

Sustainable Energy — without the hot air

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This Cover-sheet must not appear in the printed book.

high-resolution edition.

The quest for safe, secure and sustainable energy poses one of the most critical challenges of our age. But how much energy do we need, and can we get it all from renewable sources? David MacKay sets out to find the answer through a forensic numerical analysis of what we use and what we can produce. His conclusions starkly reveal the difficult choices that must urgently be taken and readers interested in how we will power our society in the future will find this an illuminating read. For anyone with influence on energy policy, whether in government, business or a campaign group, this book should be compulsory reading. This is a technically precise and readable account of the challenges ahead. It will be a core reference on my shelf for many years to come.

Tony Juniper
Former Executive Director, Friends of the Earth

Engagingly written, packed with useful information, and refreshingly factual.

Peter Ainsworth MP
Shadow Secretary of State
for Environment, Food, and Rural Affairs

David MacKay sets out to dispel the half truths, distortions and nonsense which make up so much of what we're told about climate change and our energy needs. This book is readable, accessible and thorough. He cuts through unfounded opinion and takes us to facts and figures which speak for themselves. It's a useful guide for both layman and expert. I heartily recommend it.

Graham Stuart MP

This remarkable book from an expert in the energy field sets out, with enormous clarity and objectivity, the various alternative low-carbon pathways that are open to us. Policy makers, researchers, private sector decision makers, and NGOs, all will benefit from these words of wisdom.

Sir David King FRS
Chief Scientific Adviser
to the UK Government, 2000–08

Started reading your book yesterday. Took the day off work today so that I could continue reading it. It is a fabulous, witty, no-nonsense, valuable piece of work, and I am busy sending it to everyone I know.

Matthew Sullivan
Carbon Advice Group Plc

This is a really valuable contribution to the continuing discussion of energy policy. The author uses a potent mixture of arithmetic and common sense to dispel some myths and slay some sacred cows. The book is an essential reference work for anyone with an interest in energy who really wants to understand the numbers.

Lord Oxburgh KBE FRS
Former Chairman, Royal Dutch Shell

This is a brilliant book that is both a racy read and hugely informative.

Prof David Newbery FBA

So much uninformed rhetoric is thrown about on climate change and energy systems that there is an urgent need for an authoritative study setting out just what can and cannot realistically be done to achieve sustainable energy. This hugely important book fills that gap both technically and highly readably. It should be a 'must read' not only at home and in industry, but on each Government Minister's desk, and not just in the UK.

Michael Meacher MP
Former Environment Minister

David MacKay's book sets the standard for all future debate on energy policy and climate change. His dedication to the facts and to rational argument is admirable in a field beset by propaganda and wishful thinking on all sides, and even if his conclusions eventually date, as all scientific work must, his approach will live on for a very long time.

David Howarth MP

The choices that we make (or fail to make) in the coming years about sustainable energy will determine what world future generations will inherit. How do we arrive at rational decisions? In his book, David MacKay does not tell us what to choose but how to. Basic arithmetic is all it takes to distinguish between viable strategies and pipedreams. Anybody who feels responsible for the future of our society should read this book.

Prof Daan Frenkel FRS

A total delight to read. Extraordinarily clear and engaging.

Chris Goodall
Author of *Ten Technologies to Save the Planet*

continued on next page

David MacKay's book is an intellectually satisfying, refreshing contribution to really understanding the complex issues of energy supply and use. It debunks the emotional clap-trap which passes for energy policy and puts real numbers into the equations. It should be read by everyone, especially politicians.

Prof Ian Fells CBE
Founder chairman of NaREC,
the New and Renewable Energy Centre

Preventing climate chaos will require sophisticated and well informed social, economic and technological choices. Economic and social 'laws' are not immutable – politicians can and should reshape economics to deliver renewable energy and lead cultural change to save energy – but MacKay reminds us that even they “canna change the laws of physics”! MacKay's book alone doesn't have all the answers, but it provides a solid foundation to help us make well-informed choices, as individuals and more importantly as societies.

Duncan McLaren
Chief Executive, Friends of the Earth Scotland

MacKay brings a welcome dose of common sense into the discussion of energy sources and use. Fresh air replacing hot air.

Prof Mike Ashby FRS
Author of *Materials and the environment*

By focusing on the metrics of energy consumption and production, in addition to the aspiration we all share for viable renewable energy, David MacKay's book provides a welcome addition to the energy literature. “Sustainable Energy – without the hot air” is a vast undertaking that provides both a practical guide and a reference manual. Perhaps ironically for a book on sustainable energy, MacKay's account of the numbers illustrates just how challenging replacing fossil fuel will be, and why both energy conservation and new energy technology are necessary.

