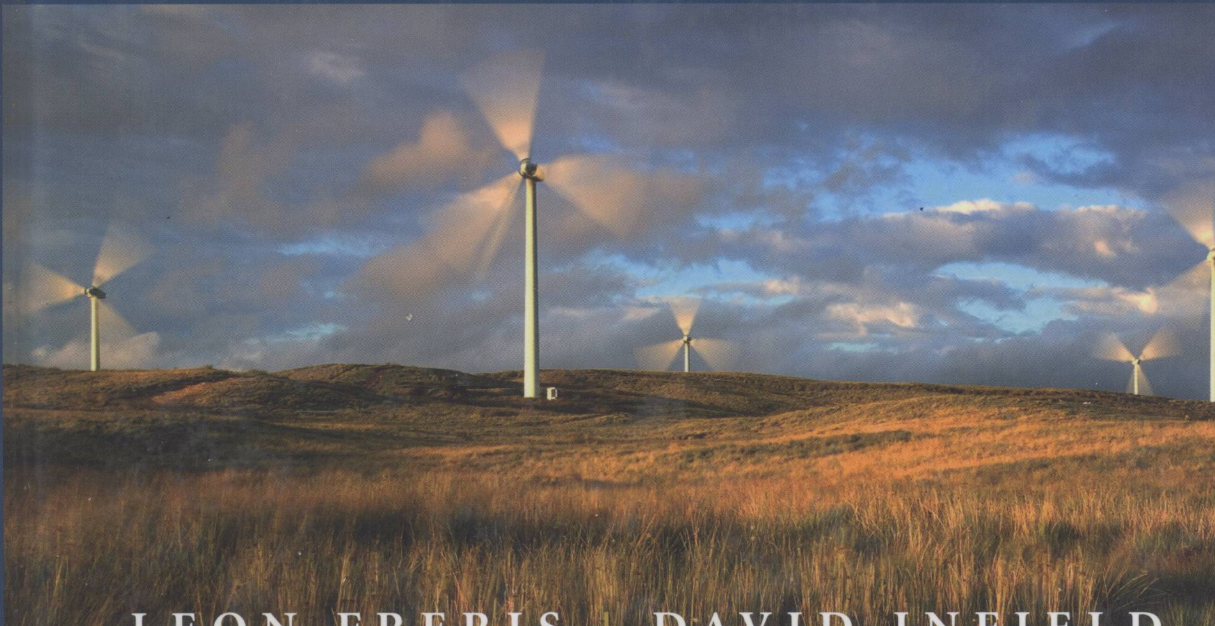
RENEWABLE ENERGY IN POWER SYSTEMS



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Renewable Energy in Power Systems

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Renewable Energy in Power Systems

Foreword

By Jonathon Porritt

You can read the current state of awareness about climate change any which way you want. You can continue to ignore (or even deny) the overwhelming scientific consensus that has gradually emerged over the last few years. You can get totally lost in the intricacies of climate policy and the political controversies about who is doing or not doing what. But 20 years into the debate about climate change, one thing is overwhelmingly clear: the future of human kind depends in large measure on the speed with which we can massively expand the contribution of renewable energy to our overall energy needs.

That the world is now on a collision course is not seriously disputed. The International Energy Agency constantly reminds people that overall energy use will at least double by 2030 and that most of that expansion will be powered by growth in fossil fuels. On the other hand, climate scientists now tell us that we will need to reduce emissions of CO_2 and other greenhouse gases by at least 60% by 2050. It doesn't remotely begin to add up.

Which makes it hard to understand why so many people are still so crabby and cautious in defining the role for renewables. All their projections are based on 'business-as-usual' economic models – as if any of those are going to be terribly relevant for very much longer.

Indeed, this is the one area where I believe it really is legitimate to talk about 'going onto a war footing' in combating the threat of runaway climate change. And that may not be so far off. For instance, if the price of oil stays at or around \$100 a barrel, and the price of a tonne of CO_2 rises rapidly over the next 3 or 4 years, much of the rubbish still being talked about renewables being 'uneconomic' will just wither away.

That, however, is only the start of it. I have been giving lectures to CREST students for the best part of 10 years, and have learnt during that time that even if the technologies themselves are rapidly improving, and even if the political and economic context could be completely transformed, as I believe is now possible, the real challenge lies in accommodating high penetrations of these new technologies in the electricity supply system, by adapting existing networks and/or the creation of new infrastructure for transmission and distribution. That's where much of the innovation (and huge amounts of new investment) will be needed over the next few years.

And that is one of the greatest strengths of this hugely informative new book: connecting up all the dots so that a clear and utterly convincing picture emerges. And that means taking proper account of the critical importance of energy efficiency (so often ignored in treatments of renewable energy), energy security, and the kind of governance systems which will be needed to drive forward so very different an energy economy.

