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Debate

Capitalism, Climate Change and the Transition to Sustainability: Alternative Scenarios for the US, China and the World

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ABSTRACT

This contribution evaluates the geopolitical and technical issues involved in climate stabilization and discusses alternative technical paths towards the required emission reductions in the US, China and the world. There are no plausible scenarios in which climate stabilization is compatible with a pace of capital accumulation required for economic and political stability under a capitalist system. Meaningful and effective actions towards climate stabilization presuppose and require fundamental social change.

INTRODUCTION

As a historical system, capitalism first emerged in Western Europe at the beginning of the sixteenth century and has since expanded to encompass the entire globe (Wallerstein, 1979). In the capitalist era, world population, consumption and production have experienced unprecedented, explosive growth. The activities of material exchange between humans and the earth's ecological system have overwhelmed the ecological system's natural operative capacity.[1] We are now confronted with a multi-dimensional global environmental crisis that threatens to undermine the basis of civilization and the survival of the human species. Global climate change is among the most important, and potentially the most catastrophic, symptoms of the crisis. There is now scientific consensus that the emission of greenhouse gases, which primarily results from the consumption of fossil fuels (which global capitalism has relied upon as its main source of energy supply), has been the

The author would like to thank the editors and the anonymous referees for many of their excellent suggestions concerning both the style and the content of the paper. These suggestions have made the paper much stronger than it would otherwise have been.

1. According to the *Living Planet Report 2008*, the world's total ecological footprint, which measures humanity's demand of the earth's living resources, now exceeds the earth's regenerative capacity by 30 per cent (WWF et al., 2008).

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primary factor behind the observed increases in global temperatures (IPCC, 2007a).

In recent years, China has become a major driving force of the global capitalist economy and has overtaken the US to become the world's largest emitter of greenhouse gases. China and the US together account for about 40 per cent of the global emissions of carbon dioxide, the principal greenhouse gas. Unless both countries take meaningful steps to reduce emissions in accordance with their global obligations, there is virtually no hope for global emissions to be reduced to levels consistent with those required for climate stabilization.

It would be naive to think that climate stabilization can be accomplished within the historical framework of the existing social system. In the US, China and the world as a whole, meaningful and effective actions towards climate stabilization presuppose and require fundamental social change. In this contribution, I evaluate the geopolitical and technical issues involved in climate stabilization and discuss alternative technical paths towards the required emission reductions in the US, China and the world. I argue that there are no plausible scenarios in which climate stabilization is compatible with a pace of capital accumulation required for economic and political stability under a capitalist system. The article concludes by discussing possible social changes required for achieving climate stabilization in the US, China and the global context.

CAPITALISM AND SUSTAINABILITY

It is no coincidence that modern economic growth (the kind of economic growth that takes place at exponential rates and seems to go on indefinitely) has taken place only in the capitalist era. Capitalism is a social system in which society's surplus product (the total product minus what is necessary to meet the population's basic needs) is controlled by a privileged minority that forms the ruling class. Capitalism is unlike all previous societies; it is the only social system so far in which market relations are pervasive and dominant in the economic and social life of the society.

When market relations are pervasive and dominant — so that virtually every aspect of economic and social life can be measured and valued by money — individual capitalists, businesses and states are under constant and intense pressure to compete against one another. Those who fail in this market competition will cease to exist as capitalists. To survive and prevail in competition, each capitalist, business or state is compelled to use a substantial portion of the surplus product at its disposal (profits or taxes) to engage in capital accumulation. As a result, under capitalism, there has been a systematic tendency for population, production and consumption to expand on increasingly larger scales. Even today, this is still considered by many as the primary virtue of capitalism.[2]

To achieve ecological sustainability, human impact on the ecological system in all its dimensions must stabilize at levels within the system's natural operative capacity. Theoretically, economic growth may be made compatible with ecological sustainability if ecological technological progress can proceed sufficiently rapidly so that environmental impact per unit of economic output falls more rapidly than economic output grows. Technological optimists, such as Hawken et al. (1999) and Brown (2008), argue that through massive reductions of material and energy throughputs per unit of economic output, ecological sustainability can be achieved without undermining economic growth and material prosperity. However, in reality, it is impossible for human economic activities to have zero impact on the environment. As long as the environmental impact per unit of economic output remains positive and does not approach zero, an infinitely growing economy will sooner or later lead to an environmental impact on an increasingly large scale, and will violate the requirements of ecological sustainability (Huesemann, 2003; Trainer, 2001).

More importantly, the arguments of the technological optimists fail to take into account the political, technological and environmental realities within which global capitalist accumulation has taken place. First, the capitalist world system is based on inter-state competition. The inevitable conflicts of interests between nation states and the constant pressure for them to pursue national capital accumulation make it very difficult, and in the case of climate stabilization nearly impossible, for global environmental regulation to function effectively. Second, the existing physical and technical infrastructure of the global capitalist economy is based on non-renewable resources and ecologically unsustainable technologies. Even if economic growth can be made compatible with sustainability under idealized technological conditions, it would nevertheless take several decades to replace the existing infrastructure with a new, ecologically sustainable infrastructure.

However, the global environmental crisis (and especially the climate change crisis) is now developing so rapidly that the global ecological system is literally on the verge of collapse. Thus, as long as the global economy continues to be organized in accordance with capitalist principles committed

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2. The idea that market competition under capitalism motivates and compels individuals and businesses to generate savings and use savings to accumulate capital is a fairly conventional concept, widely accepted by classical, neoclassical, Austrian and Marxist economists. For the economic ideas of Smith, Ricardo, Mill and Marx, see Hunt (2002). For a modern neoclassical analysis of how capitalism drives innovation and economic growth, see Baumol (2004). Immanuel Wallerstein, the leading world system theorist, explicitly defines capitalism as a historical system based on the pursuit of the 'endless accumulation of capital' (Wallerstein, 1979). James Gustave Speth, a leading environmental scholar, also regards the pursuit of perpetual economic growth as the defining feature of modern capitalism (Speth, 2008).

to endless economic growth, there is virtually no hope that ecological catastrophes can be averted.

