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The Little Ice Age and the Coming of the Anthropocene

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Abstract
This paper examines the historical relationship between the Little Ice Age and the Anthropocene, which has not yet been studied. The Little Ice Age is the coldest multi-century period in the Holocene. The reforestation of huge farmlands, abandoned due to pandemics in the Americas, aggravated the cooling weather of the Little Ice Age. It was in the long and severe cold of the Little Ice Age that the transition from renewable energy to non-renewable energy was completed in Britain in the latter part of the eighteenth century, and when the pattern of linear growth in greenhouse gas concentrations was forged in the ecosystems of the Earth. The Little Ice Age forced humans to depend on fossil fuels while the advent of warmer and more stable climate in the Holocene enabled them to start agriculture in an energy revolution 11,000 years ago, thus making the coming of the Anthropocene possible.

Keywords
Anthropocene, Little Ice Age, greenhouse gas, wood, coal, fossil fuel, climate change

In the last 11,000 years of human history, the Little Ice Age (LIA) is the coldest multi-century period and one of several global millennial-scale climate anomalies.[1] The cooling climate and alpine glacial advances were recognized in many areas around the globe. In 1939, François Matthes introduced the term, "Little Ice Age," as "an epoch of renewed and moderate glaciations" in order to describe the trend of climate change, not only in Europe but across the world.[2] Fully aware of the repeated Holocene glacial advances caused by climate factors for the past 4,000 years, Matthes noticed the recession after 1850. He did not regard 1850 as the end of the LIA, but rather, as one more mild fluctuation. In 1969, paleoclimatologist Willi Dangsgaard and others presented Greenland ice-core isotope studies as the first direct paleoclimate evidence for the cold LIA climate.[3] Now, the term "Little Ice Age" has been widely employed by geographers and climatologists for the cooling climate, but there are no universally accepted dates to identify the onset and end of the LIA,[4] since temperatures declined over the first half of the millennium with geographical variations and short-term fluctuations.[5] The period from about 1550 to 1850 has commonly been used, with intervals of slight warming, although the LIA could be considered as long as 1250 to 1900.[6]

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[1] Raymond S. Bradley, "Past Global Changes and Their Significance for the Future," *Quaternary Science Reviews* 19 (2000): 391-402. Raymond S. Bradley has regarded the LIA as the coldest period of the Holocene.

[2] François E. Matthes, "Report of Committee on Glaciers, April 1939," *Transactions of the American Geophysical Union* 20, no. 4 (1939): 520.

[3] W. Dangsgaard et al., "One Thousand Centuries of Climate Record from Camp Century on the Greenland Ice Sheet," *Science* 166, no. 3903 (October 1969): 377-80.

[4] Scholars did not agree on the exact dates of the LIA. For instance, Hubert H. Lamb has presented different dates, 1550-1700 "as the main phase for most parts of the world" despite regional fluctuations. Hubert H. Lamb, *Climatic History and the Future*, vol. 2 of *Climate: Present, Past and Future* (London: Methuen, 1977), 463. Anthony N. Penna has identified 1300-1850 for the period of the LIA. Anthony N. Penna, "Climate Change" in *Berkshire Essentials: Big History*, ed. William H. McNeill et al. (Great Barrington, Mass.: Berkshire Publishing, 2011), 45.

[5] Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes, "Northern Hemisphere Temperatures during the Past Millennium: Inferences, Uncertainties, and Limitations," *Geophysical Research Letters* 26, no. 6 (March 1999): 759-62.

[6] See Raymond S. Bradley and Philip D. Jones, "When Was the 'Little Ice Age'?" in *Proceedings of the International Symposium on the Little Ice Age Climate*, ed. Mikami T. (Department of Geography, Tokyo Metropolitan University, Tokyo, 1992), 1–4; John A. Matthews and Keith R. Briffa, "The 'Little Ice Age': Re-evaluating of an Evolving Concept," *Geografiska Annaler* 87 A, no. 1 (March 2005): 17-36; J. M. Grove, "The Initiation of the 'Little Ice Age' in Regions round the North Atlantic," *Climate Change* 48 (January 2001): 53-82; Raymond S. Bradley et al., "The Climate of the Last Millennium," in *Paleoclimate,*

