Green Energy and Technology

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Rise and Fall of the Carbon Civilisation

Resolving Global Environmental and Resource Problems

Springer

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Contents

Abbreviations

ASPO: Association for the Study of Peak Oil and Gas
b-a-u: business as usual
BITRE: Bureau of Infrastructure, Transport and Regional Economics (Aust)
BTS: Bureau of Transportation Statistics (US)
CANDU: Canadian Deuterium Uranium
CCN: cloud condensation nuclei
CCS: carbon capture and storage
CDM: Clean Development Mechanism
CFC: chlorofluorocarbon
CHP: combined heat and power
CNG: compressed natural gas
CO_2: carbon dioxide
CO_2-eq: carbon dioxide equivalent
EC: European Commission
EF: Ecological Footprint
EGS: enhanced geothermal systems
EIA: Energy Information Administration (US)
EJ: exajoule (10^{18} joule)
EU: European Union
EWEA: European Wind Energy Association
EWG: Energy Watch Group
FC: fuel cell
FFC: full fuel cycle
GCM: Global Circulation Model
GDP: Gross Domestic Product
GHG: greenhouse gas
GJ: gigajoule (10^9 joule)
GL: gigalitre (10^9 litre)
GNI: Gross National Income

Gt: gigatonne (10^9 tonne)
GtC: gigatonne carbon
GW: gigawatt (10^9 watt)
GWEA: Global Wind Energy Association
GWP: Global Warming Potential
HANPP: Human appropriation of NPP
HFC: Hydrofluorocarbon
HFCV: hydrogen fuel cell vehicle
HOV: high occupancy vehicle
IC: internal combustion
IAEA: International Atomic Energy Agency
IEA: International Energy Agency
IIASA: International Institute for Applied Systems Analysis
IPCC: Intergovernmental Panel on Climate Change
ISEW: Index of Sustainable Economic Welfare
IT: Information Technology
LWR: light water reactor
Mboe: Million barrels of oil equivalent. One barrel equals ~160 litres.
MDG: Millennium Development Goal
MEA: Millennium Ecosystem Assessment
MER: market exchange rate
MJ: megajoule (10^6 joule)
Mt: megatonne (10^6 tonne)
Mtoe: million tonnes of oil equivalent
MW: megawatt (10^6 watt)
MWh: megawatt-hour
NG: natural gas
NPP: Net Primary Production
OECD: Organisation for Economic Cooperation and Development
OPEC: Organization of the Petroleum Exporting Countries
OTEC: Ocean Thermal Energy Conversion
PETM: Paleocene-Eocene Thermal Maximum
PNS: Post-Normal Science
ppb(v): parts per billion (volume)
ppm(v): parts per million (volume)
PPP: purchasing power parity
ppt(v): parts per trillion (volume)
Pu-239: plutonium 239 isotope
PV: photovoltaic
RE: renewable energy
SPS: Satellite power system
SRES: Special Report on Emissions Scenarios (IPCC)
STEC: solar thermal electricity conversion
TMI: Three Mile Island

tpk: trillion passenger-km
TW: terawatt (10^{12} watt)
TWh: terawatt-hour
U: uranium
U-235: uranium 235 isotope
U-238: uranium 238 isotope
UN: United Nations
WEC: World Energy Council

Chapter 1
The Problems We Face

1.1 Introduction

In the year 1800, total coal production was probably only about 10 million tonnes. By 2008, coal production had risen to 6,781 million tonnes, and oil and gas produced that year added the energy equivalent of another 9,737 million tonnes of coal [5, 9]. Can such growth in our use of carbon based fuels continue for much longer? Among those who thought not was the prominent petroleum geologist Marion King Hubbert. He is famous for his analysis of peak oil, but he also thought that his insight applied to fossil fuels in general – and to all finite resources. Figure 1.1 shows his view of fossil fuel depletion, viewed in a centuries-long historical perspective.

