EARTHSCAN REFERENCE COLLECTIONS

RENEWABLE ENERGY

VOLUME I

RENEWABLE ENERGY ORIGINS AND FLOWS

EDITED BY

BENT SØRENSEN

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Renewable Energy

Volume I

List of Abbreviations

ABC	attitude-behaviour-external conditions
AC	air conditioning
agl	above ground level
APS	American Physical Society
asl	above sea level
AVHRR	Advanced Very High Resolution Radiometer
BUFR	binary universal format representation
CDAS	Climate Data Assimilation System
CDDB	climate diagnostics database
CDIP	Coastal Data Information Program
CEC	California Energy Commission
CHP	combined heat and power
CO_2-eq	CO_2 equivalent
COADS	Comprehensive Ocean and Atmospheric Data Set
COLA	Center for Ocean-Land-Atmosphere
COP	coefficient of performance
CPC	Climate Prediction Center (ex-CDC)
CQC	complex quality control
DMA	decision-making algorithm
DMSP	Defense Meteorological Satellite Program
DOE	Department of Energy
DoI	diffusion of innovations
DOS	density of states
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño–Southern Oscillation
ERL	Environmental Research Laboratories
FGGE	First GARP Global Experiment (1979)
ft	foot (0.3m)
FTP	file transfer protocol
gal	gallon
GARP	Global Atmospheric Research Program
GATE	GARP Atmospheric Tropical Experiment
GCM	general circulation model
GDAS	Global Data Assimilation System
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	greenhouse gas

GISST	Global Ice and Sea Surface Temperature data set
GLA	Goddard Laboratory for Atmospheres
GMS	Geostationary Meteorological Satellite
GPP	gross primary productivity
GrADS	Grid Analysis and Display System
GRIB	gridded binary format
GTS	Global Telecommunications System
HIRS	High-Resolution Infrared Sounder
hp	horsepower (745.7W)
hPa	hectopascal
in	inch (2.54cm)
IPCC	Intergovernmental Panel on Climate Change
JMA	Japan Meteorological Agency
KMA	Korean Meteorological Agency
kyBP	thousand years before present
lb	pound (0.454kg)
MEDS	Marine Environmental Data Service (Canada)
mil	one thousandth of an inch (25.4μm)
mph	miles per hour
MSU	microwave sounding unit
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
NCEP	National Centers for Environmental Prediction (formerly NMC)
NDBC	National Data Buoy Center
NESDIS	National Environmental Satellite, Data and Information Service
NH	northern hemisphere
NMC	National Meteorological Center (US Weather Bureau; now NCEP)
NOAA	National Oceanic and Atmospheric Administration
NORMIDCAL	north and mid-California
NPP	net primary production
NSF	National Science Foundation
NWS	National Weather Service
OA	optimal averaging
OGP	Office of Global Programs
OI	optimal interpolation
OIQC	OI-based Quality Control
OLR	outgoing long-wave radiation
PAR	photosynthetically active radiation
PCM	phase-change materials
ppm	parts per million
ppmv	parts per million by volume
PV	photovoltaic
QBO	quasi-biennial oscillation
QC	quality control
R&D	research and development

SH	southern hemisphere
SiB	Simple Biosphere Model
SIRS	Satellite Infrared Spectrometer
SMMR	Scanning Multichannel Microwave Radiometer
SOCAL	southern California
SRES	Special Report on Emissions Scenarios
SSI	spectral statistical interpolation (also known as a 3D VAR scheme)
SSM/I	Special Sounding Microwave/Imager
SST	sea surface temperature
SSU	stratospheric sounding unit
SWAN	simulating waves nearshore
T62	Triangular 62-waves truncation
TEM	terrestrial ecosystem model
TIROS	Television Infrared Observation Satellite
TOVS	TIROS-N Operational Vertical Sounder
TPB	theory of planned behaviour
TWERLE	Tropical Wind Energy Conversion and Reference Level Experiment
UKMO	United Kingdom Meteorological Office
USAF	United States Air Force
UV	ultraviolet
VBN	value-belief-norm
VTPR	Vertical Temperature and Pressure Radiometer
WA^{S}P	Wind Atlas Analysis and Application Program
WEC	wave energy converter
WEC	wind energy converter
WMO	World Meteorological Organization
WPTF	wave propagation transfer function
WTO	World Trade Organization
XBT	bathythermograph