The relations between the LIA and the coming of the Anthropocene have not yet been studied. The term "Anthropocene", the "Human Epoch", is an informal concept used to signal the profound, global and irreversible alternations of the Earth's ecosystems by collective human activity. As early as 1864, anthropogenic global change was acknowledged by George Perkins Marsh in his *Man and the Nature.*[7] Paul J. Crutzen, the Nobel Prize-winning atmospheric chemist, and ecologist Eugene F. Stoermer introduced the term,[8] but its scale, starting point, and stratigraphy have not yet been precisely defined. Focusing on the growing global concentration of carbon dioxide and methane, they favored the beginning of the Industrial Revolution, "the latter part of the eighteenth century" with James Watt's steam engine as the starting point for the Anthropocene in a 2000 article in the IGBP Newsletter; Crutzen reiterated this argument in the 2002 *Nature*.[9] In 2007, however, Will Steffen and John R. McNeill joined Crutzen to argue that the Anthropocene began around 1800 with the beginning of the Industrial Revolution, while the age of the "Great Acceleration" marked Stage 2 of the Anthropocene based on the unprecedented rapid rise of atmospheric CO_2 above the

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Global Change and the Future, ed. Keith D. Alverson, Raymond S. Bradley, and Thomas F. Pedersen (Berlin: Springer, 2003), especially 115-16.

[7] George Perkins Marsh, *Man and Nature; Or, Physical Geography as Modified Human Action* (New York, N.Y.: Charles Scribner, 1864).

[8] Paul J. Crutzen and Eugene F. Stoermer, "The 'Anthropocene'," *Global Change Newsletter* 41 (May 2000): 17-18. The idea the Earth has entered a new era is not completely new. As early as the 1870s, geologist Antonio Stoppani coined the term "Anthropozoic," while Andrew C. Revkin argued that we have entered "the Anthrocene [sic]…a geological age of our own making." Antonio Stoppani, *Corsa di geologia* (Milan, Italy: Bernardoni & Brigola, 1871-1873); Andrew Revkin, *Global Warming: Understanding the Forecast* (New York, NY: American Museum of Natural History, Environmental Defense Fund, Abbeville Press, 1992), 55.

[9] Paul J. Crutzen, "Geology of Mankind," *Nature* 415 (January 2002): 23. For the various aspects of the Anthropocene and several efforts to formalize it as a new geological epoch in the Earth's history, see Jan Zalasiewicz et al., "The Anthropocene: A New Epoch of Geological Time?" *Philosophical Transactions of the Royal Society A* 369, no. 1938 (2011): 835-41; Will Steffen et al., "The Anthropocene: Conceptual and Historical Perspectives," *Philosophical Transactions of the Royal Society A* 369, no. 1938 (2011): 842-67 and other articles in the same theme issue.

upper limit of the Holocene after 1950.[10] Some emphasized 1945 as a useful maker for this second change, based on tiny but measurable amounts of global radioactive isotopes in sediments,[11] while William F. Ruddiman proposed that the greenhouse gases experienced an anomalous increase due to agricultural developments 7,000 years ago.[12] In 2013, economic historian Dennis O. Flynn stated that the birth of globalization "arguably initiated the Anthropocene" in c. 1571 or "at minimum, Globalization's origin represented a critical 16th-century phase transition within the Anthropocene."[13] Yet a long-term understanding of the forces, including the role of humans, in the transformation of the terrestrial biosphere remains "incomplete and controversial."[14] This paper shows how and when the Anthropocene commenced by linking it to the LIA.

THE LITTLE ICE AGE: CLIMATOLOGICAL EXPLANATIONS

In general, four primary external forcing agents have been acknowledged in the engendering of the LIA: solar variability, volcanic activity, sulfate aerosols, and greenhouse gas. Volcanic activity is generally associated with short-term cooling. Since vol-

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[10] Will Steffen, Paul J. Crutzen, and John R. McNeill, "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?" *Ambio* 36, no. 8 (December 2007): 614-21. Showing the Great Acceleration graphs, W. Steffen et al. stated in 2004 that the Earth system has experienced "a profound acceleration" after the 1950s due to the increasing human activities and manipulation of the globe. They regarded the past 50 years after the 1950s "a period of dramatic and unprecedented change in human history." Will Steffen et al., *Global Change and the Earth System: A Planet under Pressure,* The International Geosphere-Biosphere Programme Book Series (Berlin: Germany, Springer, 2004), v, 132. For the Great Acceleration graphs, see ibid., 132-33, Fig. 3.66 and Fig. 3.67.

[11] William A. Marshall et al., "The Use of 'Bomb Spike' Calibration and High-precision AMS ^{14}C Analyses to Date Salt-Marsh Sediments Deposited during the Past Three Centuries," *Quaternary Research* 68, no. 3 (2007): 325-37.

[12] William F. Ruddiman, *Plow, Plagues, and Petroleum: How Humans Took Control of Climate,* First Princeton Science Library Edition (Princeton: Princeton University Press, 2010); idem, "The Anthropocene," *Annual Review of Earth and Planetary Sciences* 41 (2013): 45–68.

[13] Dennis O. Flynn, "Globalization's Birth and the Anthropocene," *IBHA Members' Newsletter* 3, no. 11 (December 2013): 2.