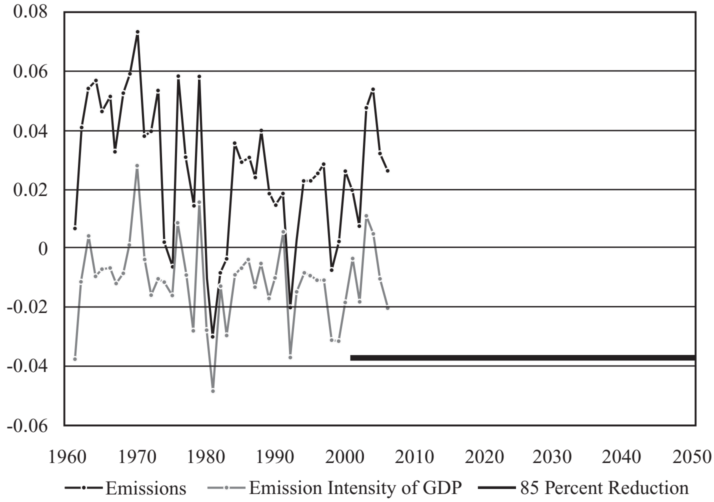
ECONOMIC GROWTH AND CLIMATE CHANGE

According to the Intergovernmental Panel on Climate Change (IPCC, 2007b), global emissions of carbon dioxide must fall by 50–85 per cent from 2000 to 2050 to prevent global warming occurring by 2–2.4 degrees Celsius from pre-industrial times (widely considered to be the threshold required to prevent climate catastrophes that could threaten the survival of humanity and civilization). Since the IPCC reports were published, new studies have pointed out that they seriously underestimated both the potential consequences and the urgency of climate change and far more drastic actions are required to prevent civilization-threatening catastrophic consequences. James Hansen, one of the world's leading climate scientists, argues that the current atmospheric concentration of carbon dioxide will have to fall from the current level of 385 parts per million (ppm) to no more than 350 ppm to prevent the climate system from moving beyond dangerous 'tipping points' that could lead to runaway global warming beyond human control (Hansen et al., 2008).

Hansen's 350 ppm requirement roughly corresponds to IPCC's 85 per cent reduction requirement.[3] The rest of this essay works with the assumption that an 85 per cent reduction of carbon dioxide emissions from 2000 to 2050 would be required for climate stabilization. This translates into an average annual rate of reduction of 3.7 per cent between 2000 and 2050. Figure 1 compares the actual annual rates of change of carbon dioxide emissions from fossil fuels and the annual rates of change of emission intensity of GDP (the ratio of world carbon dioxide emissions to world GDP) for the period 1960–2006, with the annual rates of reduction required for climate stabilization. From 1960 to 2006, for each and every year, global emissions grew at rates well above what is required for 85 per cent reduction. For almost every year, emission intensity failed to fall rapidly enough to match the 85 per cent reduction requirement. Rates of change of emission intensity essentially tell us where the rates of change of emissions would be if economic growth were to be zero. Thus, given the current pattern of technical change, the global economy needs to stop growing immediately if there is to be any hope of achieving climate stabilization. In fact, since economic growth and emissions growth have continued since 2000, climate stabilization would require more rapid reduction of emissions than is suggested in Figure 1.

3. According to the IPCC report, an 85 per cent reduction of carbon dioxide emissions from 2000 to 2050 would help the atmospheric concentration of carbon dioxide equivalent to stabilize at 445 ppm, which corresponds to an atmospheric concentration of carbon dioxide at 350 ppm.

Figure 1. Carbon Dioxide Emissions from Fossil Fuels: Historical Performance and Climate Stabilization Requirements (Annual Rate of Change)



Note: World GDP is calculated with constant 2005 purchasing power parity dollars.
Source: World Bank (2008).

THE GEOPOLITICS OF CLIMATE CHANGE

Even if it is technically feasible to make climate stabilization compatible with economic growth, efforts aimed at climate stabilization are likely to face insurmountable political obstacles under the capitalist world system. Capitalism is a system based on inter-state competition, which is essential to secure favourable political conditions for capital accumulation (Arrighi, 1994; Wallerstein, 1979). Within the world system, states are under constant pressure to compete against each other economically and militarily.

Climate stabilization would require the substitution of de-carbonized energy sources (which are currently often more expensive than fossil fuels) for conventional fossil fuels, or the adoption of energy efficiency measures that businesses otherwise would not adopt (the economic benefits of the new energy efficiency measures may be smaller than their economic costs). Climate stabilization measures would thus raise the short-term and medium-term costs for capitalists and slow down the pace of capital accumulation. Few states would be willing to take such actions towards emissions reduction unilaterally as this could seriously undermine their competitive position in the world system. On the other hand, there is no world government that can effectively discipline the individual capitalist states and help to promote the long-term, structural interest of the system as a whole. Historically, successive hegemonic powers have on occasion acted as proxies of world government and helped to maintain a careful balance between inter-state competition and the promotion of the systemic interest. However, the US hegemony is in decline and there is no obvious successor that could act as the next hegemonic power and effectively regulate the system.[4]

The problem is further complicated by the fact that the capitalist world system is characterized by fundamental inequalities in the distribution of income, wealth and power. Within the system, states are divided into three structural positions — core, semi-periphery and periphery — depending on their relative advantages or disadvantages in the global division of labour (Wallerstein, 1979). Among the core states, the European Union has been most active in promoting the global effort of climate stabilization. In 2007, the European Commission announced the objective of reducing carbon dioxide emissions by 20 per cent by 2020, measured against 1990 levels. By itself, however, the European action would fall far short of what would be required for global climate stabilization. Given current relative contributions to global emissions, the planned European emissions reduction, if achieved, could be offset by just a few years of emissions growth in China. Moreover, while the latest European Summit (which took place at Poznan in December 2008) reconfirmed the 20 per cent emissions reduction goal, it also made many concessions to heavy industries and Eastern European countries. The deal also allowed the European countries to buy 'credits' to fulfil their emissions reduction obligations by investing in emission reductions in the rest of the world. This arrangement could become a major loophole that dilutes the emissions reduction plan (*The Economist*, 2008).[5]

On the other hand, given its heavy dependence on fossil fuels (especially oil) and its highly wasteful energy infrastructure, the US capitalist class had, until recently, been much more hesitant to make a serious commitment to climate stabilization. Under the Obama administration, the US is likely to take a much more active stance, but it remains uncertain whether the Obama administration will commit itself to sufficiently serious actions and obligations.