Renewable Energy: Four-Volume Overview

Bent Sørensen

The target audience for this set of volumes is academia, businesses and smaller libraries in the private or public sector that may not wish to or cannot afford to subscribe to the full packages of journals offered by major scientific and technical publishers. This image of the potential user has led to a selection for this review collection of two types of publications in the renewable energy field: on the one hand, the fundamental papers that first defined a new technique or offered a theoretical analysis of given renewable energy systems. Occasionally there is a choice between including the absolute 'first' published mention of an option of interest, or rather to choose the first article giving a reasonably comprehensive understanding of the phenomenon. In some cases, space has allowed both to be included. On the other hand, there is included a representative selection of recent articles showing where the field and its sub-fields are now, in 2010. Several of these articles are not particularly 'fundamental' or original, and several similar papers could, as well, have been selected. Still, they show how we stand at present, and indirectly point to necessary work to be accomplished in the future.

One soon realizes that 2300 pages are not very many for the enormous field of science and technology publications dealing with renewable energy in one way or another. Therefore a strong selective process has been applied, based on the principles stated above of giving preference to the early papers defining methods and technologies, and to the late ones indicating the present state of the art. The losers in this choice of criterion for inclusion are the many papers between the first and the most recent ones that have added incremental insights, without which the field would not have reached its present state. Anyone interested in this continuous process of improvement will have to trace articles back starting from the references in the newest included papers.

Because the aim has been to provide a comprehensive view of every sub-field of renewable energy science and technology, a few overview or review papers have been included to fill any gaps between the specific articles, and to provide the 'red tread' of the development. Many overview and review papers are too lengthy to fit here; but in the few cases where I have not found a reasonably short overview, I have provided short overviews in the introductions heading each volume, taking key summarizing illustrations from the literature. I have decided not to cut articles covering several subjects into pieces to get at what I wanted. All journal articles are reproduced in full – only a few book excerpts have been cut out of larger chapters.

Some of the chapters are very technical and I hope that the introductions give some guidance to the content. Often the originators of new ideas express the findings in a more complicated form than can be found in later texts or textbooks, once the theory has been in use for some time. This implies that introductory sections of the newer articles included are often most informative, and so are, rather naturally, the review/overview articles included here. They also serve the purpose of defining words and concepts that I felt would be useful for an interdisciplinary readership. The pedagogical qualities sometimes absent from the original articles can, of course, be found in textbooks on renewable energy, such as my own (Sørensen, 2004).

When I embarked on collection of articles to include in these volumes, I sent kind thoughts to similar reprint volumes that I found very useful during my student years in the early 1960s. I particularly remember the (now extinct) publisher Benjamin that provided many inexpensive reprint volumes in the natural sciences. This underscores the fact that the publication business was much kinder to the needs of poor students then than they are now. Benjamin must have been able to obtain the permission to reprint fundamental articles from other publishers at nominal or no cost in order to be able to provide the collections at the prices they charged. Today, many publishers charge each other dearly for most reuse of material, which explains the price tag on the present volumes.

A few words should be added regarding the choice of chapter areas for these volumes. It is my intent to show that renewable energy science is a highly interdisciplinary enterprise, and that it is not consistent with the intentions of most contributors to the field to restrict themselves to merely the technical issues. There is a profound understanding that for renewable energy to constitute a new paradigm in energy systems, the shortcomings of previous energy solutions have to be avoided. These include neglect of environmental and social impacts, as well as other indirect economic factors (which the professional economists call 'externalities', meaning everything not valued in monetary terms and, in most cases, therefore simply omitted from the analysis). Many externalities can, indeed, be included in the analysis, either by assigning a monetary value by use of life-cycle analysis or by insisting that non-monetary issues be included in the decision-making processes with or without precise quantification.