[14] Erle C. Ellis et al., "Dating the Anthropocene: Towards an Empirical Global History of Human Transformation of the Terrestrial Biosphere," *Elementa: Science of the Anthropocene* 1 (December 2013): 1.

canic aerosols usually reside in the atmosphere for only for one to three days, the emission of sulfate aerosols tends to lower temperatures as it scatters radiation back into space. Thus volcanic activity does not influence long-term and/or global climate change. However, one large volcanic eruption can have a cooling effect on the global climate for a year or two, and several explosions can keep the temperature lower for as long as a decade. In the LIA, there were historic large eruptions. The 1815 eruption of the Indonesian volcano of Tambora brought the famous "year without summer" in 1816. Other volcanic eruptions during the LIA include Mount Billy Mitchell (1580) and Long Island (1660) in Papua (New Guinea), Mount Parker (1580) in the Philippines, and Huaynaputina (1600) in Peru.

Solar variability during 11-year solar cycles was probably unusually great during the LIA. During the LIA, there were three periods of sunspot minima: the Spörer Minimum (1400–1510), the Maunder Minimum (1645–1715), and the Dalton Minimum (1800–1860). Severely influenced by the Maunder Minimum, the 17th century is widely regarded as the coolest century in the last 11,000 years, and it has been used to provide a climate driven explanation for the century of "global crisis."[15] Astronomer John Eddy explained that the reduced sunspot activity during these minima was a critical factor in cooling the globe.[16] Although the annual average number of sunspots at a typical minimum in the 11-year cycles is 6, there were some weeks during these minima when no sunspots were seen. The solar cycle operated at an almost imperceptible level and practically no sunspots were observed during the Maunder Minimum. Even during the years from 1672 to 1704, no single sunspot was seen on the northern hemisphere of the sun.

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[15] Geoffrey Parker, "Crisis and Catastrophe: The Global Crisis of the Seventeenth Century Reconsidered," *American Historical Review* 113, no. 4 (October 2008): 1053-79; idem, *Global Crisis: War, Climate Change and Catastrophe in the Seventeenth Century* (New Haven: Yale University Press, 2013).

[16] John A. Eddy, "The Maunder Minimum," *Science* 192, no. 4245 (June 1976): 1189-202.

In addition to solar variability, anthropogenic greenhouse gas emissions have been linked to climate changes. As early as 1990, climatologist Jérôme Chappellaz and others argued that climate fluctuations over the 160,000 years were correlated with methane measurements of the ice core at Vostok station, Antarctica, and that early human agriculture also had an impact on the global cycling of methane.[17] Recently, paleoclimatologist William Ruddiman argued in 2003 that "the Anthropocene actually began thousands of years ago as a result of the discovery of agriculture and subsequent technological innovations in the practice of farming" due to early human agricultural practices affected the global cycles of greenhouse gas emission by deforestation, the spread of domesticated livestock, and wet rice farming, although he revised late the date of change of CO_2 from 8,000 to 7,000.[18]

Just as greenhouse gas emissions increased in the age of early human agriculture, methane and carbon dioxide emissions contributed to climate change during the LIA. As Figure 1 shows, ice-core results from Law Dome (Antarctica) and Summit region (Greenland) indicate higher CH_4 (methane) levels for 1050–1250 and lower levels for 1550–1750.[19] The former changes contributed to the Medieval Warm Period, while the latter changes contributed to the LIA. CO_2 levels also changed in the almost same pattern as CH_4. The CO_2 ratio was 280–284 ppm between 1000 and 1550 but then "dropped to a level about 6 ppm lower between 1550 A.D.

[17] J. Chappellaz et al., "Ice-core Record of Atmospheric Methane over the Past 160,000 Years," *Nature* 345 (May 1990): 127-31; David M. Etheridge et al., "Natural and Anthropogenic Changes in Atmospheric CO_2 over the Last 1000 Years from Air in Antarctic Ice and Firn," *Journal of Geophysical Research* 101, no. D2 (February 1996): 4115-28; idem, "Atmospheric Methane between 1000 A.D. and Present: Evidence of Anthropogenic Emissions and Climatic Variability," *Journal of Geophysical Research* 103, no. D13 (July 1998): 15979-93.

[18] William F. Ruddiman, "The Anthropogenic Greenhouse Era Began Thousands of Years Ago," *Climate Change* 61, no. 3 (December 2003): 261; idem, *Plow, Plagues, and Petroleum*, 208. Although William F. Ruddiman has conceded that the concentrations of greenhouse gases began to rise exponentially by 1850 as a result of the rapid growth of the population and the use of fossil fuels by industrial developments and the industrial age is marked as "a major inflection point in human influences on the environment," he has pointed out that the critical anthropogenic effects on the Earth began thousands years ago. Ruddiman, "Anthropocene," 46. Although David Christian sees Ruddiman's arguments as "overstated," he emphasizes that "the Anthropocene is not just a byproduct of modernity, but had roots many millennia in the past." David Christian, "Anthropocene" in *Berkshire Essentials: Big History*, ed. William H. McNeill et al., 11.

