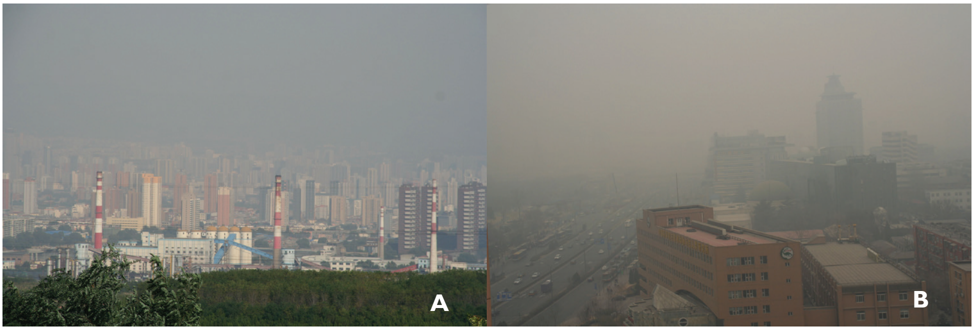

Figure 3. A Air pollution in Tayuan, Shanxi province (left, 2013), and **B** in Beijing (right, 2009).

Pakistan and India have conquered that sad crown. And this is not just because the situation got worse in those countries: the air quality has improved in many Chinese cities (except in spike periods like the one in Beijing 2013) and is now at levels commonplace in Japan in the 1970s and in Germany in the 1950s, and improving further.

Nonetheless the problem is far from being solved in China (see Figure 3) – in 2013 the air in most cities monitored reached concentrations of lung-penetrating fine particular matter $PM_{2.5}$ (diameter <2.5 µm) beyond the state standards released last March by the Chinese Ministry of Environmental Protection (MEP). The Chinese air quality index AQI for $PM_{2.5}$ defining the upper threshold of what is good air quality, is set according to the interim target 1 suggested by the World Health Organisation WHO for highly polluted areas, at less than 75 microgram of particles per cubic meter of air (<75 $\mu g/m^3$) for the 24-hour mean. This implies about 5% increase of short-term mortality as compared to the target value deemed safe by the WHO according to its 2005 Air Quality Guideline of <10 $\mu g/m^3$ for the annual mean, and <25 $\mu g/m^3$ for the 24-hour mean (WHO 2006). The WHO Air Quality Guideline recommendations for PM_{10} stand at <10 $\mu g/m^3$ for the annual mean and at <75 $\mu g/m^3$ for the 24-hour mean (WHO 2014). The EU has set a target value for the annual mean $PM_{2.5}$ concentration of <25 $\mu g/m^3$ and an exposure limit of 20 $\mu g/m^3$, both to turn into legal limits on January 1st, 2015, plus a target of 18 $\mu g/m^3$; the exposure values are calculated based on a three year mean. For PM_{10}, legally binding limits stand at 40 $\mu g/m^3$ for the annual and 50 $\mu g/m^3$ for the daily mean (European Commission 2014). In the USA, the Environment Protection Agency EPA has 2012 set a not legally binding annual target value of $PM_{2.5}$ ≤12 $\mu g/m^3$ as the three year average, and a daily mean standard of ≤35 $\mu g/m^3$ considered to be met if the 98th percentile of 24-hour $PM_{2.5}$ concentrations in one year, averaged over three years, is less than or equal to 35 ≤$\mu g/m^3$ (EPA 2012).

Recent studies confirm that Chinese government policy has played an important role in causing the pollution (e.g. by providing free winter heating via the provision of coal for boilers in cities north of the Huai River). Burning coal without environmental protection provisions has greatly increased total suspended particulates in the air, and in particular pollutes the in-door atmosphere (Larson 2010). As a result, Chen et al. (2013) estimate that due to such politically induced pollution the 500 million residents of Northern China lose more than 2.5 billion life years of life expectancy. This is a striking example how a policy introduced for social reasons, but without taking its environmental impacts into account, can turn out to be not only environmentally disastrous, but also be backfiring socially.

An additional source of sod, in particular in the Northern provinces, is the habit to burn left-over material from the harvest (mainly straw) in the fields, at about the same time as domestic heating starts. While returning biomass ad minerals to the soils is in principle recommendable, burning straw in the fields is not necessarily the best way of doing it. The dark clouds over the fields signal not only air pollution, but also a loss of organic carbon from the fields, and potentially damages to the habitats of organisms important for pollination and biological pest control.

Biodiversity

China as one of the megadiverse countries of the world faces particular challenges. For instance, the official Chinese Red List classifies almost 40% of the country' mammals as threatened. The reasons are manifold, but the development pattern has played a crucial role. As a result of growing urban agglomerations due to population growth and urbanisation, lakes around cities have been degraded or lost, or replaced by artificial ponds with high ornamental but low biological value (Figure 4).

Agricultural intensification contributed to the degradation or destruction of natural ecosystems, a development just like the one in Europe few decades earlier. Natural landscape elements suffered, such as wetlands, meadows, hedge rows and other small scale but biodiversity rich landscape structures (Figure 8). Widespread wetland and peatland degradation caused not only biodiversity loss, but also significant amounts of drying emissions of CO_2 and CH_4. Agricultural modernisation replaced a rich diversity of traditional cereal and vegetable varieties by a limited number of high yielding but not necessary resilient, fertiliser and pesticide dependent varieties from China's excellent biotech laboratories. Less fertile areas–if not ploughed–suffer from grassland desertification due to heavy grazing, in particular in Inner Mongolia and Northern Gansu, with significant losses of grassland biodiversity.

Mountain areas suffered most from large-scale logging in Northeast China, Gansu, Sichuan and Quinghai provinces from the 1970s to the 1990s; illegal logging is still a problem. Reforestation programs, the world's largest, affecting 10-15% of the agricultural area, were sometimes successful, but on other occasions suffered from a lack of economically effective incentives (Bennet 2008). On other occasions the economic orientation of local development plans led to afforestation with fast growing species as resource base for the pulp and paper industry instead of planting locally adapted species and varieties, resulting in low resilience tree plantations rather than healthy forests. This constitutes a problem in particular in the 'Green Belts' areas where forests have been planted to stop the encroaching desert (Li et al. 2009).