This is complex, challenging territory, for which reliable and very experienced guides are strongly recommended!

Jonathon Porritt is Founder Director of Forum for the Future www.forumforthefuture.org.uk, Chairman of the UK Sustainable Development Commission www.sd-commission.org.uk, and author of *Capitalism as if the World Matters; Revised Edition 2007* (in paperback), Earthscan – available through 'Forum for the Future' website.

Preface

There is worldwide agreement on the need to reduce greenhouse gas emissions, and different policies are evolving both internationally and locally to achieve this. On 10 January 2007 the EU Commission announced an Energy Package which was endorsed by the European Council. The objectives are that by 2020 EU greenhouse gases are to be reduced by 30 % if a global agreement is arrived at or by 20 % unilaterally. One of the vital components in the achievement of this goal is the intention to provide a 20 % share of energy from renewable energy (RE) sources in the overall EU energy mix.

At present, wind power is the leading source of new renewable energy. World wind power capacity has been growing rapidly at an average cumulative rate of 30 % over the last ten years. About 20 GW of new capacity was installed in 2007 bringing the world total in that year to 94 GW. This annual investment represents around 25 billion euros by an industry that employs 200 000 people and supplies the electricity needs of 25 million households. This considerable expansion has attracted investment from major manufacturing companies such as General Electric, Siemens, ABB and Shell as well as numerous electricity utilities, notably E.ON and Scottish Power. The future of wind power over the next two decades is bright indeed.

Generation of electricity from the sun can be achieved directly using photovoltaic (PV) cells or through solar concentration to raise steam and drive conventional turbines. Over the last few years considerable progress has been made in the reduction of the cost of PV generated electricity, with 2006 seeing the total value of installed capacity reaching 15 billion euros and with cell global production in that year approaching 2.5 GW. It is expected that further technology improvement and production cost reduction over the next decade will result in wide scale competitive generation from this source.

Marine energy is an exciting, but less well developed technology. Tidal barrages, tidal stream turbines and wave energy devices are all in the experimental and pre-commercial stage but are expected to make a significant contribution by around 2015. Geothermal energy is now established in countries like Iceland with a significant accessible resource, and as the technology develops could be taken up more widely. Last but not least there are bioenergy and biofuels, important because they offer many of the advantages of fossil fuels, in particular being easily stored. Not surprisingly they are receiving much attention from policy makers and researchers both in the EU and North America.

Most of this renewable energy will be converted into electricity. The renewable energy resource will be geographically highly distributed, and being mostly dependent on changing weather and climate cannot be directly controlled in the way fossil fuelled generation is. Electrical power networks were designed to operate from electricity generated in a few large power stations fuelled by coal, gas or uranium, fuels readily available on the international market and to varying degrees controllable. Significantly increasing the input from renewable energy sources requires a revision of the way power systems are designed and operated in order to accommodate these variable sources better. This book is an introduction to this important topic.

The material in this book is largely based on a Master's course module taught for over ten years at the Centre for Renewable Energy Systems Technology (CREST) at Loughborough University. The course as a whole was designed to provide general technical education in all major electricity generating renewable energy sources and their integration in electrical networks. Students taking this course normally have first degrees in numerate topics ranging from Physics or Engineering to Environmental Science. The course modules are therefore designed for students who, although they may be very knowledgeable in their speciality, will only have elementary knowledge of other topics.

Likewise, this book assumes no previous knowledge in power systems engineering and guides the reader through the basic understanding of how a power system is put together and the way in which it ensures that the consumer demand is met from instant to instant. The characteristics of traditional and renewable energy (RE) resources are described with special reference to the variability of the latter and the way this impacts on their utility. These resources are available in a form that either has to be converted into electricity and/or their electrical output has to be conditioned before it can be fed into the grid. The book covers these aspects and stresses the importance of power electronic technology in the process of power conditioning. The power flows in an electricity network have to be appropriately controlled and the book addresses the way this is achieved when these new sources are integrated. The economics of renewable sources will determine their take-up by the market, and this issue is also addressed, and in some detail. Finally, an eye is cast on the future development of RE technologies and the way that power systems may evolve to accommodate them. An Appendix is available for readers who require a more mathematical coverage of the way electricity is generated, transported and distributed to consumers.

Acknowledgements

This book contains input from other CREST staff besides the main authors. In particular, Dr Murray Thomson has provided much of the power electronics material of Chapter 4 and most of the content of Chapters 5 and 6. His comments and criticisms during the initial development of the book have been invaluable. In addition, Dr Simon Watson contributed most of the material found in Chapter 7. The material on dynamic demand control in Chapter 3 was the subject of a CREST Master's dissertation by J. A. Short. Finally, thanks are due to Dr Graham Sinden who gave us permission to use several diagrams from his recent work including some unpublished ones from his doctorate thesis and to Mr David Milborrow for permitting us to use in Chapter 7 several of his tables and figures.