[19] Etheridge et al., "Atmospheric Methane between 1000 A.D. and Present," 15983.

and 1800 A.D.”[20] before starting to rise again very rapidly with the beginning of the Anthropocene.

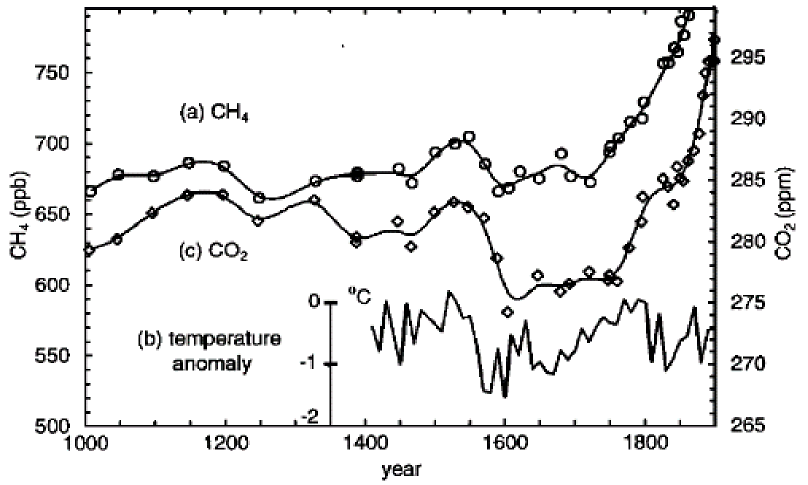

Figure 1. Methane and carbon dioxide variations during the pre-Anthropocene. Curve (a) Methane mixing ratios from Antarctic and Greenland ice-cores. Curve (b) Temperature anomaly for northern hemispheric summers, decadal means, referenced to 1860–1959. Curve (c) Ice core CO_2 record with 75-year smoothing spline fit. Source: D. M. Etheridge et al., “Atmospheric Methane between 1000 A.D. and Present,” 15985.

The Little Ice Age and an Anthropogenic Forcing

Why did the CH_4 and CO_2 levels drop around 1550? Climatologists David Etheridge and others argue that anthropogenic forcings, such as emissions from fossil fuels and land-use change were negligible during the pre-industrial period between 1000 and 1550. Instead, they have argued that the decrease of the CH_4 and CO_2 levels during the LIA was “caused by the effect of lower temperatures on the terrestrial biosphere,” thus reducing emissions of CH_4 and CO_2.[21]

But William Ruddiman turned these arguments from Etheridge and others upside down. He argues that “plague-driven CO_2 changes were also a significant causal factor in temperature

[20] Idem, “Natural and Anthropogenic Changes in Atmospheric CO_2,” 4122.

[21] Idem, “Atmospheric Methane between 1000 A.D. and Present,” 15986. See also idem, “Natural and Anthropogenic Changes in Atmospheric CO_2,” 4126.

changes during the Little Ice Age" and the decrease of the CH_4 and CO_2 levels accelerated the cooling effect during the LIA.[22] His central idea is that mass mortality caused by pandemics "allowed forests to reoccupy abandoned land, sequester carbon from the atmosphere, and drive CO_2 level lower."[23] C. MacFarling Meure et al. support Ruddiman's argument, on the basis of the refined Law Dome data, by casting doubt on previous interpretations that the lower concentration of greenhouse gas was likely driven by reduced emissions from terrestrial biosphere during the LIA.[24]

The Columbian exchange brought about virgin soil epidemics in the Americas, particularly in the most densely settled regions. The arrival of new diseases was followed by demographic collapse in America after 1492. The collapse expanded from the Caribbean islands and helped European conquerors penetrate the hemisphere. Diseases were not just smallpox but also bubonic plague, measles, mumps, tuberculosis and other epidemics new to the indigenous people. After contact with Europeans, 90%~95% of 53.9~112.5 million for the Americas died (with regional variations in mortality) in just five decades.[25] The population of the

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22 Ruddiman, "The Anthropogenic Greenhouse Era," 261.

23 Ruddiman, *Plow, Plagues, and Petroleum*, 211.

24 C. MacFarling Meure et al., "Law Dome CO_2, CH_4 and N_2O Ice Core Records Extended to 2000 BP," *Geophysical Research Letters* 33, no. 14, L14810 (July 2006): 1-4.