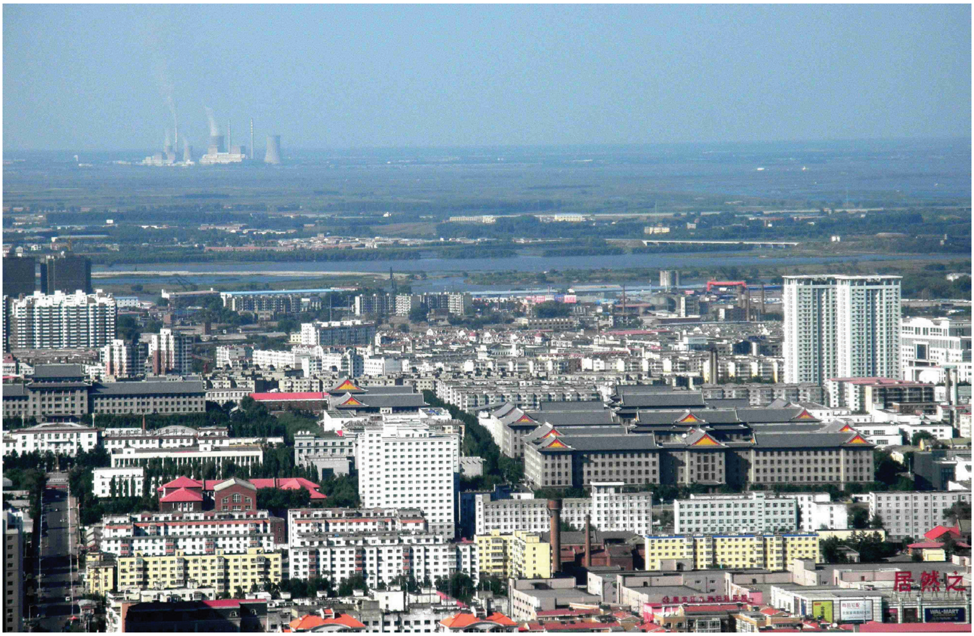

Figure 4. Cities encroaching on surrounding wetlands (and a power plant in the midst): Harbin, Heilongjiang province, 2010.

A rather recent stress factor for natural and cultural heritage sites and their often unique biodiversity is the growth in domestic tourism; China is now the world's biggest tourism market. Its spectacular but vulnerable landscapes, from wetlands at the origin of the Yangtze and the Yellow River via nature reserves (see figure 9) to cultural heritage sites like the rice terraces of Yunnan province, a UNESCO cultural world heritage site, attract tourists but mostly lack a biodiversity-conserving management.

Water

Severe water stress is commonplace in China; the water table in Beijing has fallen by 100–300m within two decades (World Bank 2009). The problem is fuelled by inefficient use on top of an uncomfortable hydrogeological situation: four fifth of the water is in the South, mainly in the Yangtze river basin, while half the population and two thirds of the farmland are located in the much dryer North. Even the massive South-to-North Water Diversion Project, transporting water from the Yangtze to the Yellow River basin, can at best moderate but not solve this problem. Water shortage, increasing climatic variability and land use pressures (plus climate change) makes the deserts grow (Li and Huntsinger 2011). Despite Green Belt plantations, farmland dries out and might lay idle due to a lack of clean water supply, and crop yields are plateauing already (The Economist 2013b).

Figure 5. Water pollution in Gansu province 2012.

The widespread loss of wetlands contributed to the loss of 27,000 rivers in China (excluding Taiwan, as in most statistics), nearly half of all those estimated to exist in the 1990s, as detected in the water census published by Chinese authorities on March 26th, 2013. Climate, although likely an important factor (this three year study coincided with a multi-year drought in central and southern China, where dramatic drops in lake levels and a shrinking Yangtze River have been well-documented), experts agree that the problem is largely man-made. Besides land use change, over-exploiting ground water for industry and agriculture, and destruction forests causing a rain shortage in the mountain areas for agricultural purposes have been named as reasons (Yan 2013).

The situation is made worse by the massive water pollution, rendering a significant share of the scarce water resources unsuitable for human use (Figure 5). For instance, for a full third of its length, the water of the Yellow River was deemed too polluted to be used in agriculture by the Yellow River Conservancy Commission. Within the urban areas, safe drinking water provision is a serious problem: about half of all urban water supplies are unfit even to wash in, let alone drink. Official statistics also showed that 85% of the length of China's six biggest river systems consisted of water deemed undrinkable even after treatment. The proportion of polluted groundwater rose from 37% in 2000 to 60% in 2013 (The Economist 2014d).

Land

Land is a precondition for at least three kinds of ecosystem services: provisioning services/*sources* supply vital material and energy resources such as fossil fuels, water, minerals, fibres and food, regulating services/*sinks* provide waste absorption, waste water purification, water storage, buffering and regulating capacity, and socio-cultural services/*space* provision, in particular for hosting human infrastructures such as settlements, production sites, transport infrastructure, but also gardening, recreation sites and places of worship (Erb et al. 2009). This "Triple S" of sources, sinks and space is currently at risk: at least 36,000 hectares, about 10% of China's farmland, was found to be contaminated with excessive levels of heavy metals such as cadmium and chemicals in 2006 according to a document authored by the Ministry of Environmental Protection of China (the study became public in 2013; current Figures are not available)(Lin 2013). Long-term industrial pollution has resulted in the accumulation of agricultural chemicals, heavy metals, and non-biodegradable organic pollutants in the soils, with most of the pollution occurring in more economically developed regions. In some cities in southern China, half of the farmland was found to be polluted with toxic heavy metals such as cadmium, arsenic, and mercury, as well as petroleum-based compounds. In the Yangtze River Delta, 10 percent of the sampled farmland was found to be no longer suitable for growing crops, because of heavy metal pollution. As a result, 12 million tons of crops harvested in China each year were contaminated, which translates into 20,000 million yuan (2.300 million €) of economic losses every year (Lin 2013).

Furthermore, with economic growth land use for other purposes than agriculture is increasing, as the possibilities for decoupling land use from economic development are limited (Xue 2012a), national legislation was not implemented, land speculation was rife, fuelled by misuse of local power positions and widely spread corruption, with severe effects on local lifelihoods and food production capacities. One reason is the growth of urban agglomerations (Figure 6), another the fact that cities are historically often located on the most productive land (unlike protected areas which are located on land of average productivity)(O'Neill and Abson 2009). While conservation (reforestation) has had positive effects on water retention and reduced erosion, it reduced further the agricultural area. These factors combine with climate change, to the end that Chinese food security is at risk (Wei et al. 2009). Land use change, in particular sealing soil for settlements and soil pollution, also contributes to the loss of other ecosystem services beyond harvest, the provisioning service. Regulatory and socio-cultural services are affected, but damages so far not quantified.