In my view of the world, there are in relation to energy and environmental policy at least three interesting groups of citizens. There are the career politicians, characterized by having a time horizon of x years and dealing with issues primarily from the angle of impact on their re-election ('x' being four or whatever the frequency of elections, or of power struggles in societies without democratic elections). Then there are ordinary people, well aware of the finiteness of human lifespan and simply trying to get the best out of the less than five scores of years accorded to us. To most of these, concern for the success of offspring is part of the struggle for a good life; therefore, issues of sustainability do play a role, although often subordinate to that of own well-being. Finally, there is a select group of people addressing the long-term fate of humanity, despite being occasionally accused of weighing the distant future higher than the more immediate one. In order to serve food for all these three groups of invited guests, or rather their subgroups wanting to read about energy, the technical survey of renewable energy has been expanded to include the following topics.

History of renewable energy devices. Some of the renewable energy sources have been in use for quite a long time, and it is interesting to see how the technology has evolved, usually with substantial improvements in efficiency of energy conversion over time. The renewable energy sources are evidently very diverse, with biomass combustion requiring solutions quite different from those of wind propulsion of ships and windmills for grinding cereals, or solar energy capture by proper architecture.

Assessment of renewable energy resource basis. Not only is it important to know how much there is, for comparison with estimates of demand, but it is also important to assess how much renewable energy can be extracted in a sustainable mode, without influencing the delicate balance of energy distribution in the earth–atmosphere system. After all, it is precisely the negative impacts upon that system (the 'climate system') from currently used energy forms that have raised major concerns over the last decades. Fossil fuels are, of course, originally of renewable origin, based on biomass; but it has taken millions of years of geological processing to bring them to the form of coal, oil and natural gas that we are briefly enjoying today. A meticulous stroll through the methods of assessing solar, wind, hydro, geothermal, wave, tidal and biomass resources by employment of both satellite data and surface measurements has given us a fairly precise picture of the situation, although there is still room for improvement.

Energy demand. It is often said that energy demand is much more important in connection with renewable energy than with stored fossil energy forms because the renewable resources cannot be utilized in a mode with arbitrary changes in time and magnitude profiles of energy delivery. This is, of course, more valid for direct solar or wind energy than for hydropower or biofuels. However, in any case the cap on renewable energy sources associated with maximum levels of sustainable usage would imply that the energy users and particularly the end-user use energy as efficiently as possible – that is, as a minimum that efficiency improvements which are less costly than the energy provision they displace are made. This is not the case today where untapped efficiency measures that could reduce energy delivery by a factor of four to five are not carried out. The reason for this is perhaps that efficiency does not have a lobby as strong as the one that induces people to believe that it is smart and a sign of affluence and welfare to use more energy. Energy use is often considered a measure of development and affluence in line with personal income or gross economic national product. Choice of cars or leisure-time activities (forest hiking versus speedboat cruising) is, at present, strongly influenced by advertising rather than by energy analysis. These 'externalities' must be discussed if renewable energy is going to become more than just another display of marginal greenness, at the level of T-shirt slogans and the ecology week of the year. However, energy demand analysis is more than a technical optimization of efficiency. The question of how decisions involving energy use are made and how they depend upon social pressure, conventions and existing infrastructure is amenable to scientific enquiry.

After having dealt with aspects of such 'prerequisites', the chapters in Volumes II and III get around in the realm of technical solutions, ordered after the renewable energy types used: solar power and solar thermal applications, wind power, biofuels and a part termed 'other', comprising hydro, geothermal, wave, tidal and ocean temperature gradient utilization. Volume IV returns to issues often referred to as non-technical, but starts off with a semi-technical issue – that of integrating individual devices within energy supply systems.