Before 1800, our civilisation was powered by energy almost entirely supplied by carbon neutral sources, mainly biomass. Hubbert foresaw that fossil fuel production would rise and fall over roughly equal time periods, based on his understanding of fossil fuel discovery and depletion. But resource depletion is not the only threat to continued use of fossil fuels. We now know that fossil fuel burning is loading the Earth's atmosphere with levels of long-lived carbon dioxide that threaten to drastically alter planetary climate. The growth in fossil fuel use may have occurred at an unprecedented rate in the 20th century as indicated by the black area in Figure 1.1, but the decline in its use will have to occur even more rapidly in the 21st century (grey area) if we are to avoid the worst effects of climate change, leaving much of our fossil fuel reserves unused (white area).

At some point in the near future we will have to rely, as we did in the past, on energy from carbon neutral sources. Future sources range from nuclear power to renewable energy (RE) derived from biomass, wind, solar, hydro and geothermal resources. Many technologists argue that the transition to carbon neutral sources from fossil fuels can be spread over many decades, provided we have the technology to prevent the carbon dioxide from fossil fuel combustion entering the atmosphere. Alternatively, if this poses too great a challenge, we could limit the effect of carbon emissions by developing technology to enable geoengineering of the planet's atmosphere.

The idea that our problems can by solved by technology is seductive but ultimately unrealistic. Despite our faith in its power, technology is limited by economic, social and environmental factors. Technology is also bounded by physical laws, in addition to constraints imposed by resources and availability. And when faced with the biggest challenges, even the best available technology might prove inadequate. An umbrella, no matter how strong, is unlikely to protect you from a tsunami.

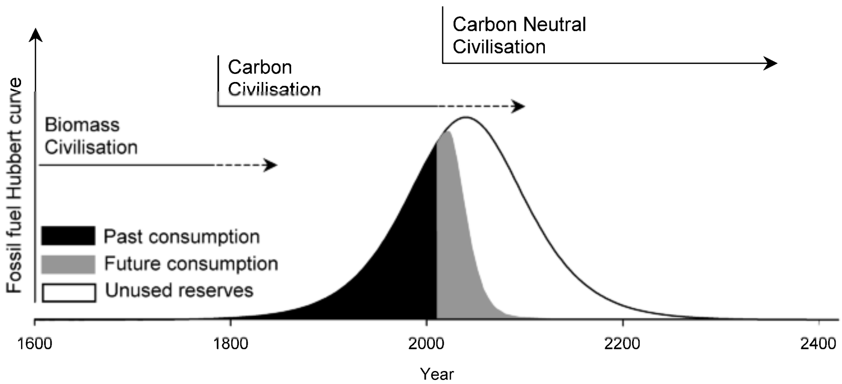

Figure 1.1 Schematic diagram of the rise and fall of the Carbon Civilisation

In this book we seek to establish the limits for the ability of our current technology to provide solutions to energy supply and global warming as we attempt the transition to a carbon neutral civilisation. We begin by providing an overview of the book's main themes, including the inadequacy of the technological fixes proposed as solutions, the limited time we have to find viable solutions, and the serious ethical challenges we face in a world with grossly unequal access to resources. We conclude that far more reliance will need to be placed on *social* solutions to our environmental and resource problems, and less on technical fixes.

1.2 Assessment of Technology Is Often Over-optimistic

We are struck by the extraordinary technological optimism shown in discussions on new sources of energy, and on climate mitigation proposals such as carbon sequestration and geoengineering. Indeed, a great deal of this book is devoted to a detailed examination of these ideas and their likely consequences. Much of this optimism has been the result of the undoubted successes – and high public profile, given the widespread ownership of its products – of the new Information Technology (IT). For IT, forecasts have often not kept pace with the progress actually made. Yet IT projections are exceptional – most technology forecasts for other areas severely under-estimate the difficulties and time needed to bring them to market [7]. As we shall see in Chapter 4, this optimism is shared by both most experts as well as the general public. It seems particularly pronounced in the energy supply sector [1, 11, 32].