One economically rather marginal, but socially/culturally relevant and environmentally highly important activity is herding in Western and Northern China, an area with relatively low NPP and resource endowments, and a comparably low development standard (Zhao et al. 2011). With about 400 million hectares China has the second largest area of natural grassland in the world. Steppe degradation is a major ecological and economic problem, in particular in the Inner Mongolia steppe region, including the Inner Mongolia province and its neighbours from Gansu via Northern

Figure 6. Growing Megacities–Shanghai/Pudong 2010.

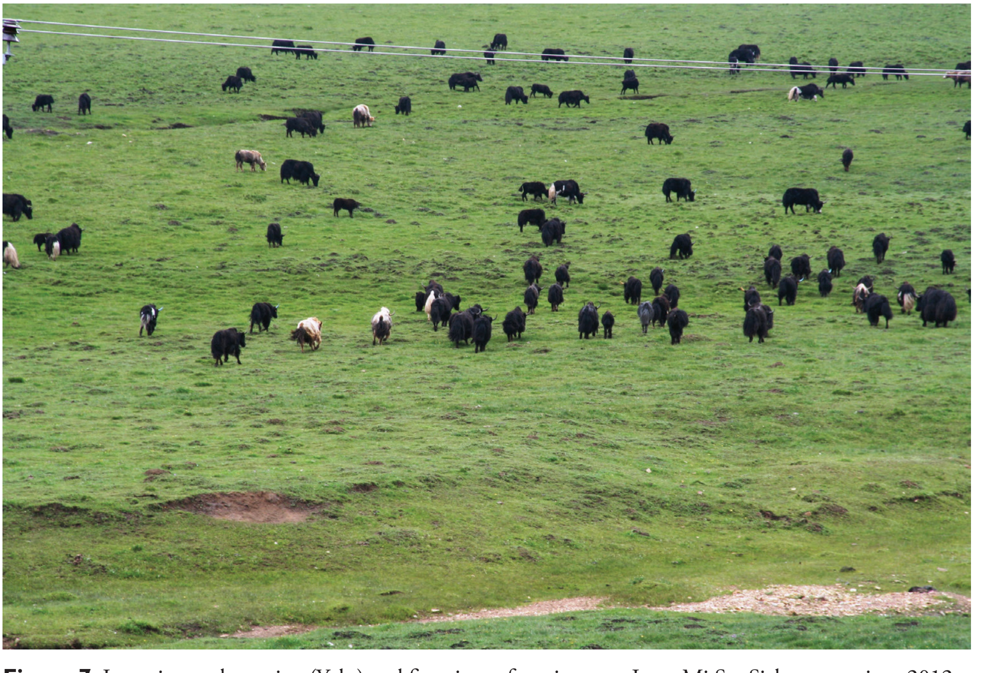

Figure 7. Intensive cattle grazing (Yaks) and first signs of erosion near Lang Mi Su, Sichuan province 2012.

Shanxi and Shaanxi to Heilongjiang (Figure 7), because it reduces grassland productivity and leads to desertification (Tong et al. 2004).

The change in herding practices, from a low-impact land use based on migratory herding, well suited for marginal soils and harsh climates, to a settlement-based way of living, keeping the animals in stables for several months and lorrying them to their up-mountain grazing grounds has severe consequences for culture, lifestyle, social cohesion and not least the fragile environment. As the herds are no longer migrating from summer to winter grazing places, the distance they cover on their hoofs (i.e. not being transported to another grazing place by lorries) and thus the area of land they graze has significantly declined, enhancing the use intensity on the area actually used (for the effects of herd composition changes induced by China in the neighbouring Mongolian steppe see Spangenberg et al. 2014). This is probably one of the main factors of ongoing destruction of top soil and subsequent erosion (Akiyama et al. 2012). Maps underline that large-scale patterns of steppe degradation were related to land use types, with climatic variations playing a minor role (Tong et al. 2004).

Take for instance Quianshan as an example. It was home to about 100,000 sheep in 2012, up from 40,000 in 1995, with the number still growing as market demand kept increasing the prices. In the region already ~90% of the steppe is damaged by excessive grazing, rural development and climate change (Cui 2012). The Chinese government has sought a solution in enforcing strict boundaries for 60% of the land exempt from grazing (including fencing). Economic compensation is paid for those prevented from using it, and financial incentives have been offered to limit the size of herds (however, they are not effective as the price of sheep continues rising with rising demand and limited supply) (Li and Huntsinger 2011). Local complaints are mounting as fencing is against all cultural traditions of the ethnic minority population affected. The restriction of grazing and migration areas has caused tensions; even a rise in crime is expected. Already now livestock theft is commonplace and hard to control with free running herds (Cui 2012). The traditional lifestyle with be finally terminated with new housing and herds kept in stables with feed and fodder imported from outside the region as it has already been practiced for instance in the Gansu province, creating deprived settlements of disrupted communities and thus a potential source of future social unrest.

Climate change

If by 2100 global average temperatures rise by 2.1°C (range 1.4–3.1°C), with atmospheric CO_{2eq} concentrations around 450 ppm, the impact of this still optimistic scenario includes major threats, such as the begin of irreversible melting of the Greenland ice sheet, subsequently (in the 22nd century) increasing global sea levels by about 7 m, affecting China's richest provinces, economic hubs and harbour cities, and hundreds of millions of people, directly and indirectly (O'Hara 2009). As in China more people live at sea level than in any other country, Chinese climate policy must do both, contribute to minimising global climate change and provide pre-emptive adaption strategies to these challenges.

A likely decrease of precipitation in already dry areas by 20-30% poses a risk for Northern and Western China, the expected major drop of crop yields in tropical regions would affect China's South, and additional 15% to 40% of species could be facing extinction all over the country.

Social sustainability

There has been growing concern over the sustainability of China's economic growth. The Chinese economy is strongly dependent on investment and exports (a quarter of the CO_2 emissions is from export goods production), a pattern that has become increasingly economically unsustainable. The dependence on investment and exports results from insufficient household consumption, which, in turn, reflects rising income inequality and improving but still limited provision of social welfare–a problem of social sustainability. As the economy has been fuelled by public investment into infrastructure and productive capacity, investment into environmental protection had been neglected for decades. In this sense, the economic growth happened at the expense of the environment, and the investment not made earlier already causes significant macroeconomic cost, which will most probably increase rapidly over the next couple of decades.