25 The pre-Columbian population estimates are still controversial because of the fragmentary, scanty and unreliable nature of the historical evidence. Massimo Livi-Bacci has stated that they are "a minimum of 8 million to a maximum of 113 for the entire continent." Massimo Livi-Bacci, *A Concise History of World Population*, 5th ed. (Malden, MA: John Wiley & Sons, 2012), 48. In 1934, Anthropologist Alfred Kroeber calculated that 8.4 million people had lived in the Americas. Alfred Kroeber, "Native American Population," *American Anthropologist* 36 (1934): 25. In 1966, by contrast, anthropologist Henry F. Dobyns argued that there lived between 90 and 112 million people in 1491 (and later revised his own estimates upward in 1983) and 95% of the Americans died after the first 130 years of contact with the Europeans. Henry F. Dobyns, "Estimating Aboriginal American Population: An Appraisal of Techniques with a New Hemispheric Estimate," *Current Anthropology* 7 (1966): 395-416; idem, *Their Number Become Thinned: Native American Population Dynamics in Eastern North America* (Knoxville, TN: University of Tennessee Press, 1983). His argument invited severe attacks from Douglas H. Ubelaker, David P. Henige, and other skeptics. In 1976, geographer William Denevan tried to present a consensus count of about 54 million people. William M. Denevan, *The Native Population of the Americas in 1492*, 2nd ed. (1976; Madison: University of Wisconsin Press, 1992), xxvii-xxix, table 1. Nonetheless, the debates have continued over the population estimates. In 1981, Noble David Cook supported Dobyns' argument, stating that death rate in six main epidemics in Tawantinsuyu is about 93 percent. Noble David Cook, *Demographic Collapse, Indian Peru, 1520-1620* (New York: Cambridge University Press, 1981). For the arguments on the high death rate, see also Linda A. Newson,

Americas decreased to 5.6 million in 1650.

Enslavement and other hardships also reduced the population as Native Americans were relocated to mining villages and agricultural estates. Massive areas of indigenous farmland were abandoned and forests took over again. Forests in tropical America recovered quickly because of high terrestrial net primary production. Even in the Amazonian rain forest, huge intensive agricultural areas were reclaimed by forest.[26] The pre-Columbian level of population had not recovered by 1750, when large-scale European settlement began.[27]

The reforestation of the Americas is closely correlated to the decline of greenhouse gas levels. The CO_2 level dropped by 8 ppm (from 281.9 to 274.3 ppm) between 1570 and 1604.[28] Before that, CO_2 levels had remained between 282.4 (1499), 283.2 (1527) and 281.9 (1570). According to the refined Law Dome data, the "the abrupt 10 ppm CO_2 decrease" was found between 1550 (282.60 ppm) and 1610 (272.56 ppm) which is meant a temperature decrease of 0.8°C in terrestrial biosphere.[29] But the reforestation of the Americas did not occur just after the arrival of the Europeans. Ecologists have found that abandoned farmland and pasture can reclaim forests to remove and store atmospheric CO_2 in trees and regain the carbon levels typical of full forest within 50 years or so. Although the population decreased rapidly, it was not instantaneous. The population of Central Mexico, the most populous area

"The Demographic Collapse of Native Peoples of the Americas, 1492-1650," in *The Meeting of Two Worlds: Europe and the Americas, 1492-1650,* ed. Warwick Bray (Oxford: Oxford University Press for the British Academy, 1993), 253-54.

But the High Counters like Dobyns have been regarded by critics as "politically motivated—self-flagellation by guilty white liberals or, worse, a push to inflate the toll of imperialism from the hate-America crowd." Charles C. Mann, *1491: New Revelations of the Americas before Columbus,* 2nd ed. (New York: Alfred A. Knopf, 2006), 95. See also David P. Henige, *Numbers from Nowhere: The American Indian Contact Population Debate* (Norman: University of Oklahoma Press: 1998).

26 Michael J. Heckenberger et al., "Amazonia 1492: Pristine Forest or Cultural Parkland?" *Science* 301, no. 5640 (September 2003): 1710-14.

27 William M. Denevan, "The Pristine Myth: The Landscape of the Americas in 1492," *Annals of the Association of American Geographers* 82, no. 3 (September 1992): 369-85.

28 Etheridge et al., "Natural and Anthropogenic Changes in Atmospheric CO_2," 4122.

29 MacFarling Meure et al., "Law Dome CO_2, CH_4 and N_2O Ice Core Records," 3.

in the Americas, for example, was 25.2 million at the beginning of the European conquest, decreasing to 6.3 million in 1548, 1.9 million in 1580, and 1.0 million in 1605.[30] Ruddiman therefore argues that the "great 'American Pandemic'-1500~1700-closely matches…the largest CO_2 drop in the Law Dome ice core."[31]

This is not to say that reforestation in abandoned fields in America alone caused the LIA. Surely, however, the radical drop of CO_2 brought about a significant decline in temperature at the start of the LIA. The reclamation of abandoned agricultural fields and lowering atmospheric CO_2 cooled the climate by 0.1°~0.2°C.[32] Europeans did not intend to change the climate, but the pandemics they brought with them to the Americas and their effects on the radical decline of the population accelerated its cooling.