We are also grateful for the support of the Wiley staff in Chichester who have guided us in the process of preparing the manuscript for publication.

Last, but certainly not least, we would like to dedicate this book to our respective partners Delphine Freris and Marion Peach who have had to put up with us slaving over the text in our spare time, rather than participating more fully in family life.

Leon Freris and David Infield

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Energy and Electricity

1.1 The World Energy Scene

1.1.1 History

Energy demand in the pre-industrial world was provided mostly by man and animal power and to a limited extent from the burning of wood for heating, cooking and smelting of metals. The discovery of abundant coal, and the concurrent technological advances in its use, propelled the industrial revolution. Steam engines, mechanized production and improved transportation, all fuelled directly by coal, rapidly followed. The inter-war years saw the rise of oil exploration and use. Access to this critical fuel became a key issue during the Second World War. Post-war industrial expansion and prosperity was increasingly driven by oil, as was the massive growth in private car use. More recently a new phase of economic growth has been underpinned to a great extent by natural gas.

A substantial proportion of coal and gas production is used to generate electricity, which has been widely available now for over a century. Electricity is a premium form of energy due to its flexibility and ease of distribution. Demand worldwide is growing, driven by the explosion in consumer electronics, the associated industrial activity and the widening of access to consumers in the developing world.

1.1.2 World Energy Consumption

The present global yearly *primary energy*[1] consumption is, in round figures, about 500 EJ.[2] This is equivalent to about 1.4×10^{17} Wh or 140 000 TWh. Dividing this figure by the number of hours in the year gives 16 TW or 16 000 GW as the average rate of world primary power

[1] Primary energy is the gross energy before its transformation into other more useful forms like electricity.

[2] The unit of energy in the SI system is the joule, denoted by J. Multiples of joule are kJ, MJ, GJ, TJ (T for tera denoting 10^{12}) and EJ (E for Exa denoting 10^{18}); the unit of power is the Watt (W) and represents the rate of work in joules per second. Electrical energy is usually charged in watt-hours (Wh) or kWh. Joules can be converted into Wh through division by 3600.

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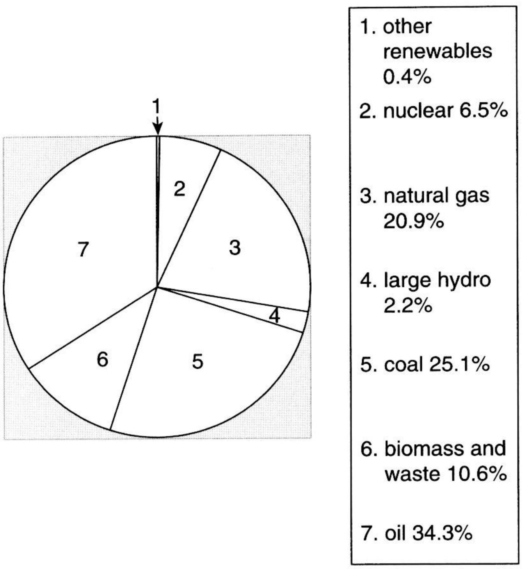

Figure 1.1 Percentage contribution to world primary energy

consumption. The pie chart in Figure 1.1 shows the percentage contribution to world primary energy from the different energy sources according to data taken from the International Energy Agency (IEA) Key World Energy Statistics, 2006.

The world demand for oil and gas is increasing significantly each year. The major part of this increase is currently taken up by India and China where industrialization and the demand for consumer products is escalating at an unprecedented pace. The world consumption in 2006 increased by more than twice Britain's total annual energy use and is the largest global yearly increase ever recorded. China alone accounted for roughly 40% of this increase. The IEA forecasts that by 2030 demand for energy will be some 60% more than it is now.

1.1.3 Finite Resources

It is extremely difficult to determine precise figures on the ultimate availability of fossil fuels. According to the major oil and gas companies, still significant new resources of oil are being developed, or remain to be discovered. A safe assessment is that there is enough oil from traditional sources to provide for the present demand for 30 years. The latest figures for global gas reserves indicate that these are approximately 50% higher than oil at some 60 years of current demand, and gas is far less explored than oil so there is probably more to be found. There are, however, unconventional hydrocarbon resources such as heavy oil and bitumen, oil shale, shale gas and coal bed methane – whose total global reserves have been assessed very roughly to be three times the size of conventional oil and gas resources. These are more expensive to extract but may become exploitable as the price of fossil fuels increases due to the steady depletion of the more easily accessible reserves. Fortunately for fossil fuel dependent economies, coal reserves are considered to be many times those of oil and gas and could