Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature

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This paper, by an international team of scientists, is being published today (3/12/2013) in the open access journal PLOS ONE, where it is freely available. The paper points out the clear and present danger that today's children may be handed a deteriorating climate with consequences out of their control. However, despite the fact that governments today seem to allow and encourage extraction of almost every fossil fuel that can be found, we suggest that "there is still opportunity for humanity to exercise free will."[1]

Here we (Hansen and Kharecha) first summarize some of the main conclusions reached in the paper. Then in a following discussion we provide our opinion concerning more detailed policy implications

Summary.

We conclude that the widely accepted target of limiting human-made global climate warming to 2 degrees Celsius (3.6 degrees Fahrenheit) above the preindustrial level is too high and would subject young people, future generations and nature to irreparable harm. Carbon dioxide (CO_2) emissions from fossil fuel use must be reduced rapidly to avoid irreversible consequences such as sea level rise large enough to inundate most coastal cities and extermination of many of today's species. Unabated global warming would also worsen climate extremes. In association with summer high pressure systems, warming causes stronger summer heat waves, more intense droughts, and wildfires that burn hotter. Yet because warming causes the atmosphere to hold more water vapor, which is the fuel that drives thunderstorms, tornadoes and tropical storms, it also leads to the possibility of stronger storms as well as heavier rainfall and floods. Observational data reveal that some climate extremes are already increasing in response to warming of several tenths of a degree in recent decades; these extremes would likely be much enhanced with warming of 2°C or more.

We use evidence from Earth's climate history and measurements of Earth's present energy imbalance as our principal tools for inferring climate sensitivity and the safe level of global warming. The inferred warming limit leads to a limit on cumulative fossil fuel emissions.

It is assessed that humanity must aim to keep global temperature close to the range occurring in the past 10,000 years, the Holocene epoch, a time of relatively stable climate and stable sea level during which civilization developed. The world cooled slowly over the last half of the Holocene, but warming of 0.8°C (1.4°F) in the past 100 years has brought global temperature back near the Holocene maximum.

We note that policies should emphasize fossil fuel carbon, not mixing in carbon from forest changes as if it were equivalent. Most of the carbon from fossil fuel burning will stay in the climate system for of order 100,000 years. Of course carbon dioxide from deforestation also causes warming and policies must address that carbon source, but good land use policies could restore most of that carbon to the biosphere on a time scale of decades to centuries. However, maximum biospheric restoration is likely to be only comparable to the past deforestation source, so fossil fuel sources must be strictly limited.

We conclude that human-made warming could be held to about 1°C (1.8°F) if cumulative industrial-era fossil fuel emissions are limited to 500 GtC (gigatons of carbon, where a gigaton is one billion metric tons) and if policies are pursued to restore 100 GtC into the biosphere, including the soil. This scenario leads to reduction of atmospheric CO_2 to 350 ppm by 2100, as needed to restore Earth's energy balance and approximately stabilize climate.

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[1] With this theme, PLOS ONE is initiating a Collection of papers "Responding to Climate Change". Papers are sought in areas of research aimed at returning the Earth to a state of energy balance, including: Atmospheric Chemistry, Geoengineering, Alternative Energy, Science Policy, Economics, Behavioral Psychology, Conservation Biology. Articles will be published immediately after passing peer review and acceptance. Information available at PLOS ONE booth #301 at the AGU meeting.

In contrast, we conclude that the target to limit global warming to 2°C, confirmed by the 2009 Copenhagen Accord of the 15th Conference of the Parties of the United Nations Framework Convention on Climate Change, would lead to disastrous consequences. For example, Earth's history shows that 2°C global warming is likely to result in eventual sea level rise of the order of six meters (20 feet). Moreover, we note that such a warming level would induce "slow amplifying feedbacks".

These amplifying feedbacks include a reduction of ice sheet area, vegetation changes including growth of forests in high latitudes of Asia and North America that are now sparsely vegetated, and an increase of atmospheric gases such as nitrous oxide and methane. These slow feedbacks are small if climate stays within the Holocene range, but substantial if warming reaches 2°C or more.

Cumulative fossil fuel emissions through 2012 are 370 GtC and increasing almost 10 GtC per year. The current emission rate would need to decrease 6% per year to limit emissions to 500 GtC. If reductions had begun in 1995, the required reduction rate would have been 2.1% per year, or 3.5% per year if reductions had begun in 2005. If emissions continue to grow until 2020, reductions must be 15% per year to stay within the 500 GtC limit, which emphasizes the urgency of initiating emission reductions.

