# Long-Term Global Heating from Energy Usage

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Abstract

Even if civilization on Earth stops polluting the biosphere with greenhouse gases, humanity could eventually be awash in too much heat, namely, the dissipated heat by-product generated by any nonrenewable energy source. Apart from the Sun's natural aging—which causes an approximately 1% luminosity rise for each $10^8$ years and thus about 1°C increase in Earth's surface temperature—well within 1000 years our technological society could find itself up against a fundamental limit to growth: an unavoidable global heating of roughly 3°C dictated solely by the second law of thermodynamics, a biogeophysical effect often ignored when estimating future planetary warming scenarios.

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Index Terms: 0416 Biogeosciences: Biogeophysics; 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions (0426, 1610); 1011 Geochemistry: Thermodynamics (0766, 3611, 8411).
Long-Term Global Heating From Energy Usage

Even if civilization on Earth stops polluting the biosphere with greenhouse gases, humanity could eventually be awash in too much heat, mainly because the dispatate heat-by-product generated by any nonrenewable energy source. Apart from the Sun's natural aging—which causes an approximately 1% luminosity rise over every 109 years and thus about 3°C over the next 5 billion years to 1 billion years—total energy budget of society on Earth will likely continue growing for three reasons. First, world population is projected to increase until at least the late 21st century, when it might level off at approximately 10 billion people [United Nations Department of Economic and Social Affairs, 2006]. Second, developing countries will mature economically, perhaps for the next several centuries, until equity is achieved among the world community of nations. And third, the per capita energy rate will probably continue rising for as long as the human species continues to live. A recent study of Tokyo, for example, found that city streets are about 2°C warmer than surrounding rural areas. A recent study of Tokyo, for example, found that city streets are about 2°C warmer than surrounding rural areas.

Current fears of energy shortfalls aside, the long-term trend in our energy predicament is that the unmitting and increasing use of energy from any resource and by any technology continues to rise. In general, the equilvtemperatures at various temperatures. Heat is an unavoidable by-product of the energy extracted from wood, coal, oil, gas, and most of all the resources that are not renewable. The renew- able sources, especially solar, already heat Earth naturally. But additional solar energy, if beamed to the surface, will also further heat our planet.

Regardless of the kind of energy utilized, Earth is energy rich and is likely to remain so long after our industrial society. We already experience the tipping points of the many other energy budgets in a broad perspective [Chaisson, 2003].

Rising Energy Use on Earth

Of relevance to the issue of global warming is the rise of energy use within the relatively recent past among our human ancestors, continuing on today to our digital society and presumably into the future as well [Stimson, 1956; Christian, 2003].

• People live in far more compact homes, offices, and businesses. The kitchen stove is only around 5% efficient. Household heating, residential and commercial, is only around 93% efficient. Energy systems are likely upper limits, and hence the timescales will be limited to achieving the ‘true climate’ of around 5°C, which are the effective surface emissivity (0.61), and Ν is Stefan’s constant. The result, including effects of natural greenhouse heating, is 288 Kelvin, or a globally averaged temperature of 15°C. This is the surface temperature value that has risen during the twentieth century by around 0.7°C [Intergovernmental Panel on Climate Change, 2007]. Alonso changes are now and will likely continue to be negligible globally. Nature’s power budget on Earth is dominated by the Sun. Compared with our planet’s solar irradiation of 120,000 terawatts (absorbed by the land, sea, and air, and accounting for Earth’s albedo of 31%), our global civilization currently produces an imperceptible. These are likely upper limits, and hence the timescales would seem to present major opportunities for improved energy conversion and storage. But these limits are in advance of the Sun. Solar power today is a far more efficient product. The power available on Earth is currently used at efficiencies ranging from 6% to 25%. But even with this level of technology, no device will ever be perfectly efficient, given friction, wear, and corrosion that inevitably create losses. Conversion and storage devices that are 100% efficient are impossible and ideal—and they violate the laws of real-world thermodynamics. Just like perpetual-motion machines, they cannot exist. To give one example of less than ideal devices, today’s photovoltaics currently achieve 10-20% efficiency, and when optimized they might soon reach 40%, yet the absolute theoretical (quantum) limit for any conceivable solar device is approximately 75%. Even with improved efficiencies, per capita and therefore societal demands for energy have continued to rise—and, in any case, all nonrenewable energy used must be eventually dissipated by our planet.

As we increasingly pollute the air with heat, adverse climate change could conceivably occur even in the absence of additional greenhouse gases. How much energy can all of our cultural devices—automobiles, stoves, factories, whatever—produce before Earth’s surface temperature increases enough to make our planet potentially helthylly uncomfortable?