Approaches to integration looks at the capacity credit that may be accorded to intermittent renewable energy sources. What is the fossil capacity that a wind turbine can replace? Forty years ago, many utility engineers would have said zero, arguing that there might be no wind at a time with concrete power demand. But this is false for three reasons. First, the probability that several wind turbines feeding into the same power grid, or into interconnected grids, produce power increases with the distance between installations, and is never zero for larger systems. Second, most systems have some amount of built-in storage, whether hydro reservoirs in regions where this is feasible or wood-fired power plants (at present, perhaps hydrogen-based in the future), and this improves the capacity credit of wind. Third, unplanned outage also occurs for fossil power plants, so a proper definition of capacity credit should not require 100 per cent availability, but some agreed maximum of non-producing hours in an average year. For other conventional ways of characterizing a power supply system (e.g. voltage or frequency stability), there are similar refinements of rationality to consider in modern systems, whether renewable based or not.

Socio-economic assessment. Both in appraisal of energy systems and other complex enterprises in society, the two tools of socio-economic analysis and assessment have proven very useful. This is not to say that they can always give quantitative judgements on one system versus another; but they can and do sharpen the awareness of the decision makers and interested public in focusing on the right issues in their social debates. Components of these methods (called life-cycle analysis and assessment if the indirect inputs and outputs to the system considered are included no matter at what point in time they occur) are risk analysis, environmental impact studies, health impact evaluations, direct and indirect economic issues (e.g. employment, foreign balance of payments), sustainability, compatibility with human rights guarantees, and many other subjects defined or waiting to be defined. The whole subject area is extremely rich and poses numerous interesting problems for scientists as well as concerned citizens. To quote one often discussed example, risk analysis will consider everything from small and frequent accidents with limited damage, to large and rare accidents with devastating consequences. The assessment following this particular analysis will have to discuss if the historic damage definition as a probability of occurrence multiplied by damage costs, say in Euros, is a proper one, or if large accidents that disrupt relief functions should not be assigned a larger weight. An example would be a Chernobyl-type nuclear accident taking place in the capital city of a nation, holding the site of government and the management of relief services and thus making these institutions further impaired in their timely handling of the situation and of any damage limitation efforts.

Scenario construction. Again, this is a tool that may greatly assist decision makers in selecting the best paths of policy making, as well as a tool that can give rise to more informed public debates on the virtues of alternative policies and alternative implementation approaches. The chapter exposes how scenarios are made, and underlines the need for scenarios to have a normative basis, as well as a sound technical appraisal of the consistency of the scenario components, and of the road proposed to lead to the implementation of a given scenario. This leaves to the final part issues of planning and policy.

Planning and policy comprise the practical use of scenarios and other input, based on both the (insisted-upon) need for medium- and long-range planning, but also recognizing that normative scenarios are, to a certain degree, idealized tools, and that deviations may have to be made in a practical political process of acceptable governance. Ingredients in this policy translation of scenario proposals is the concretization of the sustainability requirement, which – as Voltaire would mockingly have said – is the ruling principle in the 'best of all possible worlds'. In reality, it should be a ruling principle in the possibly best of all conceivable organizations of the global society.

It is important to be aware that among decision makers, scientists and the revered 'ordinary' citizens, there is a multitude of views regarding the role of renewable sources of energy in the overall supply system. At one end, proponents argue that sustainability means adopting a time horizon of thousands of years, in which case renewable solutions are the only ones that appear available. Once-through nuclear reactors and fossil energy use are transitional solutions incapable of offering lasting solutions; therefore, we may as well embark on the true long-range solution at once.

At the opposite end, you find the proponents for not planning anything: just introduce new sources when the old ones fail to deliver. Avoiding disruptions during such transitions can be secured by always developing all thinkable solutions and implementing them on a modest scale, so that they are ready to be scaled up if the need arises. The message is thus to maintain the broadest possible mix of energy options, in return for reduced risk of supply failure. One may inject that this is unlikely to constitute the cheapest solution.