The LIA not only forced its inhabitants to endure climatic anomalies, droughts, and famines but also served to catalyze social unrest, popular revolts and severe conflicts between neighboring states. Even in China, the richest and most populous state in the world at the time, the Ming dynasty collapsed in part because of major social revolts. In the 17th century "more wars took place around the world than in any other era until the 1940s."[33] As a result, states tried to increase their military power. Almost every state in Europe created standing armies. They invested in securing additional revenue in order to support their expanded armed forces as well as the growing power of the state to maintain their level of affluence. Disastrous droughts and famines caused by climatic anomalies helped to precipitate social unrest and political upheavals in several counties such as Scotland, Spain, England, France, Italy, Poland, Russia, China and Japan.[34] Although cli-

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30 Sherburne F. Cook and Woodrow Borah, *Essays in Population History: Mexico and the Caribbean,* 3 vols. (Berkeley: University of California Press, 1971), 1:82. Massimo Livi-Bacci has commented that the figures before the 1550s are "probably too high, but even restricting the analysis to the well-documented later period the catastrophe is evident." Livi-Bacci, *A Concise History of World Population*, 48-49.

31 Ruddiman, *Plow, Plagues, and Petroleum*, 138.

32 Franz X. Faust et al., "Evidence for the Postconquest Demographic Collapse of the Americas in Historical CO_2 Levels," *Earth Interactions* 10, no. 11 (2006): 12.

33 Parker, "Crisis and Catastrophe," 1056.

34 Geoffrey Parker has correctly argued that, unlike Europe, "Japan experienced the *Pax Tokugawa*" in the 17th century with rapid growth and no wars, enduring the LIA. Parker, *General Crisis*, 484. The LIA, however, was not limited only to the 17th century. Japan underwent the Warring States Period, a time of social and political unrest, nearly constant mili-

mate change was not the only factor driving social and political upheavals, climatic anomalies shaped or fatally aggravated situations in which popular revolts, urban riots, and even state collapse were triggered. Thus "no convincing account of the General Crisis can now ignore the impact of the unique climatic conditions that prevailed."[35]

In the short term, the LIA had negative effects on population growth. The second half of the 17th century witnessed a dramatic decline of population in major regions, such as Britain, France, and China. In Britain, ravaged by climatic anomalies and their effects on agricultural production, the population declined from 5.22 million in 1651 to 5.05 million in 1701.[36] In the long run, however, population sizes increased in almost every one of these regions, owing to the advancement of farming methods and the increasing and effective use of extended land. The population of Britain was 4.11 million in 1601 but rose to 5.77 million in 1750 by 141 percent. The population of the Netherlands was 1.4~1.6 million in 1600 but rose to 1.9 million by 130 percent. The population of China also increased from 138 million in 1600 to 380 million in 1820.

The Transition from Renewable Energy System to Non-Renewable Energy System

This long-term increase in population accelerated the transition from organic economies to an inorganic economy mainly because of the increasing shortages of organic fuels. European exploitation of its tropical colonies provided several high calorie foods, but could not resolve the problem caused by diminution of domestic resources of fuel. Wood is easy to collect and use for ener-

tary conflict, and a war with Joseon roughly from the middle of the 15th century to the end of the 16th century.

35 Idem, "Crisis and Catastrophe," 1077.

36 E. A. Wrigley and R. S. Schofield, *The Population History of England, 1541-1871: A Reconstruction* (Cambridge: Harvard University Press, 1981), 208-9, Table 7.8.

gy, and it seemed inexhaustible, if replanted. But the ordinary domestic use of every kind, as well as its industrial use for shipbuilding, wagon-making, iron-smelting and coke-making consumed large amounts of wood. The total number of timber trees for firewood in seven of the largest forests in Britain was 232,011 in 1608 but decreased to 51,500 by 1783, while firewood prices rose 700 percent from 1500 to 1630.[37] Britain imported wood from Baltic countries and North America, but could not solve the problem of energy scarcity without coal. Fuel prices in the eighteenth century in Europe as well as East Asia increased much more than other prices.