After the early years, China's development has been built on industrial development in a model of unbalanced growth. This has left the rural areas trailing urban areas in development. Rural residents earn less than urban residents, have inferior physical infrastructure, and suffer from poor basic amenities. These disparities have contributed to the extensive rural-urban migration. This migration, by leaving residences unoccupied, and depriving the country side of workforce and investment opportunities, has exacerbated inefficiencies in rural land use. However, while reducing inefficiency is an important policy objective in its own right, the current approach by the government suffers from major deficiencies. There exists a link between the relative impoverishment of Chinese peasants, due to declining agricultural prices, amplifying the flow of rural-urban migration, its depressive effect on industrial wages as rural migrants do not enjoy the same rights as registered citizens, the resulting increase in the profits' share of the total surplus, and rising top incomes. The enrichment of urban top income households drives the increase in the urban-rural gap and fuels the resulting tensions, while labour's loss of shares of national income ultimately accounts for the overall increase in the Gini index and is a potential source of social unrest.

Institutional challenges

Balancing the relations of nature, society and leadership was at the core of the "harmonious development" promoted by the Communist Party during the last decade. This multiple balancing approach, the Chinese version of sustainable development, has deep roots in the Chinese culture, with elements from Buddhism, Daoism and

Confucianism (Shi 2004, Xue et al. 2012). In reality, however, despite massive efforts (Xu et al. 2006), harmony with nature has taken the back seat, falling behind what is needed for China's sustainable development. The underlying cause has to do with the weakening of China's state capacity, a problem of institutional sustainability.

On the one hand, "good environmental law only gets you halfway there" as Pan Yue, vice minister of environmental protection, told the state media, highlighting a dear lesson of the last two decades on environment pollution politics. Public and civil society pressure, media and whistle blowers uncovering violations of the law, authorities both with a capacity and the willingness to act are required as well. In particular the relative lack of enforcement personnel is an obstacle to be addressed if environment politics is to become rigidly effective.

On the other hand, and more fundamentally, despite the basically centralist governance structure, strong state and party organisations in the (rich) provinces mean that the national leadership has often been more in a moderating than in a regulating and enforcing role. With economic growth slowing down (a natural process for ripening economies, in particular as the labour force has almost reached its peak) the pressure was high to refrain from environmental measures perceived as hampering growth, supported and stimulated to do so by European and US Companies, and the US and the EU Chambers of Commerce. Both factors, local power and business pressure, limited the willingness of provinces and cities to neatly implement central government's orders or legal acts, especially in booming provinces. The necessity to rule them in, in particular but not only on environmental issues, is the background to the current leadership's campaigns both against corruption and for an ecological civilisation. Easier registration for NGOs (the opposite of what is happening in neighbouring Russia), public interest litigation rights to some NGOs, legal protection for whistle blowers (EU and USA could learn from this) and repressive tolerance towards public actions focussed on environmental issues (demonstrations, strikes, etc.) point to the same direction (The Economist 2014d). Their success demonstrates that China's state capacity remains relatively strong and its ongoing strengthening will contribute to a more sustainable pattern of economic development.

China–the World's last best hope?

Institutional change: adjusting development priorities

According to Prime Minister Li Kequiang, China must "declare war on pollution", and end the "blind development" that has caused serious risks for human health, economic development and nature's integrity. If indeed the struggle to eliminate such pollution is pressing as hard and proceeding as successfully as the one to overcome poverty, as he promised, both the Chinese population and the world would benefit. In particular the new legislation announced on March 9th, 2014, toughening the 1989 environmental protection laws and due to enter in force in January 2015, represents not only ambition, but also a number of innovative measures to realise its intentions. It is paving the way for stiffer, possibly unlimited penalties for polluting companies, allowing for fines against polluters to increase daily until a violation is corrected (the one-time payment usual so far, as in Europe, had failed to be effective). It also allows for the suspension or shut down of repeated offenders (Saigon Times 2014), the detention of negligent executives, and penalties for officials failing to enforce the law (The Economist 2014d). The public interest litigation function of some NGOs, and the whistle blower protection rules, together with the encouragement of more critical reporting in official media, plus a certain level of tolerance on internet blogging on environmental and food security issues will help the case.

Measures announced are not only intended to secure private and public business compliance, but offer incentives for increasing the energy efficiency and thus reduce pollution from large, mostly state owned companies; the foreseen massive investment in wind and solar energy has a similar effect. These measures, and the carbon tax to be phased in gradually; are indeed necessary and urgent. The planned investment of some 200 billion € over the next five years to clean up China's air is most impressive by anyone's standards. For all these actions, international collaboration and support is more than justified (e.g. by making patented green technology easily and freely accessible).

An ecological civilisation requires not only new infrastructure and production facilities as China is building them with a breath-taking speed on top of the existing ones, but also requires phasing out of environmentally, socially and/or economically unsustainable old installations: *innovation* is effective only if combined with *exnovation*. Plans to shut down outdated production facilities in highly energy intensive sectors such as cement, steel and glass making ahead of schedule are promising in this respect. However, as known from modern innovation research, such improvements tend to generate incremental rather than deep structural change. Sustainable development requires three kinds of changes: technological, social and institutional, with increasing importance of social and institutional innovation (Rennings 2000).While social innovation includes the prevailing consumption patterns, the core of institutional innovation is changing the selection mechanisms according to which certain developments, inventions and strategies become dominant, and others do not (Hausknost and Haas 2013). Therefore it is probably of even greater importance than the innovation/exnovation dualism that–after years of discussion–the Communist Party decided to update its promotion criteria, making the environmental performance an asset to be considered in the selection of cadres for higher level positions, alongside the economic success. In particular this measure, combined with the threat of penalties for non-enforcement, are a carrot-and-stick approach which may be able to provide the effective tools to make the Prime Minister's declaration operational.