Many suggestions for the new sources of energy discussed in Chapter 5, or for geoengineering of Earth to avoid serious climate change (Chapter 9), are treated as serious proposals, and in the case of new energy technologies, their output sometimes even included in future energy or climate mitigation scenarios. Often, when a new energy source has been sufficiently explored so that its limitations become apparent (such as being too costly or having too low an energy return on energy invested), the response is to seize upon yet another possible source, one whose own drawbacks are not yet known, and the cycle is repeated.

A good example of technological optimism is provided by Jesse Ausubel. In a recent interview article entitled ‘Ingenuity wins every time’ [3], Ausubel argued that the world can support 20 billion people, almost three times its year 2010 population. Some of the technological advances he thinks would help the world accommodate this vast population include: a transport system with high-speed magnetically levitated (maglev) trains running in evacuated underground tunnels; ‘landless agriculture’ – farming with very high yields per hectare; and more use of e-books to save paper.

Maglev trains running in tunnels might be a possible – but extremely expensive – solution for long-distance land-based travel, if passengers can be persuaded to travel for many hours in underground pipes. But maglev trains would be no use for short-trip urban travel, or at the other extreme, for overseas travel. Most of the problems raised by high levels of mobility would still be with us, including the need for carbon neutral energy sources. Landless agriculture, while it does save some forest from conversion, ignores the heavy cost that high-intensity, industrialised agriculture has for the environment, including pollution, soil erosion and biodiversity decline [28]. E-books may save some paper – unless they are printed off for reading – but overall, global paper use has grown in step with the spread of personal computers and the Internet in the world’s offices and homes [3].

Ray Kurzweil [14] is a prominent American computer expert who is even more optimistic about the future march of technology than Ausubel. He thinks that the rate of progress in the 21st century will be 1000 times greater than that of the previous century. This view is, of course, strongly influenced by the exponential progress of IT, as exemplified by Moore’s law. Yet in the more than half-century since the development of the computer, or the nearly two decades of the Internet, we have seen little progress in solving the crucial environmental and resource challenges we face. Jonathan Huebner [10] has studied both the global technical innovations since the year 1450 and US patent numbers over the past two centuries (both measured on a per capita basis). In total contrast to Kurzweil, he has controversially argued on the basis of these studies that the global technological innovation rate peaked over a century ago, and is now in decline.

1.3 An Earth Systems Science Approach Is Needed

Throughout this book, we will be using an ‘Earth Systems Science’ approach, which can be defined as follows: ‘Earth system science takes the major components of planet earth – the atmosphere, oceans, fresh water, rocks, soils and biosphere, and seeks to understand major patterns and processes in their dynamics’ [17]. Instead of studying each of these sub-systems as a self-contained entity, Earth Systems Science ‘seeks to put the pieces together and to understand the planetary life-support system as an integrated whole.’ [18]. It attempts to look at the big picture and determine how human and ecological system are coupled together. Extending this idea further, just as we have to consider the natural world as an interconnected whole, so it is important to consider all the word’s economic and political units together when looking at environmental/resource challenges that are also global in extent.

The various environmental and resource challenges presented in Chapters 2 and 3, although often considered in isolation by their specialists, are inter-connected. We cannot afford to concentrate on just one problem, such as global climate change, because of feedbacks (many of them still poorly understood) from other Earth sub-systems, like those from biomass-climate interactions. Preventing dangerous climate change requires that we also pay attention to matters as diverse as freshwater withdrawals, land use changes, and ocean acidification [28]. Ecologist William Laurance [15] has provided evidence of how apparently unrelated problems are connected. He uses two illustrations from tropical Africa. Forest logging is harming sea turtles, because many of the felled logs float out to sea but are later washed ashore on beaches where turtles breed. Overfishing by European trawlers in the Gulf of Guinea is endangering African wildlife, since coastal communities are now hunting wildlife more intensively to compensate for the fish protein they formerly consumed.

The approach of holding nearly all variables constant, apart from the small number under study, has served us well in engineering and science. Much of the argument and data presented in this book are based on the results of such investigations. But this method may not help us predict the unexpected linkages just described for biosystems. They can even give misleading conclusions when the laboratory results are then generalised to give, for example, the potentials for some new RE sources that we investigate in Chapter 5.