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4. Historically, the hegemonic powers of the capitalist world system have relied upon control over globally effective means of violence, as well as universally accepted means of payment — that is, military and financial power (Arrighi et al., 1999). Some suggest that today's advanced capitalist countries, such as the US and Europe, could lead the global climate actions by setting an example or standard (for example, see Galbraith, 2008). However, even assuming that such example-setting is politically feasible within the advanced capitalist countries, unless the peripheral and semi-peripheral states are willing to give up economic growth or accept a much slower pace of growth, it is not clear how examples by themselves could persuade the peripheral and semi-peripheral states to take sufficient and timely actions towards climate stabilization. This will be discussed below.
5. China now accounts for about 20 per cent of the world's carbon dioxide emissions, while the European Union accounts for about 15 per cent. Thus, if China's emissions were to grow by 15 per cent in two years (corresponding to an annual growth rate of 7 per cent), it would be sufficient to offset a 20 per cent reduction of European emissions. For more discussions on the problems of carbon trading and carbon credits, see Lohmann (2006).

While historically the core states have been responsible for most of the greenhouse gases that have accumulated in the atmosphere, in recent years big semi-peripheral states (the so-called 'emerging markets') have been responsible for most of the growth of greenhouse gas emissions. According to World Bank data, the 'low and middle income' countries now account for about half of the world's total carbon dioxide emissions and accounted for about three-quarters of the world's increase in emissions from 2000 to 2004 (World Bank, 2008). Without substantial emissions reductions by big semi-peripheral states such as Brazil, China, India, Mexico and South Africa, there is virtually no hope for global climate stabilization to be achieved.

Despite their rapid pace of accumulation and economic growth, big semi-peripheral states are still far behind the core states in terms of per capita income and resources consumption. These states have relied upon cheap labour force and cheap resources as their main 'comparative advantages' in global capitalist competition. They also depend on rapid economic growth to alleviate domestic political and social tensions.[6] Not surprisingly, the ruling elites of the major 'emerging markets' have converged towards a position that vigorously opposes any climate stabilization action that would threaten to lower their economic growth rates and insist that almost the entire economic burden of climate stabilization must be placed on the core states.

At the G8 summit in Japan in July 2008, after difficult negotiations, the leaders of the eight industrial countries managed to agree on a vague goal to reduce carbon dioxide emissions by 50 per cent by 2050 (but without agreeing on a starting year). This was immediately rejected by the leaders of Brazil, China, India, Mexico and South Africa, who urged the 'developed countries' to reduce emissions by 80–95 per cent from 1990 levels by 2050 and demanded financial support to help 'developing countries' to adapt to climate change. The Chinese President, Hu Jintao, said that China, being a developing country, would have to focus on industrialization and raising people's living standards. The joint statement of the five leaders insisted that the 'developed countries' must 'take the lead in achieving ambitious and absolute greenhouse gas emission reductions' (Hornby, 2008; Wintour and Elliott, 2008).

As world leaders headed for Poland, for United Nations talks to prepare a new treaty to replace the largely ineffective Kyoto protocol, China called

6. Measured by Gini coefficient, Brazil, China, Mexico and South Africa all have higher degrees of inequality in income distribution than the advanced capitalist countries (see UNDP, 2008; also the website of Wikipedia: http://en.wikipedia.org/wiki/List_of_countries_by_income_equality). India has a smaller Gini coefficient but widespread poverty. The middle classes in these countries have strong desires to match the living styles of middle classes in western countries. The working people have tolerated their current dreadful living and working conditions as they hope for much improvement in the not too distant future. The political legitimacy of governments in these countries very much depends on the implicit promise that in the long run, the general population's living standards will catch up with those in the West.

for developed countries to spend 1 per cent of their GDP (or more than US$ 300 billion) to help developing countries to cut greenhouse gas emissions and transfer 'green' technologies. In return, China has offered no concrete emissions reduction goals. The *Financial Times* reported that: 'Officials involved in the talks said China's demand was unlikely to be agreed by developed countries, but reflected a widespread feeling among poor nations' (Dyer and Harvey, 2008).

CLIMATE STABILIZATION: ALTERNATIVE SCENARIOS

This section will evaluate alternative scenarios of energy supply and economic growth for the world. These scenarios suggest that under no plausible circumstances could the emissions reduction required for climate stabilization be compatible with the pace of economic growth required for capitalist economic and political stability.

Measured by radiative forcing, carbon dioxide accounts for about three-quarters of the total long-lived greenhouse gases in the atmosphere and more than 100 per cent of the total net anthropogenic forcing when offsetting effects from aerosols are taken into account (IPCC, 2007a).[7] Rising atmospheric concentration of carbon dioxide results primarily from the burning of fossil fuels. To reduce carbon dioxide emissions and stabilize the climate, human energy consumption and economic activities must undergo fundamental changes.

There are three possible substitutes for the current form of fossil fuel consumption: renewable energies, nuclear energy and fossil fuel consumption with carbon capture and storage. Carbon capture and storage can only be applied to large, stationary facilities. It will substantially reduce energy efficiency and raise the cost of energy investment. Most importantly, commercial scale application of carbon capture and storage is unlikely to be ready before 2030 and even then may not be applied to a large portion of the power plants, while climate stabilization requires that global carbon dioxide emissions start declining by no later than 2015 (Greenpeace International, 2008a; Viebahn et al., 2009).