Air quality and industrial emissions

Coal burning for electricity generation and in the energy intensive industries is the main source of air pollution. China has made unprecedented progress in reducing the energy intensity of its economy over the past three decades; in 2013 energy efficiency gains accelerated to a 3.7% decrease of energy consumption per unit of GDP, and a further increase of 3.9% is announced for 2014. The measures taken include efficiency programs, energy quota for state owned companies, and other laws and incentives. They have reduced the primary energy conszmption per unit of GDP from 800 t of coal equivalent (tce) per 1 million US$ of output, down to 390 tce in 2009 (constant 2005 PPP). However, China's specific energy consumption is still above the global average of 300 tce (World Bank 2013), and the gap between China and the high-income countries is huge. For instance, the primary energy intensity of Germany's economy was 167 tce per million US$. This is one of the reasons for the Germany's high international competitiveness–although comparatively small it was the no. 1 export nation until 2011 and overtaken by China only in the wake of the Great Recession–which exemplifies the potential gains for China from further improving its energy productivity, reducing the demand for coal. Thus the 40-45% improvement 2005–2020 foreseen in the current planning is a welcome objective, but it will not easy to achieve: the power plant efficiency improvements are facing limits as the average thermal efficiency has increased from 31% in 2000 to 38%, the same level as Germany (the USA are flat at 33%); the technical maximum is about 45%. Thus efficiency increase in the energy sector, indispensable as it is, is insufficient if not combined with efficient energy use, a substitution of renewable energy sources for coal, and emission reductions from other sectors (including a more sustainable consumption). This requires a corresponding allocation of research funds–economic analysis has shown that there are important conflicts between public and private welfare concerning the direction of energy efficiency research. For enhancing public welfare, the concentration of research should be in greater use efficiency, whereas for the private welfare of the extraction industry (state owned or not) research in extraction innovation would be most helpful (Wils 2001).

An important sector that could benefit from energetic measures is road transport. While gasoline cars are a rapidly growing consumer of fossil fuels, diesel cars and trucks are not only a major source of $PM_{2.5}$ in the cities, they also place a heavy burden on the country's infrastructure. Incentives to replace old, polluting and often collapsing heavy lorries with more sustainable means of transport are welcome. The sod emissions of old trucks, together with sulphur dioxide SO_2 from the energy sector, are one main origin of the unhealthy smog. Therefore the rapid reduction of SO_2 emissions is a great achievement, with 3.5% reduction in 2013 and another 2% announced for 2014. A Harvard university study characterised the SO_2 reduction programme of recent years as "one of the most swiftly effective air-pollution policies ever implemented anywhere" (The Economist 2014c).

However, as long as the efficiency growth lags behind the economic growth rate, the energy demand will continue to increase, and with it coal consumption and emissions unless the composition of sources is changed. This points to the urgent need to continue the rapid expansion of renewable energies such as wind and solar which will be needed to turn the trend on China's CO_2 emissions, bringing them back to sustainable levels by the second half of the century. The development of solar energy will have effects far beyond China itself; it could put the energy systems and politics of affluent countries in Europe and America upside down (Schleicher-Tappeser 2012).

Energy generation and climate change

China has been surpassing the USA to become the biggest investor in renewable energy, spending 50 billion € in 2012, three time the investment in Germany (in all three countries the need to modernise the grid is one of the key obstacles to more and efficient use of wind and solar power). In the meantime, the total installed wind energy capacity in China has surpassed the level reached in the EU. Although it contributes only four to six percent to the national electricity consumption so far, the acceleration foreseen in the five year plan (doubling the already high speed of expansion) can contribute to the desired turn-around. As the investment in solar energy is similarly striking, hydropower has been systematically exploited (sometimes even over the top, given the local social and environmental impacts) and other sources are being explored (e.g. tidal, geothermic), China has become the world's largest investor in renewable energies research, innovation and installation. It may reach a peak of carbon emissions by the end of the decade, followed by a decrease in absolute terms.

Other options under consideration look less promising: enhancing the nuclear sector comes with high up-front investment, long-term capital fixation, uncertain but extremely high follow-up cost (decommissioning cost in Germany has surpassed 4,000 million € for one plant). The question of nuclear safety is a public concern, so a nuclear expansion strategy carries with it the risk of provoking multiple local resistance, if not even-for the first time-a nation-wide protest movement. Regarding energy provision and safety, nuclear power does not offer the "biggest bang for the buck"; without heavy subsidies, it would not be economical (compared to coal as much as to solar energy made in China). Also the investment in Carbon Capture and Storage CCS seems misguided: judging from the progress made over the last ten years and the projections for further development, CCS–if it works at all–will come too late to prevent a climate collapse. At the same time, it stimulates further coal use, potentially undermining China's politically set goal to produce 20% of its energy from renewable sources until 2020. It would absorb billions of Yuan which, if invested in energy saving and renewable energies, would have stronger economic, social and environmental effects: investments in renewables are more reliable, are expected to pay-off in a shorter period of time and have the potential to create employment and income opportunities in remote parts of Central and Western China. The energy consumption of CCS (one additional power plant to fuel CCS for each three providing electricity) and the technical uncertainty are additional economic arguments against CCS. For these reasons the CCS euphoria has already declined in most European countries (for instance Island and Norway cancelled their ambitious projects), but it still flies high in the USA–not because technology and cost calculations would be different, but as result of a path-dependent development, an attempt to recuperate the sunk cost already invested, and a face saving measure for those who promised a solution to the climate problem from CCS: a sink for money, but not for carbon. China, given its governance structure, should be in a position to opt out of a strategy which was tested and proven to be no solution.

Both CCS and nuclear energy are burdened with economic and safety problems of their long-term legacies: nuclear waste disposal sites, as much as large underground high pressure CO_2 storages require continuous surveillance. The resulting cost of guarding and maintaining the deposits for several hundreds to thousands of years are beyond any calculation, but most probably exceed any economic gain from these technologies.

For other forms of geo-engineering the uncertainty is even higher, the success more questionable, the cost more worrisome and the side effects more dangerous (Scheer and Renn 2010, Gardiner 2011). For instance, technologies to cool the earth by reflecting sunlight may be able to decrease the temperature, but would result in changing weather patterns, including the possibility of a faltering or relocated monsoon, the main water source for more than 2 billion people, including significant parts of China. Even armed conflicts and pre-emptive strikes to avoid such developments have already been discussed (Grunwald 2010).

Beyond CO_2 and the energy sector, and CH_4 and N_2O which are discussed in the next section, some trace gases with extremely high radiative forcing are an element not to be neglected. Insofar the phasing out of hydrofluorcarbons HFCs, a particularly potent class of greenhouse gases, and the cause of stratospheric ozone depletion, is a much welcome voluntary action China has undertaken.

Agriculture and land use policy

Agricultural problems in China have a qualitative and a quantitative aspect. Regarding quality, a recent Greenpeace study found dangerous levels of heavy metals contamination on rice grown near mines and factories, underlining the need to rein in emissions to air, land and water, and ending the sale of contaminated fertiliser (The Economist 2014d). The environmental law will be of importance to address these problems.