These potentials are often discussed with no consideration of the impact that massive commercialisation of, for example, a new photovoltaic cell type might have on the global availability of the scarce metals vital to their manufacture. Also usually ignored is the impact that on-going climate change will have on RE potential, an important case being the impact of the lower rainfall expected for some regions on both hydropower and biomass potential. Conversely, these studies often also ignore the impact that some RE sources, if developed on a global scale, would in turn have on global climate.

'Displacement' effects are also frequently ignored when the focus of study is a single region or country. For example, an effective ban on illegal logging in one country can lead to an increase in illegal logging in other countries with poor supervision, to supply timber to importing countries [6]. This appears to have happened in response to a tightening up on local illegal logging in China and Vietnam. Similarly, any rise in bio-plantations for fuel can be increasingly expected to have an adverse impact by displacing agriculture to areas presently under natural vegetation. Again, this displacement may not necessarily even occur in the country developing the bio-plantations; if bioenergy plantations reduce their food exports, importing countries will try to raise food production.

As already mentioned, for many issues, it is necessary to consider the global economy, rather than just a single national economy, no matter how large. Often, progress in one country in reducing its carbon or energy intensity (carbon emitted, or energy used, per unit of GDP) is held up as an example for the rest of the world's economies. Alternatively, a low energy intensity country may be compared with other, similar, countries. But different sectors of an economy have different energy intensities, the intensity being in general higher for the manufacturing than for the services sector. If a country exports services and imports manufactures, it will have a lower energy intensity than a country where the opposite is true. We can still learn much by comparing the experiences of different countries, but the results need to be carefully interpreted.

This is not to say that many problems that face us are not national, or even local, such as pollution from a point source like a fossil fuel power station. These problems, can, indeed must, be solved at a national or sub-national level. If a relatively isolated Australia restricts air pollution from national sources, its air quality will receive the full benefit – although this will not be the case for national pollution control in the small countries of continental Europe. But climate change is a global problem, as is oil depletion. Even if Australia greatly restricts emissions of carbon dioxide (CO_2), it will not have any significant effect upon the continent's future climate; this will only happen if most of the world's major emitters do likewise.

1.4 Uncertainty About the Future Is Increasing

The progress of science was supposed to steadily remove our ignorance about the natural world. This has happened in many areas, and in the past few centuries, science has enormously enriched our understanding of the universe and the planet we live on. Given these marked successes of science, scientists have long had a role in advising policy-makers about science-relevant issues. The usual approach for science policy is that scientists provide expert advice to politicians, who then decide whether or not to proceed. Consider the case of whether or not it was feasible during the last World War to build a workable nuclear weapon. It was, as the people of Hiroshima and Nagasaki discovered to their cost. This simple ideal model does fit much expert scientific advice.

However, according to the late Alvin Weinberg [33], this simple model is increasingly found wanting. He was interested in exploring more deeply the interactions between scientific knowledge and politics, and saw many of these as examples of what he called ‘trans-science’: questions that are asked of science, but which science is unable to answer. He identified a number of areas that were indisputably the province of science, in that they are questions of fact about the nature of the physical world, not questions about values, and could be framed in the language of science.

One example he used is the calculations that have been done on the ‘probability of extremely improbable events’, such as catastrophic nuclear reactor accidents. He argued (before the Three Mile Island and Chernobyl accidents) that if probabilities of such events are very small, then we cannot provide answers based on established probabilities, as we do for frequent events like traffic collisions. As he puts it, we cannot build 1000 reactors then follow their operating histories for millions of reactor-years to get empirical data on accident frequencies similar to those for traffic collisions. It may be that the future will see more of these trans-science issues.