Consequently, the shortage of fuels became acute regionally and nationally as severe cold climates continued during the LIA. Western Europe and China began to depend heavily on coal as wood became increasingly scarce, while the United States maintained its dependency on wood because it had a sufficient supply of virgin and second-growth forests. In particular, the situation was much direr in Britain than other nation-states because of its small size and smaller supplies of wood. Britain entered "a period of energy crisis" in the seventeenth century.[38] Previously in Britain, the Romans had carved coal to make beautiful jewelry. China had begun to burn coal to meet daily needs as early as around 3th century BCE.[39] It was the first time for the British, however, to exploit coal on such a large scale for energy. In 1550 CE, coal production in Britain was 0.2 million metric tonnes but rose to 2.7 million metric tonnes by 1700. And by 1800 the coal production tripled to 9 million metric tonnes. This increase in the production of coal was sparked by the wood scarcity itself as well as a fearful construct of an energy crisis. "The first major exploitation

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[37] Alfred W. Crosby, *Children of the Sun* (New York: W. W. Norton, 2006), 69.

[38] Kenneth Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton: Princeton University Press, 2000), 220. Cf. Joachim Radkau has argued that there existed wood shortages, but not a crisis in many cases. Joachim Radkau, *Wood: A History,* trans. Prick Camiller (Cambridge: Polity Press, 2012). Needless to say, wood shortage was not evenly spread. A general shortage of wood was "hardly plausible for any period before 1750" in many areas of Europe, but it appeared quite plausible by 1820. Paul Warde, "Fear of Wood Shortage and the Reality of the Woodland in Europe, c.1450–1850," *History Workshop Journal* 62, no. 1 (Autumn 2006), 39.

[39] Barbara Freese, *Coal: A Human History* (New York: Penguin Books, 2003), 16, 204. It was 6,000 years ago when the Chinese people used coal for rather than for energy source. Ibid., 204.

of the world's fossil fuel reserves, created from the great tropical forests that existed over 200 million years earlier, began in the 17^{th} century" in the period of the LIA.[40]

Fortunately, Britain found large deposits of coal near the places that were easily accessible to big cities and manufacturing centres. The coal moved by sea from Newcastle to London was about 35,000 metric tonnes a year in 1550 and this rose to 560,000 metric tonnes by 1700. Meanwhile, "before the end of Elizabeth's reign, in 1603," coal had become the chief energy source in Britain.[41] But Britain soon faced a rapid exhaustion of its available fossil fuel. Coal accessed by open-pit mining no longer provided sufficient quantities by 1700. Unsurprisingly, China also became "a society subject to a growing energy crisis" as it grappled with deforestation and a shortage of wood at economical prices.[42] With inconsistent government policies[43] and an inefficient coal distribution system, growing demand from an increasing population in the mid-17^{th} century exhausted coal supplies in China within a century.

The long cold climate in the LIA, which caused this imminent crisis of wood scarcity and increased exploitation of coal, ultimately increased the cost of production, flooded mine shafts and galleries, and broke off coal veins. As a result, the price of coal was inflated enough to foment social unrest in Britain and China. China constructed drainage canals in order to remove water from shafts, and allowed merchants to exploit coal mines which had previously been prohibited by Feng Shui, the oriental theory of geomancy. In the mid-seventeenth century, the Qing dynasty ended prohibitions on mining and tried in vain to devel-

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[40] Clive Ponting, *A New Green History of the World: The Environment and the Collapse of Great Civilizations*, rev. ed. (New York: Penguin Books, 2007), 280.

[41] Freese, *Coal*, 33.

[42] John F. Richards, *The Unending Frontier: An Environmental History of the Early Modern World* (Berkeley: University of California Press, 2003), 44. See also S. A. M. Adshead, "An Energy Crisis in Early Modern China," *Late Imperial China* 3, no. 2 (December 1974): 20-28.

[43] Huang Qichen, *Zhongguo gangtie shengchan shi, shisi-shiqi shiji* (A History of Chinese Iron and Steel Production, Fourteenth to Seventeenth Centuries) (Zhengzhou: Zhongzhouguji chubanshe, 1989), 109-40.

op an efficient administrative system of coal mining while opening new coal mines. Yet China never fully solved the problem of ventilation to prevent spontaneous combustion inside coal mines.[44]

By contrast, the invention of coal-powered steam engines in Britain made it possible to efficiently pump water from flooded mines into shafts and circulate fresh air.[45] The machines made it possible to transform fire from a source of heat to a source of mechanical power. Efficient coal-powered engines increased coal production at low prices. Cheap coal encouraged the invention of more efficient machines to combat the crisis – real or socially constructed – of imminent deforestation. After Thomas Newcomen invented a large and inefficient steam engine, a Scotsman, James Watt, improved it to generate a far more efficient rotary power in the 1770s. Due to Watt's more efficient new steam engine, coal was able to leave the coal mines and cheap coal-powered engines were integrated with all kinds of mechanical processes across British industries. By the mid-1780s, coal was welcomed with the development of new technology that turned coal into coke for all stages of iron production. Moreover, with coal-powered steam engines and coke, blast furnaces grew big enough to produce lots of inexpensive domestic iron. By the latter part of the eighteenth century, Britain entered into an irreversible dependency on non-renewable energy, as it was the most efficient and inexpensive way to fuel its economy and achieve hegemony around the world.[46] With weapons based on the most efficient iron production system, Great Britain soon became the most powerful empire on the globe in the mid-nineteenth century.