On the quantitative side of the coin, the Chinese government correctly perceives the need to redress the rural-urban gap, and sees land consolidation as an appropriate approach not only to rationalise land use but also as an important component of rural development. This approach, together with a number of consolidation models, has been endorsed by many scholars.

China's new family farm policy is intended to initiate and accelerate the shift from small farms of 0.5 to 5 ha to larger units, more efficiency and more mechanisation. However, US-like mega-farms are neither desirable for social and environmental reasons, nor are they possible. Unlike the Great Plains, much of China's agricultural area is sloped requiring terrace construction to minimise erosion even in the loess plateau (see Figure 5). Furthermore, managing irrigation rice fields requires units of a maximum size of a few hectares to control the water flow, and the paddy dykes necessary to that behalf, while not excluding mechanisation, still limit its dimensions. Other downsides include that oversized fields, managed not by transplanting but by direct seeding require more of the expensive and energy intensive external inputs and show a declining input/output ratio (Pan and Pan 2012). Farming incomes could be increased through reduced cost and their reliability enhanced by reduced vulnerability to pest infestations by changing the land management to methods such as ecological engineering (restrictions to insecticide

Figure 8. Agriculture in Xiyang, Shanxi province, China 2013.

use, less fertilisation reducing the attractiveness to pests, larger distances between plants resulting in higher tillerage), substituting pesticide use for supporting biological control mechanisms and organic for chemical fertiliser (Gurr et al. 2012). Such fields are less prone to plant hopper infestations than conventionally managed fields, which pose a serious threat to food security in particular in Southern China–ecological engineering is enhancing food security and by reducing soil and water pollution also food safety (Gurr et al. 2012). The system of rice intensification SRI technique has some commonalities with ecological engineering (except for the biocontrol), and reduces water demand by keeping soils wet but not necessarily flooded throughout the growing season (Noltze et al. 2013). This could be a significant contribution to relaxing China's water stress.

Reducing external inputs, together with quality standards and control, can also contribute significantly to halting soil pollution in China, which is another reason for concern regarding food security. Airborne soil pollution will be reduced in future by programmes to clean and reduce emissions from energy generation and heavy industries initiated for other purposes.

Biodiversity

Effective biodiversity conservation requires both, protected areas as a retreat for sensitive species, but also between them a landscape which is not a "biological desert". Ecological engineering in agriculture contributes to the latter by promoting a land-

Figure 9. Protected areas–International Ramsar wetland reserve near Siblungkeka, and a national reserve in the mountain region, both Gansu province 2012.

Figure 10. The trend to high rise buildings in urban construction, Shanghai 2010.

scape management not pursuing a monoculture structure without any intermittent structures providing ecological niches.

China has established a number of protected areas, some of them registered under international conventions, such as the Ramsar Convention for the protection of ecologically valuable wetlands (see Figure 6). Although still more could be done, the size and the management of protected areas have been improving. Afforestation is taking place on a large scale (considered as the largest afforestation program in human history), but choice of species could be improved, with a focus on locally adapted ones. This would support biodiversity conservation while at the same time contributing to more resilient systems (which can be expected to pay out economically as well, but only in the longer-term).

Finally, for a number of years sealing soil for settlement purposes has been restricted or more or less effectively banned (Xue 2012a, b), which is one reason for the absence of urban sprawl and the mushrooming of high rise buildings in the growing urban agglomerations (Figure 7). A similar space consumption restricting effect can be expected from continuing politically prioritising rail freight transport over road transport, although in both cases implementation could be improved.

Social sustainability

China today is a rapidly growing middle income country, home to a segment of less than 10% of the population living in absolute poverty, a broad middle class and a small super-rich elite, including 20% of the world's dollar-billionaires. This income polarisation causes a number of problems:

- The social discrepancies in a formerly rather egalitarian country cause dissatisfaction, if not protest. Internationally it is well known that income disparities contribute to conflict, violence and degradation of the social fabric (Wilkinson and Picket 2009).
- High wealth is a key driver of CO_2-emissions; consequently, specific policies addressing the rich are needed (Hurth and Wells 2007).

Furthermore, if the Chinese development model were modified to reduce the export and investment dependency, private consumption would have to play a larger role. This requires eliminating the remaining pockets of poverty, strengthening the rural economy, and increasing the median income. Doing so will hardly be possible without redistribution of incomes and assets; growth alone will hardly be able to offer a solution (and has done the opposite in the past). To improve the average standard of living the consumption opportunities for the so-far underprivileged will have to be enhanced, and with it, unfortunately, resource consumption and emissions. This will hardly be possible without massive efforts towards social justice and dramatically increased resource productivity, and sustainable consumption (Lorek 2010, Lorek and Spangenberg 2014). In the past the Chinese leadership has reacted sensitively to social unrest, trying to address the causes of dissatisfaction. However, income and asset redistribution may be a different case as it inevitably produces winners and losers, and the would-be losers tend to be associated with the ruling political and economic/financial elites. Getting towards a more equitable income distribution will require true leadership.

From villain to hero?

China has shown unprecedented efforts to clean up its environmental performance, and plans to continue and even accelerate its progress. Nonetheless, regarding climate change, its net ecological debt keeps growing as its emissions are still the world's highest, and efforts to reduce CO_2 emissions will affect global warming only with a long delay, due to the 120 years atmospheric residence time of carbon dioxide. To avoid interference with the internal affairs of other countries, claim an international leadership role, and to meet its international obligations (Rio Principle 2: "States have […] the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction") China has to start reducing its climate debt rather soon, and stop building up its ecological debt soon after. Here three proposals are presented how this could be achieved: the methane strategy, capping inputs and developing a new growth model.

The Methane strategy–an example of common but differentiated responsibilities

Rio-Principle 7: "[…] In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities."

So far rather neglected in climate protection policies, due to its physical characteristics methane CH_4 could potentially play an important role in short-term effective Chinese climate policies. For instance, if between 2006 and 2050 the global CH_4 emissions were reduced by about half the 2005 rate, due to its high radiative forcing RF the result by 2050 would be equivalent (in terms of RF) to a complete phasing out of carbon dioxide emissions over the same period (Smith et al. 2013). With its short residence time, the maximum effect would appear within a couple of decades, while in the longer run the extended residence time of CO_2 and N_2O dominates the climate effect of current emissions.