Nuclear electricity generation uses uranium, which is a non-renewable resource and will not last very long with conventional nuclear reactors. According to the Energy Watch Group (2006), the world's proven and possible uranium resources could only last between thirty and seventy years. Moreover, given the slow pace of nuclear reactor construction, the building

7. Carbon dioxide and other greenhouse gases (such as methane and nitrous oxide) contribute to global warming. But anthropogenic contributions to aerosols together produce a cooling effect. The cooling effect of aerosols is slightly greater than the warming effect of non-carbon dioxide greenhouse gases. Thus, carbon dioxide accounts for more than 100 per cent of the net warming effect.

of new nuclear power plants in the coming years will be barely enough to replace the old nuclear plants that are going to retire.

Fast breeder reactors (which could increase the lifetime of uranium resources 100-fold) are expensive to construct, difficult to operate and maintain, and have serious safety concerns. The technology may not be mature for decades. The long-term prospect of nuclear fusion technology, which theoretically could provide almost unlimited energy supply, is even more uncertain (Heinberg, 2004: 132–9; Kunstler, 2005: 140–6; Trainer, 2007: 119–24).

Among the renewables, only wind and solar power have the long-term physical potential to provide an energy supply that is comparable to or possibly greater than the present world energy supply. Even wind and solar are subject to long-term physical limitations, however. They are intermittent energy sources, which could limit their penetration in electricity supply; and in general, they can only be used to produce electricity (Lightfoot and Green, 2002; Trainer, 2007).

Energy is the foundation of the modern industrial economy. To replace fossil fuels with other forms of energy consumption requires fundamental changes of society's energy, transportation and industrial infrastructure. Even leaving aside more fundamental limitations, the potential for emissions reduction and energy de-carbonization could simply be limited by the realistic pace of infrastructural construction.

In the post-fossil fuel world, electricity from various renewable sources will have to play a dominant role in overall energy consumption. However, the construction of power plants and other electricity facilities requires not only financial resources, but also workers, technicians and engineers with special skills and expertise, as well as equipment and materials that have to be produced by specialized factories. One cannot simply print billions of dollar bills and expect renewable electricity to be generated. Instead, workers need to be trained in the necessary skills, and new equipment and materials need to be produced. All of these — as well as the construction process itself — will not only consume resources but also take time. Thus, as a rule of thumb, over any particular period, the power industry's total installation capacity must set the upper limit to the expansion of renewable energies.[8] Moreover, massive investment is required to expand and transform electric grids, and to electrify much of the transportation, industrial and residential infrastructure.

Table 1 presents the historical performance and three different projected scenarios of world energy supply, with fossil fuel consumption falling in accordance with the requirement of climate stabilization. Some assumptions

8. For example, suppose an economy, given its engineering and construction capacity, can install no more than 50 giga-watts of power plants of any type over a year. Roughly speaking, this economy's renewable electricity generating capacity can grow at a maximum annual rate of 50 giga-watts.

Table 1. World Energy Supply: Historical Performance and Projections

Years and Scenarios	Fossil Fuels (Mtoe)	Nuclear (TWH)	Hydro & Other (TWH)	Wind & Solar (TWH)	Wind & Solar (GW)	Energy Supply (Mtoe)	Energy Efficiency ($/toe)	Real GDP (Trillion $)
Historical Performance:								
2005:	9260	2771	3193	139	64	9785	5720	56.0
1980–2005 (annual rate of change):						1.7%	1.4%	3.1%
Projections:								
Scenario 1								
2050	1187	5542	6386	19863	9070	3921	13944	54.7
2005–2050 (annual rate of change):						−2.0%	2%	−0.05%
Scenario 2								
2050	1187	5542	6386	39573	18070	5616	13944	78.3
2005–2050 (annual rate of change):						−1.2%	2%	0.7%
Scenario 3								
2050	1187	5542	6386	78993	36070	9005	13944	125.6
2005–2050 (annual rate of change):						−0.2%	2%	1.8%

Notes:
Mtoe: million metric tons of oil equivalent.
TWH: trillion-watt hours (11.63 trillion-watt hours = 1 million metric tons of oil equivalent).
GW: giga-watts (measure of electricity generating capacity, 1 giga-watt generates 1 billion-watt hour or 0.001 trillion-watt hour of electricity per hour at peak capacity).
Energy supply: total energy supply from fossil fuels, nuclear, hydro and other renewables, and wind and solar.
Energy efficiency: measured by 2005 purchasing power parity dollars per metric ton of oil equivalent.
Real GDP: measured by trillions of 2005 purchasing power parity dollars.
Source: Author's construction. Historical data of world energy supply and GDP are from BP (2008a) and World Bank (2008).

Assumptions of Table 1

1. Total world emissions of carbon dioxide fall by 85 per cent from 2000 levels by 2050, implying a reduction by 87 per cent from 2005 levels. This is consistent with the emission reduction required to prevent global warming of 2 degrees Celsius as is suggested by the IPCC report.
2. Emissions from land development and other sources fall by the same proportion as emissions from fossil fuels burning.
3. Changing composition among different types of fossil fuels is ignored. Thus, total fossil fuel consumption is assumed to fall by 87 per cent from the 2005 level by 2050. This assumption could prove to be too optimistic because, as global oil production peaks and starts to decline, there may be incentives for businesses and national governments to replace oil with coal, which has a much higher carbon intensity.
4. Carbon capture and storage is ignored because of its negative impact on energy efficiency and investment cost.
5. Liquid fuels made from biomass are ignored. Biomass potential is limited by the availability of productive land and fresh water. Moreover, recent studies suggest that bio-fuels could in fact result in even more greenhouse gas emissions than conventional fossil fuels (Fargione et al., 2008; Monbiot, 2008; Trainer, 2007: 73–92).
6. Wind and solar electricity is assumed to undergo massive expansions so that by 2050, under alternative scenarios, wind and solar electricity generation is expected to be roughly 100, 200, or 400 per cent of the world's total present electricity generation.
7. Wind and solar generating capacity is assumed to have a 25 per cent annual capacity utilization rate. Thus, one giga-watt of wind or solar generating capacity would generate 2.19 trillion-watt hours of electricity over a year. By comparison, in 2007, the average capacity utilization rate of wind electricity in the US was 23 per cent and that of solar electricity was 14 per cent (EIA 2008a).
8. Electricity generation from nuclear, hydro, and other renewable sources is expected to double from 2005 to 2050.
9. Primary electricity, such as electricity from renewable and nuclear sources, is measured by its electrical energy content (11.63 trillion-watt hours = 1 million metric tons of oil equivalent). The substitution of primary electricity for fossil fuels is treated as efficiency improvement.

are presented in the text box related to Table 1. Each of the three scenarios presents a particular trajectory of world energy supply, which implies a particular trajectory of world economic growth given the assumed energy efficiency improvement. The relationship between energy supply, energy efficiency and economic output is explained by the following identity:

$$\text{World Real GDP} = \text{World Energy Supply} * \text{World Energy Efficiency}$$

In Scenarios 1, 2 and 3, the world is assumed to build 200, 400 and 800 giga-watts of wind and solar electricity capacity, respectively, every year from 2005 to 2050. Under these scenarios, the world economy is projected to grow at an average annual rate ranging from -0.05 per cent to 1.8 per cent.