Jerome Ravetz [26] has taken these points further in his discussions on ‘Post-Normal Science’ (PNS). PNS deals with problems that combine two elements: not only are the decision stakes high, but so are the uncertainties regarding the science. In contrast, what he labels Applied Science has both low decision stakes and system uncertainty. The debate on global climate change fits PNS well, since the stakes are undoubtedly high, and there are varied opinions – even among the vast majority of climatologists who accept climate change – about such matters as the regional effects of climate change. Of course, when the stakes are high, uncertainty or doubt will also be ‘manufactured’. In an article entitled ‘How science makes environmental controversies worse’ Daniel Sarewitz [29] made a similar point. His conclusion was that ‘progress in addressing environmental controversies will need to come primarily from advances in the political process, rather than scientific research.’

Our general knowledge about the workings of the natural world continues to expand. But sometimes further research uncovers new uncertainties, with the result that in certain areas, scientists will not be able to offer the results necessary for traditional informed policy-making. As we show in Chapter 4, nowhere is this truer than for global environmental change. Why is this? An important reason is that we are in danger of approaching one or more ecological thresholds, or tipping points, as the global economy continues to expand [15, 16, 28, 30]. Tipping points arise because nature is dynamic, often non-linear, and above all, complex and inter-connected in its parts.

William Laurance [16] has discussed three ways in which tipping points can arise:

- runaway chain reactions;
- abrupt thresholds;
- positive feedbacks.

Epidemics are a form of chain reaction, in which one infected person infects several others, each of whom in turn infect several others, and so on, until it becomes a global health problem – a pandemic. The high mobility of modern societies help the rapid spread of diseases to distant locations, with jet air travel providing a most effective pathway.

Abrupt thresholds for ecological change occur in many ecosystems, and may result because the ecosystems can exist in alternative stable states. Gradual changes in temperature or some other variable may have little effect until a threshold is crossed, with an accompanying large shift in the ecosystem. The relatively sudden collapse of Saharan vegetation some 5500 years ago might be an example of such a shift [30]. Once the shift has occurred, it can be very hard to reverse.

Positive feedbacks can occur when two or more phenomena amplify each other. Rainforests such as the Amazon have an important feedback in that they generate much of their own rainfall. Transpiration from the forest vegetation returns it to the atmosphere where it again falls as rain [20]. Deforestation causes less water vapour to be recycled, so rainfall declines, the forest dries out, forest fires destroy even more forest, resulting in further rainfall declines. The end point could be the collapse of the Amazon [15]. As we will see in Chapter 2, such feedbacks are also common in the climate system.

The presence of such tipping points makes prediction about complex systems such as the global climate system very difficult, as shown by abrupt climate changes. The mathematical models that are used to predict climate change have a poor record in predicting the abrupt changes that are known from empirical data to have occurred in the past [24]. When we consider that multiple tipping points can occur in both the climate system and the various Earth ecosystems, and that there is a strong coupling between climate and the biosphere, the difficulties in making reliable forecasts given fixed changes in, for instance, atmospheric greenhouse gas levels, is evident. Yet it is too easy to ignore important effects that cannot be easily incorporated in numerical models, or to include only a dangerously simplified version of their effects. As Laurance puts it [15], we will have to learn to 'expect the unexpected'.

1.5 Equity Issues Are Central in a Finite World

In a world with plenty of room left for economic expansion, as was still the case at the beginning of the 20th century, equity issues were arguably less important than today. Population was then only a little over 1.5 billion, compared to nearly 7 billion today. World Gross Domestic Product (GDP) – defined as the total sum of goods and services the world's economies produce in a given year – was then less than 5 % of today's level in real (*i.e.*, inflation adjusted) terms [19]. The impact of the human population on resources and the world's ecosystems was also correspondingly lower. If there were sharp differences in per capita national GDP, at least further growth was possible for all nations – all could aspire to catch up with the leaders in the west.

Beddoe and his co-workers [4] point out that we are no longer in the 'empty world' of former times, but in a 'full world'. In such a world, the low-income nations can no longer aspire to the material living standard of the high-income countries, which today are mainly grouped in the OECD. (Furthermore, even the high-income countries may not be able to maintain present standards of material consumption for many decades more.) An important (and popular) way of avoiding this equity question is to argue, as we have discussed above, that technology can potentially overcome any limits that would seem to block endless expansion for all.