So if methane is such an important factor for global climate change, and was in 2005 responsible for 43% of the global climate debt, why is it not discussed more intensively? This is an example of not taking the differentiated responsibility seriously enough. For countries with a share of less than 25–30% CH_4 in their climate debt, further reducing this limited contribution is not the most effective climate protection strategy due to methane's limited atmospheric residence time, and this is the case for most industrialised countries. For instance, the methane share in their national climate debt is 23% for the USA, 21% for the UK and 16% for Germany, but 93% for Bangladesh, 83% for Vietnam, 81% for Brazil, 66% for India and 53% for China (Smith et al. 2013). Thus while early industrialised countries rightfully (and more or less forcefully) focus on reducing CO_2 emissions, the developing countries and emerging economies would be well advised to focus on CH_4 emission reduction (without neglecting a sustained, mid to long term effort to limit their CO_2 emissions), as the most effective and efficient climate change mitigation strategy.

Globally CH_4 emissions originate in equal parts from biomass production, use and disposal (with cattle breeding the dominant source), and from fossil energy production, distribution and use. Thus investment to minimise emissions from fossil fuel distribution systems are the first option for minimising CH_4 emissions; they reduce losses and are therefore economically beneficial. Similar benefits arise when CH_4 emissions associated with coal mining are captured and used as energy source. Reducing methane emissions from biomass use requires a broader strategy, including improved waste management (organic matter in waste disposal sites generates CH_4), and by capturing and using the methane, a relatively cheap technology commonplace in Europe. Such measures can be implemented without deep structural changes of the economy, that is, faster and at lower cost than reducing CO_2 emissions. Changing consumption patterns, minimising beef in the diet (pork and chicken are less methane intensive) is more challenging, but not impossible in a country like China (Feng et al. 2009). Most importantly, specifically for South and East Asia, agricultural management methods like ecological engineering and some elements of the system of rice intensification are social innovations which together with technical innovations like the choice of appropriate rice varieties may help reducing CH_4 emissions. Integrating the low-methane producing varieties developed in China into such innovate land and crop management systems would be an important next step, with reduced N_2O emissions resulting from less fertiliser use a welcome side effect.

As this would result in a higher labour force demand in rural areas, financial incentives for shifting to such methods may be a method of choice, combining rural income generation and environmental protection. China has extensive experience with such schemes and how they have to be implemented, not least from their use in the afforestation programs.

Controlling CH_4 emissions can be the low hanging fruits to pick, buying enough time for the aggressive CO_2 reduction strategies to become effective regarding the climate debt. It does not change the necessary carbon reduction targets, but makes it easier to achieve them.

Unburnable fuels–capping consumption

In the past China has formulated its climate policy targets as reducing greenhouse gas emissions per unit of GDP, resulting in ever increasing emissions in absolute terms. As a result, despite massive efforts, China's emissions per capita have now surpassed those of the European Union. What is urgently needed is a strategic plan how to bring back greenhouse gas emissions from more than 7 t CO_{2eq}/cap (including CO_2, CH_4 and N_2O but not LUCF) to the level the world's atmosphere can absorb, about 2 t CO_{2eq}/cap. It will require the combination of technical, social and institutional innovation on both the supply and the demand side. "Peak demand" does not occur on its own and must be brought about politically; only by getting "the Rich and the Dirty" under control can the dynamic of ever increasing consumption and pollution be reverted (Spangenberg 2014). In the context of increasing wealth concentration and poverty gaps, this subject is central to issues of social justice as well as environmental integrity (Hurth and Wells 2007). However, to avoid runaway climate change policies to cut demand are not sufficient; the must be complemented by supply-side policies to stem the flow of fossil fuels.

Leaving 2/3 to 9/10 of all known fossil fuel reserves in the ground has been explained to be a necessity to limit the damages caused by climate change to a level human civilisation can probably handle; this is arguably the biggest challenge in shaping how we will live in the anthropocene. China still lacks a strategy in this respect, including a ranking of fuels to be used from by domestic extraction and from fuel imports. Economically, the book value of proven reserves should be written down accordingly (possible once priorities have been defined), by both public institutions and private corporations, even if that implies loosing virtual value (the current overvaluation is similar to the one of the other toxic assets causing the 2009 banking crisis). However, the increasing cost of mobilising such reserves should make it easier to give up on bringing them to the market.

When deciding which kinds of fossil fuels to use, plausibly the most CO_2 producing fossil energy carriers should be phased out first, notably lignite (brown coal). This would affect the lignite mining areas in Germany, Australia, the Czech Republic, and Inner Mongolia in China, where some of the largest lignite development projects are under way. Regarding reserves, Germany has the world's largest ones (40.5 Gt), followed by Australia (37.2 Gt), the USA (30.2 Gt), China (18.6 Gt) and Serbia (13.4 Gt)(WEC 2013). Taking into account not only the lower caloric content of lignite and the resulting high specific emissions, but also other negative side effects and the emissions, lignite is the dirtiest fossil fuel. Add to this the high water consumption in open pit mining, the heavy transport loads on rail and road with all the resulting damages, and the high sulphur content which has caused acid rain particularly in Southern China, investment into lignite is incompatible with climate and general environmental responsibility. The second fossil fuel to be phased out would be hard coal (before oil and gas), affecting a wide variety of producers and consumers (coal is mined in over 100 countries), and in particular China which consumes more than half all coal produced on Earth (2011: China 50.7%, United States 12.5%, India 9.9%, Russia and Germany 3.3% each) and produced almost half of all coal on Earth (2011: China 49.5%, United States 14.1%, Australia 5.8%, India 5.6%, the European Union 4.2%)(Olivier et al. 2012).

Once the decision has been taken which kinds of reserves to explore and exploit, the choice must still be made where to do it, domestically as well as regarding imports. Such a decision should be taken not exclusively based on cost considerations, but on an assessment of social and environmental impacts associated with drilling and pumping oil or gas, and for digging coal in each place. Oil and gas extraction, and coal mining, even using the most modern techniques, will always be dirty business. There is no ethical, environmental or social justification for mobilising reserves with above-average environmental and social impacts, including deep sea oil, tar sands, or hydraulic fracturing for shale gas, destroying riverine delta ecosystems and other wetlands, densely populated farmland, or biodiverse forests. These are places uniquely unsuited for fossil fuel extraction, now and in the future. Halting the fuel frontier should begin in such fragile ecosystems as saving the most vulnerable locations from extraction would avoid huge ecological and social costs. For any mining or drilling operation outside these fragile systems, the environmental impact, in particular the carbon emissions, ecological degradation by specific land use practises and water consumption should be minimised, biodiversity and ecosystems conserved and the social, economic and environmental rights of local resident communities and minority groups safeguarded. Today, some countries are already taking steps to limit their emissions out of a necessity to increase energy independence as much as to reduce pollution.