For example, in Scenario 1, fossil fuel consumption is projected to fall by 87 per cent from 2005 to 2050. On the other hand, by 2050, the world is assumed to have built more than 9,000 giga-watts of wind and solar electricity. Nuclear electricity, hydro electricity and other renewables are projected to double from 2005 to 2050. Despite the massive expansion of renewable energy, the world total energy supply falls by about 60 per cent from the 2005 level. However, the world energy efficiency is more than doubled, resulting in a world economic output in 2050 that is marginally smaller than that in 2005.

These projected rates of wind and solar power installation compare favourably with the actual rates of installation of the world electricity industry. In 2005, the world's total net installation of all types of power capacity was only 134 giga-watts (EIA, 2008b). In 2007, the world installed 20 giga-watts of wind electricity and in 2006, the world installed less than 2 giga-watts of solar photovoltaic electricity (BP, 2008b). The projected installation rates also compare favourably with some other long-term energy projections. For example, the International Energy Agency projects an average annual construction of 70 giga-watts of wind power and 50 giga-watts of solar power (a total of 120 giga-watts) from now to 2050 (IEA, 2008). Greenpeace International (2008b) projects a total installation of 6,600 giga-watts of wind and solar electricity by 2050, implying an average annual construction of about 150 giga-watts from 2005 to 2050.

From 1980 to 2005, the average annual growth rate of the world's energy efficiency (the ratio of energy consumption to GDP) was 1.4 per cent. In Table 1, it is assumed that the rate of improvement of the world energy efficiency would accelerate to 2 per cent a year. By comparison, International Energy Agency expects the average annual growth rate of world energy efficiency from 2005 to 2050 to be between 1.4 and 1.7 per cent (IEA, 2008). Lightfoot and Green (2001) studied the long-term physical potential of world energy efficiency and concluded that assuming the full potential were to be realized by 2100, then the long-term average annual growth rate of energy efficiency from 1990 to 2100 would be in the range of 0.8–1.3 per cent.

Despite such optimistic assumptions, to achieve the required emission reduction the world economy would have to stop growing completely under Scenario 1. Considering that world population grows at about 1 per cent a year, only Scenario 3 could bring about some growth of per capita income. For Scenario 3 to be realized, however, the world would have to build 800 giga-watts of wind and solar power capacity a year. According to the US Energy Information Administration, the near-future capital cost for 1 giga-watt of wind electricity is estimated to be US$ 1.4 billion and that for 1 giga-watt of solar photovoltaic electricity is estimated to be US$ 5.6 billion (EIA, 2008c). If the world were to build 800 giga-watts of wind and solar electricity each year, and if wind and solar were each to account for half of the installations, then annual investment cost would amount to US$ 2.8 trillion. This huge amount represents about 5 per cent of the world's current GDP, and about one-quarter of the world's gross savings or total fixed investment. Over forty-five years, the total investment cost would be US$126 trillion. And that does not include any of the investment cost that would be required to expand and rebuild the electric grids and to electrify the entire economic infrastructure.[9]

As mentioned above, the affordability of financial resources is not the only issue here. There is also the constraint of engineering and technical capacity. Building 800 giga-watts of power capacity a year is roughly equivalent to rebuilding the entire power industry of the US or China, each year. It would require a quintupling of the world power sector's installation capacity and would demand that this entire capacity be used for the building of wind and solar electricity. Since wind and solar are intermittent energy sources, they need to be backed up by substantial amounts of conventional power. Each giga-watt of wind or solar electricity may need the backup of an additional giga-watt of conventional electricity (such as coal, natural gas or nuclear). This consideration alone would make it impossible to convert a society's entire power installation capacity to the building of solar and wind electricity (Trainer, 2008).

From 1913 to 1950, a period that included two world wars and the Great Depression, the world economy grew at an average annual rate of 1.9 per cent (Maddison, 2003). Between 1960 and 2005, the world economic growth rate fell below 2 per cent on only three occasions: during 1974–75, 1980–82 and 1991–93. These were generally considered to be periods of major world economic crisis (as well as political and social instability).[10] Thus, even Scenario 3 would represent a performance that is no better than previous periods of global economic depression and geopolitical chaos, and could very well qualify as permanent global depression. If past historical experience serves as a guide, then none of the three scenarios could secure economic and political stability for the capitalist world system.

SOCIAL CHANGE AND CLIMATE STABILIZATION

Social Change in the US and Climate Stabilization

Table 2 presents alternative scenarios of energy supply for the US and China under assumptions required for climate stabilization. To achieve the global

9. According to IEA (2008), to reduce global carbon dioxide emissions by 50 per cent by 2050 from the current levels will require an additional fixed investment of US$ 45 trillion or US$ 1.1 trillion a year. The IEA estimate refers to the additional investment on top of the business-as-usual investment in the energy sector. As discussed earlier, based on the current scientific evidence, climate stabilization requires reducing emissions by 85 per cent from the 2000 levels.
10. There is no generally accepted definition of global economic recession, as contraction of some parts of the world economy may be offset by expansion of some other parts. However, the International Monetary Fund now defines global recession as any period when world annual economic growth rate, measured by purchasing power parity, falls below 3 per cent; see http://www.economist.com/finance/displaystory.cfm?story_id = 12381879