In today's world, inequality has many dimensions, based on such differences as race, gender, class, and religion. The one we are most concerned about in this book is international inequality, the idea that entire nations can be said to be poor or rich. In Chapter 10 we present data showing, for instance, that average electricity consumption per capita differs one thousand-fold between the highest- and lowest-use countries. Our emphasis is not meant to downplay other dimensions of inequality, or the inequality *within* nations, which is rising in many countries. There are millions of low-income households in the US, and many high-income households even in the nations of tropical Africa. Nevertheless, there are important differences at the national level: most low-income US households operate at least one private vehicle; those in tropical Africa do not. In most countries in Western Europe, with their extensive welfare provision, differences for low-income households compared with African countries are even more marked.

Anil Hira [8] has even proposed that it is now time for a form of global welfare system. This proposal could of course be argued on conventional ethical grounds, but Hira's point is that it may even be cheaper for the high-income countries that would presumably be required to finance it. When the huge costs of outlays for items such as ensuring 'security' of oil supplies, or attempts to stem illegal immigration or drug trafficking are considered, the idea does not seem so utopian. The industrial countries must win the cooperation of the presently low-income ones if we are to avert serious environmental damages, and a rudimentary global welfare system would greatly help here. The UN Millennium Development Goals, discussed in Chapter 10, also fit in with this proposal. Hira presents cost estimates to show that meeting these goals would be cheaper than continuing the present defensive expenditures discussed above.

1.6 Energy Is Vital for Economies

For nearly all of the many millennia that humans have lived on Earth, our energy sources have been renewable: firewood, food for human labour, forage for our domesticated animals. Small amounts of tidal, water and wind power were also harnessed. Only since the late 18th century have we used fossil fuels on a significant scale. These combustible fossil fuels have high energy densities compared with renewable sources, and so can be readily and economically moved to distant locations for use. The result is a world economy which is heavily reliant on the finite resource base of fossil fuels – the Carbon Civilisation.

Conventional economists have been slow to recognise energy as a factor in economic production, along with the traditional production factors of land, labour and capital. Yet a moment's thought shows that our modern factories, offices, homes, farms and transport vehicles cannot function without large inputs of useful energy. Without these inputs (and those of non-fuel minerals like metal ores) all production would cease. Given this dependency, it is little wonder, as we shall show in Chapter 10, that global use of primary energy (the energy content as produced, before conversion) correlates very highly with Gross National Product.

But energy is vital in a second way. Not only could future desired energy use be constrained by a shortage of energy sources that can give an adequate return rate on either energy or money invested, but the consequences of continued large-scale energy use, whether fossil or alternative energy sources, might produce serious environmental damage. As we discuss in Chapter 2, the combustion of fossil fuels is the major source of greenhouse gas emissions driving global climate change. Several researchers go further, and argue that our rising energy use, whether 'green' or not, is contributing to Earth's environmental deterioration, including biodiversity loss [20, 22]. If they are right, cutting our energy consumption from all sources may be just as important as moving away from fossil fuels. We could soon need to rely almost entirely on alternatives to fossil fuels, but use them much more sparingly – the Carbon Neutral Civilisation.

We are also building up energy debts that will have to be repaid in the future from our future energy production. For some energy sources this will be minor, like the energy costs for dismantling old wind turbines or coal power plants. Decommissioning large nuclear power plants, and safely and reliably sequestering high-level nuclear wastes for millennia will involve greater energy (and monetary) costs. But the greatest future energy costs will come from attempts to right past environmental damages, such as excess levels of atmospheric CO_2, particularly if we are left with CO_2 air capture and storage (see Chapter 8) as the only feasible way of drawing down CO_2 to safe levels. We will be effectively stealing energy from future generations.

1.7 Time to Make the Needed Changes Is Limited

Looking at the slow response of the world's nations to the challenges we face, one would think we had all the time in the world to overcome them. We have known since measurements began on Mauna Loa, Hawaii, in the late 1950s that CO_2 levels in the atmosphere were rapidly rising, yet so far our only binding response has been the Kyoto Protocol, which runs out in 2012. Even the minor reductions of