In between, there are a number of additional positions. One would be to maintain careful planning, but to introduce the most sustainable solutions only when they are competitive relative to existing ones. This means wind power now because in many locations it is competitive relative to coal power, but photovoltaics only when the price of produced power is some five times lower than today, or alternatively when the price of coal power is five times higher. One possible fallacy of such arguments is that they rarely include the environmental and social costs of the solutions being compared, using the argument that these are anyway uncertain (just as the global warming debate has tended to delay decisions for the reason that scientific evidence is only 90 or 99 or 99.9 per cent certain). Arguing that energy policy should stand on as many legs as possible is, of course, characteristic of those favouring the least attractive solutions, such as nuclear.

Is nuclear energy really as bad as that? It has no CO_2 emissions, and the accidents are fairly rare; so what is the problem? There are several. The present light-water reactors are a spin-off from military technology and therefore have fundamental flaws in safety philosophy (because in military operations, a higher level of risk is accepted) and in environmental management (proposed technologies for nuclear waste handling need care to be taken for many hundred years, with methods and problems unknown, implying, essentially, that the problems are passed on to future generations; Sørensen, 1974). Nuclear technologies with such problems are no longer considered acceptable; and are unsustainable because nuclear fuels can only be considered available for a decent period of time if fast breeder technologies are used. These have been researched and given up, just as several alternative designs with lesser potential problems (inherently safe reactors, accelerator-breeders; see Sørensen, 2005). With respect to accidents, the problem is that while the probability of nuclear accidents (in countries with highly trained nuclear operators) is low, the possible consequences can reach levels where the consequences are globally unacceptable (Sørensen, 1979). Major radioactive fallout may not choose a fairly remote location (as in the Chernobyl case), but may, as mentioned, hit the administrative centre of a nation, rendering decision making and the establishment of countermeasures very difficult. The nuclear industry has not developed its technology for the last 30 years (as is evidenced by the refusal to take part in the accelerator-breeder concept, even with funding from the European Commission; see Sørensen, 2005).

The second objection to renewable energy: we have coal enough to cover demand for several hundred years, so we just remove the CO_2 from coal or from coal combustion and thus make coal technologies acceptable. Why bother about other solutions? The reason that there is still something to bother about is that while it may become technically and economically feasible to remove CO_2 from coal, this does not relieve the problems of coal mining and dust, and, more importantly, may just create another waste problem. The problem is that CO_2 is not a small nuisance than can be removed as SO_2 or NO_x emissions from power plants. Burning coal means that for each 12kg of coal combusted, you add two times 16kg of oxygen, thus having 44kg of waste to get rid of. The plan is to leave the waste, typically in the form of carbonates, in depleted mines and gas fields, and when these are filled up, then to dump the waste in oceans, hoping that the carbonates will sink to the bottom and stay there. This gigantic experiment may or may not succeed; but it will take a century or more of trials to determine if the scheme is acceptable, so as a solution to the present greenhouse gas problem, 'clean coal' is simply not ready and will not be so in time to have any mitigating effect. Because of the bulkiness of the by-product, using depleted wells for storage will only last us a few years, not enough for clean coal to have any significant mitigating effects on negative climate impacts.

To complete the list of arguments voiced in favour of continued reliance on fossil fuels, one sometimes hears reference to untapped resources in oil-containing tar sands and shales (Canada and Venezuela) or unconventional natural gas fields. As for the low-quality oil deposits, there are, at present, no environmentally acceptable methods for exploiting them, and the unconventional gas deposits are part of an unproven geological theory and have so far never been seen.

Allow me now to generalize the remark made on the attitudes held by different individuals regarding the problems of environmental degradation, overpopulation, economic collapse and various disasters hitting us. I see two basic stances (compare with Kuemmel et al, 1997):

- If the consequences of an action or a policy cannot be stated with reasonable certainty, it is better to forgo that option until more light is shed on the risks involved. As regards already ongoing activities, this also applies once the possibility of negative impacts is drawn to our attention.
- Progress has always involved jumping into new avenues, even if their consequences were not known beforehand. In most cases, solutions have come forward along the way, when problems arose. They may even be cheaper to deal with then, as our understanding and technological level may have improved.