Table 2. Energy Supply Scenarios: The US and China (annual rates of change)

Years and Scenarios	Energy Supply	Energy Efficiency	Real GDP
US			
Historical Performance (1980–2005):			
	0.9%	2.1%	3.1%
Projections (2005–2050):			
Scenario 1	−2.6%	2%	−0.6%
Scenario 2	−1.5%	2%	0.5%
Scenario 3	−0.3%	2%	1.7%
China			
Historical Performance (1980–2005):			
	5.3%	4.2%	9.8%
Projections (2005–2050):			
Scenario 1	−1.4%	3%	1.5%
Scenario 2	−0.5%	3%	2.5%
Scenario 3	0.7%	3%	3.7%

Source: Author's construction. Historical data of world energy supply and GDP are from BP (2008a) and World Bank (2008).

objective of required emissions reduction and assuming that by 2050 the US per capita emissions would converge towards the world average, US fossil fuel consumption is assumed to fall by 97 per cent from 2005 to 2050.

Under Scenarios 1, 2 and 3, the US is assumed to build 50, 100 and 200 giga-watts of wind and solar electricity, respectively, every year from 2005 to 2050. By comparison, in 2007, the US total installed power capacity was about 1,000 giga-watts and the US net installation of all types of power capacity was only 12 giga-watts (EIA, 2008a). In addition, US electricity generation from nuclear, hydro and other renewable sources is assumed to double from 2005 to 2050. The US energy efficiency is assumed to converge to the world average by 2050.

To achieve the required emissions reduction, the average annual growth rate of the US economy would have to be −0.6, 0.5 and 1.7 per cent, respectively, under Scenarios 1, 2 and 3. Only Scenario 3 would deliver some positive growth of per capita income. But for Scenario 3 to be achieved (which would still represent, in conventional term, a significant deterioration relative to past economic performance), the US must build 200 giga-watts of wind and solar power capacity each and every year. If half of the 200 giga-watts were to be wind electricity and the rest solar electricity, then given the near-future cost, this would represent an annual investment cost of US$ 700 billion.[11] Regardless of the financial cost, in engineering terms,

11. If all of the 200 giga-watts of power capacity were to be wind electricity, then the total cost would be 'only' US$ 280 billion. However, wind electricity has severe intermittency problems and may seriously undermine the reliability of the conventional electric grid if its share in total power capacity is more than 20 per cent. In the long run, wind electricity is also subject to the limits of available land. Trainer (2007: 15–17) estimates that the maximum technical potential of wind electricity in the US may be no more than 300 giga-watts of full capacity power or approximately 1,200 giga-watts of wind power capacity (which would be exhausted in six years if 200 giga-watts of wind power were built each year).

this represents a task that would require the rebuilding of an entire US power industry every five years.

On the other hand, emissions reduction helps to save expenses on fossil fuels. From 2005 to 2050, US fossil fuel consumption is expected to fall by 2,040 million metric tons of oil equivalent, with an average annual reduction of 45 million metric tons of oil equivalent (or 330 million barrels of oil equivalent). Valued at US$ 70 a barrel (roughly the average price in 2007), the initial annual financial saving would amount to only US$ 23 billion. After ten years, the annual saving would rise to US$ 230 billion. Only after thirty years would the annual financial saving resulting from reduced fossil fuel consumption start to rise above the investment cost required for building renewable electricity.

The construction of new renewable electricity capacity would not be enough by itself. The current electric grid is outdated and cannot accommodate more than a small proportion of electricity being from intermittent sources, such as wind and solar. The entire national electric grid thus needs to be rebuilt. In addition, wind and solar can only be used to generate electricity: they cannot be used to power transportation, industry and many other uses. Given the limitations of biomass (see text box after Table 1), for renewable energies to become the primary energy sources in the economy, much of the transportation and other infrastructure will need to be rebuilt and electrified. Taking into account all of these expenses, in the coming decade, the annual investment cost to develop renewable energy and to transform the US energy infrastructure would amount to at least US$ 500–700 billion and possibly even more.

The Obama administration promises to develop and implement a new energy policy and commit the US to ambitious goals of greenhouse gases emissions reduction. However, there has not yet been any evidence suggesting that the actions Obama is ready to take are up to the task of climate stabilization. During the 2008 election, he promised to spend US$ 150 billion on alternative energy over a period of ten years (Walsh, 2008). In the new economic stimulus plan recently proposed by Obama, US$ 100 billion were assigned to spending on energy and environmental projects over two years (McDonough, 2008). These spending commitments fall far short of what would be required for the US to meet its global obligation of climate stabilization while achieving what is, in effect, no more than economic stagnation.

How could the annual investment required for climate stabilization be financed? The revenue could be collected from auctions of carbon permits, carbon tax or other forms of taxes. But one way or another, someone has to pay for it. Who will that someone be? Can it be financed by taxes on the US working class? The US working class has already been struggling with declining real wages, overwhelming household debt and ever-escalating health care costs (as well as the lack of universal health insurance). A further, major increase in tax or cost of living for the US working class could threaten to destroy the political legitimacy of American capitalism. Can it be financed by taxes on the US capitalist class? The US total after-tax corporate profits amount to about US$ 1 trillion. It is unlikely that the American capitalists will give up more than half of their corporate profits. Can it be financed by more borrowings from foreigners? An additional annual borrowing of US$ 500–700 billion would expand the US trade deficit from the current 5 per cent of GDP to 10 per cent of GDP. The US foreign debt would soon reach astronomical levels and the bankruptcy of the US treasury would be guaranteed.[12]

Leaving aside the question of whether the US climate stabilization investment can be adequately financed, for the US to meet its global obligation, fossil fuel consumption in that country needs to fall at an average annual rate of 7.7 per cent. Whether this is achieved through carbon trade, carbon tax or other mechanisms, it is obvious that climate stabilization actions would lead to large, sustained increases in fossil fuel costs (this is the only way in which fossil fuel consumption can be reduced in a market economy). Unless the cost of renewable energy falls sharply and the production of renewable energy is scaled up rapidly in the coming years, this will translate into large, sustained increases in energy costs.