Meanwhile, the increasing atmospheric concentration of greenhouse gases, a product of the increased burning of wood and coal, reversed the downward trend of the previous era. The CO_2 level rose steadily from 276.7 ppm after 1760. In fact, CO_2

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[44] Pomeranz, *Great Divergence*, 65.

[45] Jack A. Goldstone, *Why Europe: The Rise of the West in World History, 1500-1850* (Boston: McGraw-Hill, 2009), 131. Jack A. Goldstone has argued that "the combination steam and coal power broke all prior barriers of energy use in earlier societies."

[46] It was by the early 18th century when coal had become the main source of fuel in iron industry. Charles K. Hyde, *Technological Change and the British Iron Industry, 1700-1870* (Princeton: Princeton University Press, 1977), 23.

levels had oscillated between 275.9 ppm and 277.5 ppm for the period from 1647 and 1760.[47] Refined Law Dome data show that CO_2 levels were at the lowest point in 1614 (272.24 ppm) over the last 2000 years, fluctuating for a while but steadily increasing to the present without any significant decrease after 1759 (276.57 ppm.).[48] In short, the pattern of linear growth in the increase of greenhouse gas concentration was established in the latter part of the 18th century and remains until today, causing global warming. The pattern of linear growth was made possible by the growing consumption of coal and industrial development in Britain, China, and other nation-states as well as deforestation in the Americas caused by rapid economic growth and large scale migration from Europe and Africa.

Driven and invented during the long, cool climate of the LIA, coal-powered steam engines "enabled humans, as a species, to cross a fundamental ecological threshold by granting them access to vast and previously untapped sources of energy."[49] But this does not necessarily mean that other leading nation-states began to experience the irreversible transformation as a response to the exhaustion of organic energy in their biospheres. Although they had not faced the same problems as Britain, which faced a severe energy crisis, they attempted successfully to adopt new, more efficient energy systems in order to grow their economies at an unprecedented speed in a more competitive world.

CONCLUSIONS

Historian John R. McNeill argued that at the end of the Little Ice Age, "luck" enabled the human species to shatter the constraints

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[47] Etheridge et al., "Natural and Anthropogenic Changes in Atmospheric CO_2," 4122.

[48] "Reconstructed Evolution of CO_2, CH_4, N_2O over Past 2 Millennia," accessed November 25, 2013, http://climate.uvic.ca/EMICAR5/forcing_data/ghg_lawdome_giss_merge_c5mip_24jul09.1-2000.txt. See also MacFarling Meure et al., "Law Dome CO_2, CH_4 and N_2O Ice Core Records."

[49] David Christian, *Maps of Time: An Introduction to Big History* (Berkeley: University of California Press, 2004), 346.

and rough stability of the old biosphere and to achieve a long economic boom.[50] However, it was in the cold heart of the LIA that Britain invented and innovated coal-powered steam engines to exploit coal deposited in deep mines. It was in the severe cold of the LIA that Britain began to become dependent on coal-powered engines to take advantage of non-renewable fossil fuels rather than renewable energy. The irreversible transition from renewable organic energy to non-renewable inorganic energy was experienced by Britain as an active response to the coldest weather in the last ten thousand years and competition from all round the world.

This does not mean that the anthropogenic forcing agent of the LIA single-handedly changed the climate of the planet. Changes in the biosphere caused by pandemics in the Americas accelerated the cooling climate of the LIA and the human species responded to this partly self-inflicted climate change of the LI, consequently exhausting renewable energy sources. While the cooling weather of the LIA appeared globally, it did not persist permanently in the ecosystems of the Earth. The population in the Americas increased, the American forest was cleared for farms and cities, and greenhouse gas levels began to rise from these causes as well as from burning of fossil fuels in the atmosphere. Responding to the LIA, however, the human species began to exploit the Earth's non-renewable resources at an unprecedented level. The human response to the LIA remains evident in the ecosystems on the Earth. We can see the beginnings of the Anthropocene at the height of the Little Ice Age. As climate change enabled humans start agriculture in an energy revolution 11,000 years ago, climate change–the LIA–forced them to depend on fossil fuels and made the coming of the Anthropocene possible.

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[50] John R. McNeill, *Something New under the Sun: An Environmental History of the Twentieth-Century World* (New York: W. W. Norton, 2000), 17.