The huge fossil fuel energy infrastructure now in place makes it practically certain that the 500 GtC limit will be exceeded. However, the need to come as close as possible to that target is made clear by the specter of likely climate impacts from 2°C warming. Although it is difficult to predict the timing of consequences such as large sea level rise, its eventual occurrence likely will be locked in if we allow warming to reach a level as high as 2°C. The situation would then be out of humanity's control, because, even if the atmospheric CO_2 amount declines, it would take many centuries for the ocean to cool down.

We draw attention to the difficulty, and possible impracticality, of extracting much CO_2 from the air, once it becomes clear that an acceptable level of CO_2 has been overshot. Specifically, we note that the American Physical Society estimates a cost for air capture of 1 GtC with current technology as about $2 trillion, thus about $200 trillion to remove 100 GtC. Improved technologies might reduce this cost, but fundamental energy considerations imply that extraction will be very costly and very unlikely to be deployed at a sufficient scale in the required time frame. At most CO_2 extraction might help alleviate a modest overshoot of the safe CO_2 level at a high cost to future generations.

The research team, which includes three economists, covers a broad range of fields and does not shy away from "connecting the dots" all the way to policy implications. It concludes that the essential underlying policy, albeit not sufficient, is a rising price on carbon emissions that allows the costs of pollution and climate change to be internalized within the economics of energy use. We note that a rising carbon fee collected from fossil fuel companies would improve economic efficiency, as it allows energy efficiency and alternative low-carbon and no-carbon energies to compete on equal footing. The resulting energy transformations would generate many jobs, especially benefitting nations still in economic recession.

An advantage of a carbon fee or tax is the relative ease with which it can be made global. An agreement among even a few of the largest economies (United States, China, European Union, Japan) could spur near-global agreement. Countries agreeing to have a rising carbon fee would likely place border duties on products from countries without a carbon fee, thus providing strong incentive for other countries to join.

Governments should also support technology research, development and demonstration of carbon-free energy including advanced generation nuclear power as well as renewable energy, especially in view of the urgency with which emissions from coal and unconventional fossil fuels must be eliminated. (Unconventional fossil fuels include tar sands, shale-derived oil and gas, and methane hydrates.)

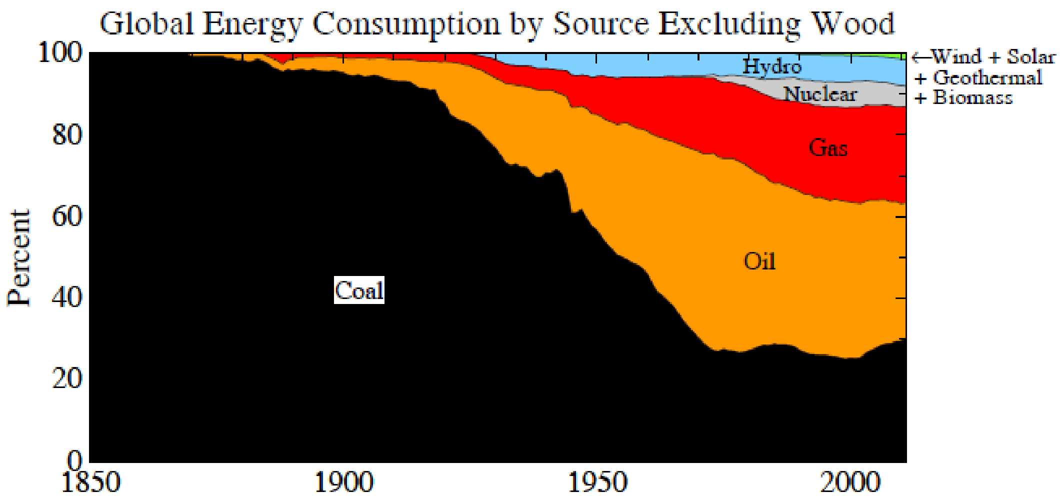

Fig. 1. World energy consumption for indicated fuels, excludes wood [2].

<u>Opinion: Further Policy Implications.</u>

In the following pages we discuss policy implications of the science in more detail. We have no indication that the conclusions drawn would be especially controversial with the co-authors on our paper, but the discussion goes well beyond that in the paper, so we do not want to imply that we have discussed these topics and reached a consensus on these specific conclusions.