A new growth model: Degrowth by design, not by disaster

Capping the carbon or total energy input (as foreseen by the Chinese government as a later step after first capping the CO_2 output and charging for it) is necessary to complement existing policies and enhance their effectiveness. It requires a growth model in which the increase of resource efficiency Y/R is permanently higher than the economic growth rate Y: d(Y/R) > dY (R total national resource consumption, Y size of the national economy, Spangenberg et al. 2002, Spangenberg 2011). This in turn requires accepting limitations to national affluence (measured in terms of resources consumed), and for reasons of justice and social stability effort towards a more egalitarian distribution of income and assets.

While at first glance this this may sound like a development suppressing policy proposal and big challenge to China, at a second look it is rather an opportunity compared to a strategy of economic growth and the attempt of technical remediation. Today, the cost of soil degradation and health impacts of air pollution amount to 9% of the GDP per year, according to the World Bank. This Figure makes the reported growth rates seem rather hollow; net growth seems to have been in the lower one digit realm. Thus with lower gross growth rates to be expected, one way of securing economic stability is reducing the environmental and health cost, reaching a comparable gain in the standard of living (net growth) with much reduced GDP growth rates. Reducing air and water pollution, conserving biodiversity, limiting land use change and restoring fertile soil are immense tasks, but they have to be tackled with full force in order to sustain the basis for the country's further development.

Nonetheless an *abrupt and massive* reduction of energy and resource consumption is no politically viable option. It probably would reverse economic growth into recession, and lead to a collapse of development, if not of the economy, due to a lack of physical inputs. Such a *Degrowth by Disaster* is the more probable the later the change course is initiated. The choice is between:

- demand side management through higher energy prices, behaviour change involving energy conservation, and lower economic growth but a number of cost saving fringe benefits such as avoidance of acid rain and reduced health care cost, a more healthy and productive labour force and less environmental motives for public unrest, versus
- supply side management focussing on higher growth rates and technology transitions–with probably limited gains for society as the transition investment absorbs the surplus from the higher growth rate.

The higher level of uncertainty lies with the growth strategy as it relies on the development and successful implementation of not-yet-existing technologies for climate management, such as CCS and geo-engineering, solutions expected to be available on a large scale in due time and without undesirable side effects.

Outlook

Humankind is at a turning point, and a point of no return: there is no way back, and the prevailing development trajectory is a dead end street we drive down with ever increasing speed. Policies to accelerate growth are policies to increase the speed with which we are going to hit the wall. Having population growth, resource availability and planetary boundaries in mind, it is high time for implementing a development paradigm which allows for a high quality of life at about 1/10 of the current resource consumption. This will require the most ambitious and far reaching innovation program ever, including the "ex-novation" of obsolete, unsustainable technologies and installations. Not adding new and better technologies to the portfolio is what is needed, but replacing outdated, resource intensive production processes and factories, together with a change of consumer preferences towards "prosperity light". The second element besides reducing the pressures through resource efficiency, renewable energy and sustainable consumption is deceleration of developments, social and technological, to provide nature the time necessary for ecosystems and species to adapt to and co-evolve with a changing environment.

Taking the differentiated responsibility approach seriously requires taking methane and LUCF into account when defining climate policy strategies. While this is a challenge, it also provides additional opportunities for effective climate policies for countries like China. One such option is a strong focus on CH_4 emission reduction, which would have a comparably rapid effect on effective warming and thus reduce the climate debt much faster than a reduction of CO_2 emissions can do, due to the necessary structural change of the energy and wider economic system, and the atmospheric residence time of carbon dioxide. It enhances the range of policy options available, providing additional short term effective affordable options. For instance, Green belt/green frontier and afforestation programs are an example of how LUCF emissions can be reduced. They have been implemented by the Chinese government for a number of years now; however, to provide success in the long run, they need to be improved regarding the social and environmental standards applied (better compensation for peasant participants, stakeholder participation, technical advice and education, selection of local species instead of wood production for the pulp and paper industry, …) (Li et al. 2009, Bennett 2008).

If, to cut carbon emissions, we need to limit economic growth severely in the rich countries, then it is important to know that this does not mean sacrificing improvements in the real quality of life–in the quality of life as measured by health, happiness, friendship, *and community life, which really matters. However, rather than simply having fewer of all the luxuries which substitute for and prevent us recognizing our more fundamental needs, inequality has to be reduced simultaneously. We need to create more equal societies able to meet our real social neEds Instead of policies to deal with global warming being experienced simply as imposing limits on the possibilities of material satisfaction, they need to be coupled with egalitarian policies which steer us to new and more fundamental ways of improving the quality of our lives. The change is about a historic shift in the sources of human satisfaction from economic growth to a more sociable society.*

Wilkinson and Pickett 2010

Besides reducing the pressures by redirecting the drivers causing them, immediate rescue measures are needed. They need to be based on a foresight based governance/management of social and ecosystems which make use of all available potentials and system characteristics to avoid system collapses by enhancing their adaptive capacities, including cultivating carbon sinks by ecosystem restoration. Strengthening the capability of the central government not only to pass legislation (pollution laws and thousands of decrees) but also to enforce their implementation, administratively and legally, may be a necessary step; independent reporting about the local situation–in Europe often a function of civil society organisations– would help the central government to gain a better control of the implementation of its policy measures on the ground and to further improve policy design. That the Communist party included the environment into its four focal areas (Ecological Civilisation) may further help the implementation of necessary measures, in particular as officials will be promoted with a view on their environmental performance, and will be held accountable for their overall execution of his position also long after having taken up other responsibilities.

Any country aspiring a leadership role in 21st century should be aware that the majority of humankind, and in most severely G77 country inhabitants, will be negatively affected by climate change. A country that is causing havoc on their lands and people will lose the legitimacy of any such claim for leadership, regardless of its economic or military strength. Thus for social, economic, environmental and geopolitical reasons, a rapid transition towards a sustainable economy, making use of all available means, is an urgent necessity, for Europe, the USA and not least for China.

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