Of these positions held by political actors, as well as by citizens trying to form an opinion of the matter at hand, the first one has recently (by the European Union) been termed the *precautionary principle.* In political debates, it has been around for a long time through what is usually described as *concerned citizens.* The second position is the one followed by most past national and global policies, such as those linked to ideas of *liberalism* and not putting obstacles to the *market forces.* Enterprises are allowed to embark on paths that may present risk to society, and only when negative impacts surface, will the political system try to regulate or legislate the problems away. The precautionary principle, on the other hand, has been used very rarely. One notable example is the curbing of emissions of stratospheric ozone-depleting gases, politically decided before the ozone depletion had become definitely established. In relation to additional greenhouse warming by fossil emissions, a similar precautionary limitation has not found political support.

Seen from a humanistic angle, the debate between these two points of view has been very beneficial in bringing the issues onto the table and ensuring at least that discussion does take place. One argument would be that without the 'let us do it despite the risk' attitude, the technology used by human society would not have developed as rapidly as it has during the last centuries. Another line of argument is that without the discussions raised by the 'cautious' people, things would have got much more out of hand than is actually the case.

An interesting question is whether we will be able to enjoy such balancing in the future, as the open debate of political issues is rapidly disappearing even in the formerly most democratic nations because of the commercialization of news media and the disappearance of traditional discussion forums. Grassroots action has been replaced by publicity stunts, such as the ones involving small rebel boats disturbing big establishment ships with their Greenpeace banners. Three thousand television stations worldwide broadcast the same pictures of the boats, but none of them have time to reveal details of the issues behind the action.

One gratifying development has been the increased acceptance of renewable energy in societies across the world. During the 1970s, you could hear politicians and electric utility managers refer to renewable energy as 'supplementary energy', deeply convinced that renewable energy solutions could never amount to anything substantial. This attitude gradually evaporated, but was replaced by statements such as 'In principle, yes; but renewable energy solutions are so far from economic viability, that they cannot be part of energy policy for many years to come.' The fallacy of sweeping economic appraisals is that they are most often missing the qualification of what exactly is being compared. Are we talking about consumer prices or are we talking about national economy? Even when it becomes scarce, oil essentially costs nothing to get out of the ground (in the Middle East), so to compare raw prices has no clear meaning. The market price of oil is totally determined by political decisions of Organization of the Petroleum Exporting Countries (OPEC) countries regarding how much oil is going to be extracted per year, relative to demand estimates. To this comes taxation in consumer countries, possibly reflecting, in part, the environmental cost of using fossil fuels, but currently varying greatly between countries (about twice as high in the European Union as in North America).

These difficulties do not mean that cost is unimportant; but they should warn against comparing renewable energy cost with the pure extraction cost of fossil fuels. A comprehensive appraisal is required, including environmental and social costs, and comparing average prices over the lifetime of the equipment rather than instantaneously. Averages of fossil energy consumer costs over the next 30 years are likely to be higher than current prices, while the cost of most renewable energy systems is dominated by the initial capital cost; they are therefore insensitive to fuel shortages, supply problems and political interference throughout their operational life. Once installed, the lifetime energy cost is known to within the uncertainty of equipment maintenance costs. It is upon this background that statements such as 'wind power is now competitive to coal' become meaningful. Extraction of coal has different costs in different parts of the world, depending upon the nature of the deposit (open mine or underground) and upon the environmental and safety precautions used in the extraction process. Wind energy, on the other hand, depends upon the wind regime at the location of the wind turbine or wind farms, with offshore sites typically having the highest power per swept area, but also higher construction and maintenance costs due to foundation work at sea and marine access (although the latter is less important for large offshore wind farms). On land, wind conditions vary substantially depending upon wind regimes (being best under the temperate atmospheric jet streams) and topology (roughness of terrain), and only the better locations can compete economically with typical offshore installations.