The huge task of phasing out fossil fuel emissions is illustrated in Fig. 1, which shows that fossil fuels provide more than 85% of global energy today. Non-hydro renewable energy, despite laws in many nations that require utilities to employ increasing amounts of renewable energy, still provides only about 2% of global energy. Thus cumulative efforts over several decades to expand renewable energy use offset only about one year's current growth in global energy use and CO_2 emissions (Fig. 2).

The urgency of halting the rapid growth of emissions (Fig. 2), reversing that trend, and phasing down CO_2 emissions implies a need for an extraordinary change of energy systems and international cooperation. It is crucial that the major international powers today realize that we are all in the same boat together and we will all sink together or sail together. At such a time, when true leadership is needed, and on the 50th anniversary of John F. Kennedy's death, it is worth recalling words from his 1963 Peace speech: "No problem of human destiny is beyond human beings. Man's reason and spirit have often solved the seemingly unsolvable--and we believe they can do it again."

The solution of a challenging problem in science is often revealed by clear objective problem definition. Indeed, an outline of the political approach required to stabilize climate is implied by the basic science described in the present paper. The principal task is to limit the amount of CO_2 injected into the climate system by burning fossil fuels. Two subsidiary but important tasks are: (1) to achieve a net storage in the biosphere and soil of at least ~100 GtC via reforestation and improved agricultural and forestry practices, and (2) to at least stabilize human-made non-CO_2 climate forcings (no net increase of present forcing).

Fig. 2 helps define what is needed to phase down CO_2 emissions. The main cause of growing emissions is coal use, especially in China and developing countries. The biggest use of coal is electricity generation. Electricity is a clean energy carrier, the fastest growing form of energy use, and a key to solution of both the climate and pollution problems. With abundant affordable carbon-free pollution-free sources of electricity, it becomes feasible not only to eliminate most of the CO_2 emissions from coal (now approaching half of the CO_2 emissions), but also to phase down oil and gas use, because electricity can be used for heating and for vehicles or to produce liquid fuels for vehicles.

Coal is used for electricity generation because it seems to be cheap, but that is only because it does not pay its costs to society. Those costs include not only climate impacts but air and water pollution, which

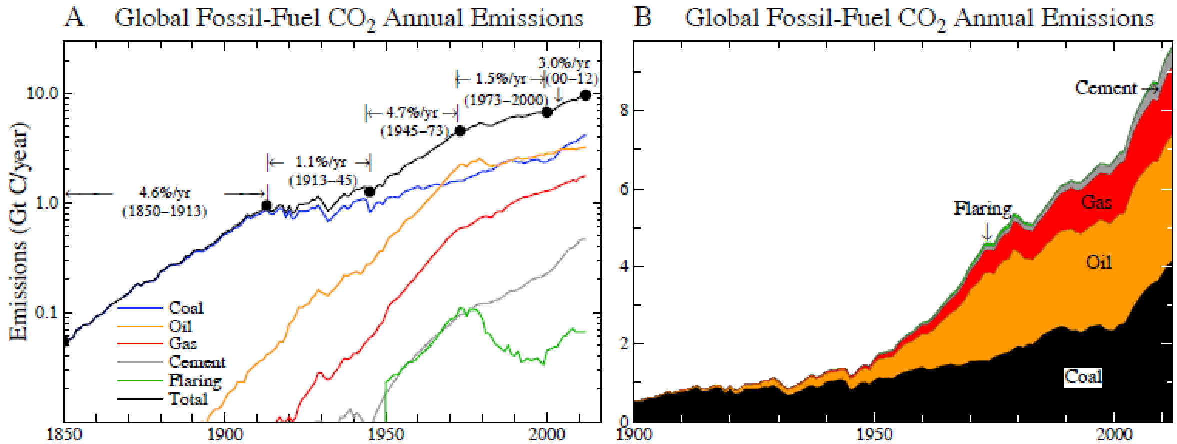

Fig. 2. CO_2 annual emissions from fossil fuel use and cement manufacture, based on data of British Petroleum [2] concatenated with data of Boden et al. [3]. (A) is log scale and (B) is linear.

kills enough people in China, via increased incidence of cardiorespiratory mortality, to reduce average lifespan by more than 5 years [5]. China is initiating large scale production of syngas, synthetic natural gas extracted from coal. Syngas power plants produce less air pollution than pulverized-coal-fired power plants, but life-cycle greenhouse gas emissions are 36-82% higher than direct burning of coal [6].