Unless China, India and other large semi-peripheral states are willing to participate in serious and meaningful global climate stabilization actions (a very unlikely scenario), rising energy costs in the US and Western Europe would simply drive the remaining industrial capital from the core states to the periphery and semi-periphery. The US government could attempt to regulate capital flows and enforce 'fair trade', but would this be politically feasible? The regulation of capital flows will have to include not only financial capital flows but also foreign direct investment and intra-corporation cross-border trade. Can this be done without changing the basic capitalist property relations?

If the Obama administration fails to put the US firmly on track to climate stabilization (meaning not only making some gestures, but committing to emissions reduction by 97 per cent by 2050), then far more radical political changes would be required than the 'change' Obama has been talking about.

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12. Throughout this paper, the basic argument is that the expansion of renewable electricity is constrained by an economy's engineering and technical capacity as well as its ability to mobilize the required financial resources (rather than that individual units of renewable electricity are more expensive than those of conventional electricity). In the future, as fossil fuels and carbon prices rise and renewable energy costs fall, private capitalists certainly will find the investment in renewable energy more attractive. However, no matter what happens to relative prices in the future, to build 200 giga-watts of wind and solar electricity a year now, the US would still need to find US$ 500–700 billion somewhere. Given the obvious urgency of the climate situation, this needs to happen now rather than later, which means that the investment plan would have to be based on the current renewable energy cost (rather than the possibly lower cost in the future). Moreover, to build the 200 giga-watts, the US power sector needs to find engineers, workers and equipment at a rate 10–20 times greater than the current rate.

Social Change in China and Climate Stabilization

To achieve the global objective of required emissions reduction and assuming that by 2050 China's per capita emissions would converge towards the world average, China's fossil fuel consumption needs to fall by 86 per cent from 2005 to 2050. Under Scenarios 1, 2 and 3 of Table 2, China is assumed to build 50, 100 and 200 giga-watts of wind and solar electricity, respectively, every year from 2005 to 2050. By comparison, in 2006, China's total installed power capacity was 622 giga-watts and the net installation of all types of power capacity was 105 giga-watts (Cui, 2008: 218). China's electricity generation from nuclear, hydro and other renewable sources is assumed to quadruple from 2005 to 2050 and China's energy efficiency is assumed to converge to the world average by 2050.

Under Scenarios 1, 2 and 3, China's economic growth rate needs to fall to 1.5, 2.5 and 3.7 per cent respectively. It appears that China could manage to achieve some levels of positive economic growth. However, this represents a sharp deceleration from its historical rapid growth rate. China's economic growth has been accompanied by rapid rises of inequality and intensified social conflicts. It is widely believed that China needs to have at least 7–8 per cent growth rate to generate employment growth and maintain social stability (Roubini, 2008). The projected 1.5–3.7 per cent growth rates thus fall far short of what would be required to maintain economic and political stability in China.

The projected growth rates refer to average growth rates from 2005 to 2050. If China continues to maintain rapid growth in the coming years, then it would have used up its economic growth 'quota' very soon. For example, if the Chinese economy were to grow at an average annual rate of 8 per cent from 2005 to 2020, then to achieve the required emissions reduction objective by 2050, its average annual economic growth rate from 2020 to 2050 would have to fall to −1.6, −0.1 and 1.7 per cent, respectively, for Scenarios 1, 2 and 3.

The scenarios assume that China could build 50–200 giga-watts of wind and solar electricity every year without being subject to technical and physical limits. However, China actually has a relatively limited physical potential of renewable energy. Its long-term onshore and offshore wind electricity potential is estimated to be 1,000 giga-watts (Cui, 2008: 273). Solar photovoltaic electricity is much more expensive and is limited to day-time use. The more promising solar technology is known as the solar thermal technology or concentrated solar power, which allows solar energy to be stored as heat and thus has less of a problem of intermittency. However, the solar thermal technology works best in tropical and sub-tropical deserts. China does not have access to such geographical areas.

We have already noted that unless China takes serious and meaningful actions to fulfil its obligation of emissions reduction, there is little hope that global climate stabilization can be achieved. However, it is very unlikely that the Chinese government will voluntarily take the necessary actions to reduce emissions. The sharp fall of economic growth that would be required is something that the Chinese government will not accept and cannot afford politically. Does this mean that humanity is doomed? That depends on the political struggle within China and in the world as a whole. China's current model of capitalist development has rested upon three pillars: export-oriented economic growth, the exploitation of a large, cheap labour force and the exploitation of the world's natural resources and environmental space. As the global economic crisis continues to deepen, the leading capitalist countries in North America and Western Europe will face prolonged economic difficulties. If the global economy does manage to recover in the next few years, global economic growth could soon be limited by the decline of world oil production.[13] A prolonged global economic crisis will impose serious constraints on China's export-oriented economic growth.

Up to now, Chinese and foreign capitalists in China have enjoyed almost complete freedom in exploiting Chinese workers. However, as China's rural surplus labour force starts to be depleted and tens of millions of migrant workers gradually settle down in the cities, the relation of forces between the capitalists and the workers will start to shift slowly in favour of the workers. In recent years, there has been some pressure for wage rates in the coastal provinces to rise and the Chinese government has also taken some limited actions to improve workers' conditions in order to secure social stability. In one or two decades, one would expect that the Chinese working class would follow the examples of workers in other countries, getting organized for economic and political struggles and demanding a growing range of economic, social and political rights. The political awakening of the Chinese working class will undermine the foundation of the current model of Chinese capitalism.

China depends on coal for 70 per cent of its energy consumption. It produces nearly half of the world's total coal production but has only one-eighth of the world's official coal reserves (BP, 2008a). According to Richard Heinberg (2008), China's coal production could peak between 2015 and 2030. Beyond 2020, China is likely to face an insurmountable energy crisis as coal production growth slows sharply.[14] The coming energy crisis could

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13. There is a growing body of evidence suggesting that world oil production will peak very soon or is likely to have already peaked. For a projection of the future world oil production, see ASPO (2008).
14. It is unlikely that China could deal with the coming energy crisis through energy imports from the rest of the world. By 2020, world oil production is likely to be in irreversible decline. Massive imports of coal are unlikely because of the high cost of long-distance coal transportation, and because coal production in the advanced capitalist countries (such as in the US and Australia) could be limited by domestic social and environmental constraints. In the coming years, there is likely to be growing international pressure on China to deal with climate stabilization, which could lead to political pressure to limit energy exports to China.

trigger a series of economic and political chain reactions that would in turn destroy China's entire existing social regime. What will happen next?