Darran Messem
Vice President Fuel Development
Royal Dutch Shell

This is a must read for anyone who wants to help heal our world.

Carol Atkinson
Chief Executive of BRE Global

At last a book that comprehensively reveals the true facts about sustainable energy in a form that is both highly readable and entertaining. A “must read” for all those who have a part to play in addressing our climate crisis.

Robert Sansom
Director of Strategy and Sustainable Development
EDF Energy

So much has been written about meeting future energy needs that it hardly seems possible to add anything useful, but David MacKay has managed it. His new book is a delight to read and will appeal especially to practical people who want to understand what is important in energy and what is not. Like Lord Kelvin before him, Professor MacKay realises that in many fields, and certainly in energy, unless you can quantify something you can never properly understand it. As a result, his fascinating book is also a mine of quantitative information for those of us who sometimes talk to our friends about how we supply and use energy, now and in the future.

Dr Derek Pooley CBE
Former Chief Scientist at the Department of Energy,
Chief Executive of the UK Atomic Energy Authority
and Member of the European Union Advisory Group
on Energy

The need to reduce our dependence on fossil fuels and to find sustainable sources of energy is desperate. But much of the discussion has not been based on data on how energy is consumed and how it is produced. This book fills that need in an accessible form, and a copy should be in every household.

Prof Robert Hinde CBE FRS FBA
Executive Committee, Pugwash UK

What a lovely book . . . I feel better in a way that a cancer patient might feel after reading something in-depth about his disease.

Richard Procter
Beautifully clear and amazingly readable.

Prof Willy Brown CBE
I took it to the loo and almost didn't come out again.

Matthew Moss

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David JC MacKay

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to those who will not have the benefit
of two billion years' accumulated energy reserves

Preface

What's this book about?

I'm concerned about cutting UK emissions of twaddle – twaddle about sustainable energy. Everyone says getting off fossil fuels is important, and we're all encouraged to "make a difference," but many of the things that allegedly make a difference don't add up.

Twaddle emissions are high at the moment because people get emotional (for example about wind farms or nuclear power) and no-one talks about numbers. Or if they do mention numbers, they select them to sound big, to make an impression, and to score points in arguments, rather than to aid thoughtful discussion.

This is a straight-talking book about the numbers. The aim is to guide the reader around the claptrap to actions that really make a difference and to policies that add up.

This is a free book

I didn't write this book to make money. I wrote it because sustainable energy is important. If you would like to have the book for free for your own use, please help yourself: it's on the internet at www.withouthotair.com.

This is a free book in a second sense: you are free to use *all* the material in this book, *except* for the cartoons and the photos with a named photographer, under the Creative Commons Attribution-Non-Commercial-Share-Alike 2.0 UK: England & Wales Licence. (The cartoons and photos are excepted because the authors have generally given me permission only to include their work, *not* to share it under a Creative Commons license.) You are especially welcome to use my materials for educational purposes. My website includes separate high-quality files for each of the figures in the book.

How to operate this book

Some chapters begin with a quotation. Please don't assume that my quoting someone means that I agree with them; think of these quotes as provocations, as hypotheses to be critically assessed.

Many of the early chapters (numbered 1, 2, 3, ...) have longer technical chapters (A, B, C, ...) associated with them. These technical chapters start on page 254.

At the end of each chapter are further notes and pointers to sources and references. I find footnote marks distracting if they litter the main text of the book, so the book has no footnote marks. If you love footnote marks, you can usefully add them – almost every substantive assertion in the text will have an associated note at the end of its chapter giving sources or further information.

The text also contains pointers to web resources. When a web-pointer is monstrously long, I've used the TinyURL service, and put the tiny code in the text like this – [yh8xse] – and the full pointer at the end of the book on page 344. yh8xse is a shorthand for a tiny URL, in this case: <http://tinyurl.com/yh8xse>. A complete list of all the URLs in this book is provided at <http://tinyurl.com/yh8xse>.

I welcome feedback and corrections. I am aware that I sometimes make booboos, and in earlier drafts of this book some of my numbers were off by a factor of two. While I hope that the errors that remain are smaller than that, I expect to further update some of the numbers in this book as I continue to learn about sustainable energy.

How to cite this book:

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