A preferable approach, for the sake of both global climate and local pollution reduction, would be a combination of renewable energy and advanced (3rd and 4th) generation nuclear power plants[2]. Abundant affordable clean energy is essential to provide the energy needed to raise billions of people out of poverty, which empirical evidence indicates is a requirement for reducing fertility rates, thus lowering human population, and giving hope that we can provide the opportunity of a good life to all humanity while allowing other life on the planet to flourish.

When the world's leading nations recognize the urgency of phasing out fossil fuel emissions, and realize that we are all in the same boat, it should be possible to agree on cooperative technology development and deployment. History, including World War II and the Apollo program, reveal how rapidly technology can be developed and deployed. Phase-out of most coal emissions and a substantial reduction of oil and gas use could be achieved rapidly. This would require agreement among leading nations not only to have common internal rising carbon fees, but also an agreement to cooperate in rapid technology development.

Surely rapid phase-down of coal emissions requires a major role for advanced-generation safer nuclear power. Nuclear technology has advanced significantly over the past few decades such that there is now the potential to produce modular 3rd generation light-water reactors that are passively safe, i.e., reactors that would shut down automatically in case of an anomaly such as an earthquake and have the ability to keep the nuclear fuel cool without an external power source. The same concept, modular[3] simplified reactor design with factory production and shipping to the utility site, is appropriate for 4th generation reactors, and these should also be pursued to deal with nuclear waste, utilizing the waste as fuel.

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[2] The existing fleet of nuclear power plants, largely 40-year-old 2nd generation technology, itself saved a large number of lives and reduced carbon emissions by replacing fossil fuel plants [7]. However, 3rd generation reactors incorporate additional safety features including automatic shutdown in case of anomalies and the ability to cool the nuclear fuel without external power. 4th generation power plants add an ability to utilize more than 99% of the nuclear fuel (compared with about 1% in earlier generations) including the ability to "burn" nuclear waste, depleted uranium, and excess weapons material as fuel. Stockpiles of these latter materials contain enough fuel to power 4th generation reactors for centuries. Japan and the United States have demonstrated that nuclear fuel can be sieved from the ocean, where there is enough nuclear material to last billions of years. Thus it will be possible to eliminate mining of uranium on land, should there be strong incentives to do that.

[3] An example of 3rd generation modular reactor is Gen III++ mPower (http://en.wikipedia.org/wiki/B&W_mPower). An example of 4th generation is the Integral Fast Reactor, Till and Chang [8]

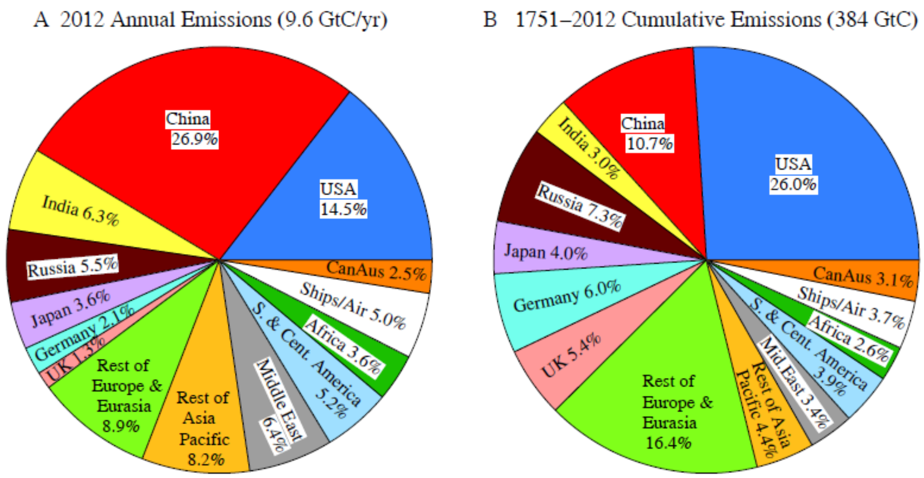

Fig. 3. (A) Fossil fuel CO_2 2012 emissions by source region and (B) cumulative 1751-2012 emissions (update of Fig. 10 of [4] using data from [3]). Emissions include gas flaring and cement manufacture.