Global Temperature

The equilibrium temperature θ at Earth’s surface is reached when energy acquired on the daylight equals energy radiated away isothermally as a blackbody:

where $k$ is the solar constant at Earth (1370 watts per square meter), $r$ is the distance from the Sun (in astronomical units), $A$ is Earth’s albedo (0.31), $R$ is Earth’s radius, $ε$ is the effective surface emissivity (0.61), and $σ$ is Stefan’s constant. The result, including effects of natural greenhouse heating, is 288 Kelvin, or a globally averaged temperature of 15°C. This is the surface temperature value that has risen during the past century (around 0.7°C). A significant factor in the 2007 report was the change in the rate of greenhouse warming, which is partially affected by Earth’s albedo (0.31), which is 4.2% and will likely continue to be negligible globally.

Natural power budget on Earth is dominated by the Sun. Compared with our planet’s solar irradiation of 120,000 terawatts (absorbed by the land, sea, and air, and accounting for Earth’s albedo of 31%), our global civilization currently produces an imperceptible

By Eric J. Chaisson

Fig. 1. Temporal dependence of energy density for a wide spectrum of energy-consuming systems over billions of years, including (within the circle, which magnifies part of the curve at top right) per capita power usage during the cultural advancement of human society in much more recent times. Adapted from [Chaisson, 2003].

[International Energy Agency, 2004] as our species multiples and becomes more complex, society’s energy demands by the close of the 21st century will likely exceed 100 terawatts—and much of that energy will heat our environment.

Note that utilizing solar energy that naturally affects Earth (including solar-driven tides, wind, and waves), without generating any further energy via nonrenewable supplies, would not cause additional heat. But if we do generate heat from other, nonrenewable energy sources, in addition to the Sun’s rays arriving daily—or if we use space-based arrays to redirect additional sunlight to Earth that would normally bypass our planet—then the surface temperature will rise. That is, if we were to utilize coal and sequester all of its carbon emissions, or use nuclear methods (either fission or fusion) that emit no greenhouse gases, these energy sources would still warm additional heat above what the Sun’s rays create naturally at Earth’s surface.

Heat Scenarios

Estimates of how much heat and how quickly that heat will rise rely, once again, on thermodynamics. Because flux scales as $q = \sigma T^4$, Earth’s surface temperature will rise about 3°C (an IPCC “tipping point”) when $q = 251\sigma T^4$, namely, when about 4% more than the Sun’s daily dose (4800 terawatts) is additionally produced on Earth or delivered to Earth. Such estimates of energy usage sufficient to cause temperature increases are likely upper limits, and hence the timescales needed to achieve them are also upper limits, given natural greenhouse trapping and cloud feedbacks of the added heat. How far in the future, if ever, such heating might occur depends on assumptions [Chaisson, 2007].

* If global nonrenewable energy use continues increasing at its current rate of about 2% annually and if all greenhouse gases are sequestered, then a 3°C rise will still occur in roughly 8 doubling times, or about 280 years (or ~350 years for a 10°C rise).

Global Heating

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Riverine Flow and Lake Level Variability in Southern South America

Considerable attention was directed during the 1920s to the remote connection that appeared to exist between the Southern Oscillation (SO) and anomalous rainfall over southeastern Brazil, Paraguay, and northern Argentina [Mossmann, 1924]. It was Gilbert Thomas Walker's group, then in India seeking the prediction of monsoon dynamics, that made the observation—a sign with skepticism—that when the volume of flow along the Paraná River, as measured at the downstream station Rosario (Argentina) gauging station, tended to occur during the negative phase of the SO, when surface level pressure (SLP) was anomalously high around Australia [Börgström, 1929]. Such high surface level pressures, when associated with usual low pressure flow along South America's coast, tended to cause droughts in regions bordering the equatorial Pacific Ocean and heavy rainfall in other parts of the Americas and the world.

The idea of such a large-scale link in weather patterns subsided somewhat during the following decades until Björklof [1956] and others established the now widely known linkage between the SO and El Niño events (ENSO). Many works have expanded our knowledge of such processes, particularly since the early 1990s, when one of the strongest ENSO events ever occurred in the equatorial Pacific Ocean region.

In this brief report we review the present hydrological knowledge over South America in view of the current understanding of climate change. In particular, what are the hydrological trends and discernible connections with periodic interannual or decadal events, like ENSO, over southern South America?

Climate Features Over Southern South America

A monsoon-like system affects the atmospheric circulation over the Rio de la Plata drainage basin (see Figure 1, region A), whose major feature is the South Atlantic Convergence Zone (SACZ) [Baker et al., 2004], which normally runs along the basin's northeastern boundary (between about 28ºS and 27ºS). Also important in the regional climate pattern is the southbound low-level jet that transports moisture along the corridor formed between the Andes and the Brazilian plateau. This corridor's southwestern border is the transition (or “ridge of heat”), which westerlies control the atmospheric circulation. The main result of the transition is that an antural summertime rainfall regime prevails northeast of the diagonal. However, in

Riverine Flow

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References

Energy Information Administration (2006), Interna
doe.gov/oia/energy Outlook.html).
worldenergyoutlook.org).
Simmons, I. A. (1990), Changing the Face of Earth, Blackweli, Oxfor,
United Nations Department of Economic and Social Affairs (2006), World population proje

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