One might hope that China's ruling elites would be willing to voluntarily give up their political and economic power, allowing China to undergo a peaceful democratic transition. The Chinese people would then engage in an open, rational debate, reaching a democratic consensus regarding China's future. Hopefully, through such a debate, the Chinese people would collectively reach the conclusion that China's own long-term interests ultimately depend on climate stabilization and global ecological sustainability, which have to take absolute priority in the shaping of China's future social transformation.

Unfortunately, the more likely scenario is that the Chinese ruling elites will attempt to retain their power and privileges as long as possible. The country's existing social regime nevertheless will no longer be sustainable: as a result, the collapse of the regime is likely to be followed by decades of political and social chaos, with devastating consequences for the Chinese people. On the other hand, with the collapse of industrial production and massive declines of material consumption, China's greenhouse gas emissions will fall sharply. This is by no means to be seen as a preferred outcome, but objectively the collapse of the Chinese economy could provide the space and time for the rest of the world to make the necessary climate stabilization adjustments. Different social classes and political forces will then engage in a long-term struggle that will decide who eventually will prevail and how China's future will be constructed.

Global Social Change and Climate Stabilization

Like all other social systems, the existence and operation of capitalism depend on certain historical conditions. But underlying historical conditions have a tendency to change: it is inevitable that beyond a certain point, the underlying conditions will have changed so much that capitalism is no longer viable. Immanuel Wallerstein has argued that after centuries of relentless accumulation, the underlying economic, political and ecological contradictions have grown to the point that they can no longer be resolved within the framework of capitalism. Capitalism has by now entered into its structural crisis and is unlikely to survive beyond the middle of the twenty-first century. The future of humanity depends on the global class struggle, which will determine what social system or systems (if any) will emerge and prevail after the demise of the existing system (Wallerstein, 2003).

The global climate crisis is just one of these fundamental contradictions. Because of inter-state competition and geopolitical conflicts under the capitalist system, climate stabilization efforts are confronted with insurmountable political obstacles. Moreover, as discussed above, even with wildly optimistic assumptions, there is no way for climate stabilization to be made compatible with rates of economic growth required for capitalist economic and political stability.

In his most recent book, James Gustave Speth, one of the world's leading environmental scholars and by no means a political radical, argues that it is impossible to achieve environmental sustainability within the framework of modern capitalism (understood as the economic system that promotes perpetual economic growth); he contends that fundamental social changes must take place if a global environmental breakdown is to be avoided: '[Today's] system of political economy, referred to here as modern capitalism, is destructive of the environment, and not in a minor way but in a way that profoundly threatens the planet; people will therefore demand solutions, and the current system will not be able to accommodate them; so the system will be forced to change' (Speth, 2008: 194). Thus, capitalism is no longer a viable historical option. One way or the other, fundamental social changes will happen in the coming decades. The task of the world's oppressed and exploited is to take this historical opportunity and build a new society based on democracy, egalitarianism and ecological sustainability.

The collapse of capitalism and the establishment of a post-capitalist society will not automatically guarantee the solution of the climate change crisis and a successful transition to ecological sustainability. However, without the compulsive competitive demands imposed by the global capitalist market, humanity will be freed from the constant and intense pressure of ceaseless accumulation. Humans will be in a position to apply their collective rationality. Hopefully, people throughout the world will engage in a transparent, rational and democratic debate which is open not only to economic and political leaders and expert intellectuals, but also to the broad masses of workers and peasants. Through such a global collective debate, a democratic consensus could emerge that would decide on a path of global social transformation that would in turn lead to climate stabilization and ecological sustainability.

This may sound too idealistic. But can we really count on the world's existing elites to accomplish climate stabilization while meeting the world population's basic needs? Ultimately, climate stabilization can only be achieved if the great majority of the world's population (not just the elites and the ecologically conscious middle class individuals) understand the implications, relate these implications to their own lives, and actively and consciously participate in the global effort of stabilization.

While it is impossible to predict the precise form that the future post-capitalist society will take, there are certain objective constraints that will be imposed on future generations as they make their own history. First, to be ecologically sustainable, the future society must not be dominated by market relations. As we have seen, as long as the market dominates a society's economic and social relations, individuals and businesses fall under a constant and inescapable pressure to pursue economic growth. This cannot be removed through limited government regulations that do not challenge the dominance of the market, as the national governments themselves are also under constant pressure in the global market to compete against one another to pursue economic growth.

Thus, for an ecologically sustainable society, the use and allocation of society's surplus product must come under some form of social control through either political procedures or established social norms. Such a society may or may not be economically less efficient than the current capitalist society (with 'efficiency' measured by current conventional criteria). However, efficiency would, at most, be of secondary importance in the post-capitalist era. For the sake of the survival of humanity and civilization, it is absolutely essential to ensure that the human economy operates within the ecological system's natural capacity. With an 'inefficient' economic system (conventionally measured) that operates with limited and stable flows of material consumption, humanity can survive. With an economic system that is highly efficient in generating economic growth, humanity will very soon be committing collective suicide.

Second, the future post-capitalist society will not emerge out of a historical vacuum. Rather, it will have to reflect the political and social developments that have taken place in the capitalist era. Most importantly, it will have to accommodate the relatively high levels of political consciousness and organizational capacity of the working classes (in comparison with what prevailed in the pre-capitalist societies) as well as manage to meet the population's 'basic needs' as they have been historically defined.

These two historical constraints imply that when the future post-capitalist society does emerge, it is likely to be based on some form of social control over the surplus product (i.e. the appropriation and the use of the surplus product take place through political and social processes, preferably through democratic planning, rather than through the market) and some forms of social and community ownership of the means of production.

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