Fortunately, the place where deployment of advanced nuclear technology is most urgently needed, China, is also the place that has the potential to rapidly build and grow the manufacturing capability. What is needed is cooperation with nations that have developed relevant technical abilities, especially the United States. Such cooperation has potential for enormous mutual and global benefits via development of scalable affordable carbon-free energy. Contrary to assertions of dedicated anti-nuke activists, such technology can be made more resistant than existing technology to exploitation by terrorists who may seek weapons material. Dangers from rogue states or terrorists will always exist, and the best way to minimize such danger is to cooperate in developing the safest technology, not to pretend that anti-nuclear activism will cause nuclear technology to disappear from the planet.

The principal policy allowing renewable energies to grow to almost 2% of global energy use has been laws imposing specified "renewable energy portfolio standards" (RPS) on utilities or other mandates for renewable energy use. These policies have aided growth of renewables, and by spreading costs among all utility customers of feed-in tariffs, added transmission lines, and the backup power needed for intermittent renewables (usually fossil fuel based), the electricity cost has been bearable as long as the portion of renewables is small. Now for the sake of moving rapidly to carbon-free power while minimizing electricity costs, the need is for "clean energy portfolio standards" (CPS), thus allowing nuclear energy to compete with renewable energies.

Every energy source has environmental and economic costs, and these need to weighed and considered by local populations, but given the enormous challenge of stabilizing climate it is inappropriate to eliminate any candidates a priori on a global basis. Some nations and states, e.g., Germany and California, seem to have a preference to eliminate nuclear power a priori and they have populations that are willing to pay high electricity costs. However, such nations and states need to understand that they must phase out fossil fuels entirely, and environmentalists need to recognize that attempts to force all-renewable policies on all of the world will only assure that fossil fuels continue to reign for baseload electric power, making it unlikely that abundant affordable power will exist and implausible that fossil fuels will be phased out.

As mentioned above, stabilizing climate requires, besides phasing down fossil fuel use: (1) storing at least ~ 100 GtC in the biosphere and soil, and (2) stabilizing or even reducing human-made non-CO_2 climate forcings. Much of the solution of these matters necessarily will occur in developing countries and it is appropriate that the countries who caused the climate problem provide financial and other assistance to achieve these goals.

The burden for climate change causation is accurately specified by cumulative fossil fuel emissions [4] (Fig. 3B). It is important for this burden to be recognized now and for all nations to realize that their proportion of the burden will continue to change as emissions continue. Thus, for example, if China chooses to build extensive syngas plants, China will incur a heavy future obligation, which should be factored into their decision-making process. Obligations implied by human-made climate change tend to be ignored by today's political leaders, but the leaders need to become aware that this matter and the global cacophony for reparations will grow as climate change impacts accelerate.

We do not attempt to define specific agreements that must be reached to achieve the goals of increasing biospheric/soil carbon storage and decreasing non-CO_2 climate forcings. However, certain general characteristics are apparent. Financial assistance deserved by any given nation will be dependent upon climate impacts that are being suffered by that nation. However, the support delivered should be dependent on another factor: the cooperation of that nation in achieving the goals of biospheric/soil storage of carbon and reduction of non-CO_2 (and CO_2) climate forcings.

In other words, developing countries have a legitimate claim for assistance to deal with climate change. However, for their own good as well as for the good of all other nations, they should be encouraged to contribute to the actions that minimize climate change. Thus the support provided to participating nations should be continually evaluated and the level of support to any nation adjusted in proportion to their success in contributing to the carbon and non-CO_2 objectives in the preceding reporting period. Although goals and assessments for biospheric/soil carbon and non-CO_2 forcings are not as easy to quantify as fossil fuel carbon emissions, they can be set and assessed based on best available and developing science.

Our paper [1] was initiated to provide the scientific basis for legal actions against national and state governments for not doing their job of protecting the rights of young people and future generations. A lower court ruling in the case against the U.S. federal government, suggesting that the "trust"[4] doctrine [9] does not give the court a constitutional basis for ordering actions on the executive branch, is now being appealed to a higher court. The appeal places greater emphasis on "equal protection of the laws" and "due process", which the U.S. Constitution guarantees to all people. Amici briefs have been filed with the court concerning both the scientific [10] and legal [11] aspects.

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[4] The concept that the current generation has a usufruct (use and enjoyment) obligation to deliver an undamaged environment to the next generation was recognized by U.S. founding fathers, e.g., Thomas Jefferson argued that the soils must be left in equally productive condition. Other cultures have similar concepts, e.g., Native Americans speak of obligation to the 'seventh generation.'