Following up on the acceptance of renewable energy solutions, political leaders and energy planners currently have learned always to include the renewable energy options in public statements, even if they may fundamentally be under the influence of fossil or nuclear lobbies in their actual decisions. This is a characteristic trait of current behaviour by politicians, in accordance with the advice they get from spin doctors: always recognize the socially and environmentally best solutions in the rhetoric exposition, even if it is already decided to postpone concrete action to after the end of the political term of the person speaking.

This pattern of the political decision-making strategy has recently been very plainly exposed in the debate over global warming. Here, it has become clear that no one wishes to commit themselves unless all other leaders have already done so. This is true whether we are talking about traditionally affluent countries responsible for the current accumulated greenhouse gases in the atmosphere, or about the emerging economies that due to extreme population sizes will more than double greenhouse gas loading over a very short time, if they continue to rely on fossil energy solutions. It is not even a question of whether or not there is sufficient fossil energy to satisfy the growth economies (probably there is not), but simply a question of whether the remaining fossil CO_2 will be released over a few decades rather than being retained and reserved for non-energy purposes.

Not surprisingly, the leaders of both new and long-term fossil energy-based countries are beginning to talk about whether adaptation to a warmer climate will not be cheaper than the renewable energy transition needed to avoid further emissions. The voices from drowning Pacific island states are clearly not considered important, and Siberian observers welcome the possibility of a warmer climate. In all cases, there is a fundamental unwillingness to listen to the scientific observations.

Global warming will not be a smooth process of raising the temperature at each location by a few degrees. There will be major disruptions of the climate system, probably including more frequent extreme events and impacts that have not even been identified yet. At worst, there could be a transition to an entirely different climate regime. It is not even certain that this would be a warmer climate. The initial warming could trigger a transition to a more stable climate system, which most likely would be one with extended glaciation (Sørensen, 2004). We know quite a lot about the climate system, but we do not know enough to rule out such devastating scenarios. This is also why we should refrain from tampering with the climate system, one way or another. It has seriously been suggested that warming by greenhouse gas emissions could be countered by injection of light-absorbing dust into the atmosphere (to induce cooling), or if cooling gets too much, then to spread soot over the ice-covered parts of the earth. These 'engineering solutions' are based on a grossly simplified understanding of the climate issue: the differential warming or cooling of the atmosphere by the three anthropogenic interference methods mentioned is highly dependent upon geographical location and circulation through atmosphere or oceans, and the suggested cancellation of warming and cooling may be replaced by an enhanced oscillatory behaviour triggering major disasters, such as the mentioned movement of the earth–atmosphere system to a more stable 'White Earth' energy equilibrium.

These general remarks of course represent my personal interpretation of the energy and environmental sciences as I see them. I hope that they can serve as points of departure for further qualified debates of the issues, between the two types of humans sketched above: those who are willing to take risks in the hope of rapidly moving the human society to new heights of technology and affluence, and those who want to exert caution and not embark on new roads before the possible adverse consequences have been reasonably well explored and discussed in a cost–benefit context. Such debates must also ask the question of whether sustainable solutions for energy use or other basic manifestations of society can be forthcoming without major modifications of the economic paradigms currently in vogue. Increased magnitudes and frequencies of financial crashes may provide signals more loud and convincing than increased magnitudes and frequencies of climate excursions.

Back to the choice of material: I thought of modestly omitting papers to which I have myself contributed, but finally decided that they should appear in those cases where they are the earliest to describe a certain technology or theoretical method. Because my work has been prolific, you will find such articles in several sections. If there are earlier contributions that have escaped my attention, I apologize. This also applies more generally to all the selections of fundamental work. The issue is that to be considered, a paper must either have reached my desk at some point in time, or be in the available electronic compilations on the web, or be in libraries I have access to. In the latter case, I have enjoyed a fantastic enthusiasm for helping me from the Roskilde University Library, which both has an outstanding collection of books and journals in the renewable energy field, and also great skill in digging up and loaning publications from other libraries, even books and journal articles absent from most databases. Still, I am, of course, solely responsible for any important contribution that may have been overlooked.

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