

# Sustainable Energy — without the hot air

*Version 3.5.2. November 3, 2008.*

*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 "cannot 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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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](http://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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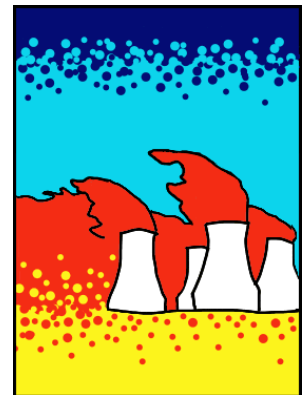
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## *Part I*

# Numbers, not adjectives



# 1 Motivations

*We live at a time when emotions and feelings count more than truth,  
and there is a vast ignorance of science.*

James Lovelock

I recently read two books, one by a physicist, and one by an economist. In *Out of Gas*, Caltech physicist David Goodstein describes an impending energy crisis brought on by The End of the Age of Oil. This crisis is coming soon, he predicts: the crisis will bite, not when the last drop of oil is extracted, but when oil extraction can't meet demand – perhaps as soon as 2015 or 2025. Moreover, even if we magically switched all our energy-guzzling to nuclear power right away, Goodstein says, the oil crisis would simply be replaced by a *nuclear* crisis in just twenty years or so, as uranium reserves also became depleted.

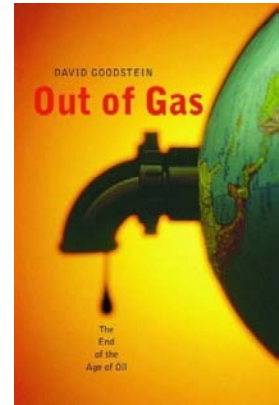
In *The Skeptical Environmentalist*, Bjørn Lomborg paints a completely different picture. “Everything is fine.” Indeed, “everything is getting better.” Furthermore, “we are not headed for a major energy crisis,” and “there is plenty of energy.”

How could two smart people come to such different conclusions? I had to get to the bottom of this.

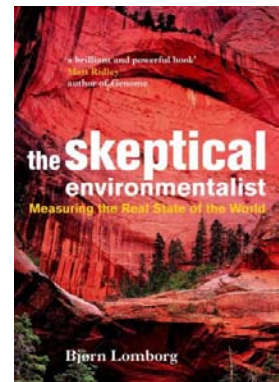
Energy made it into the British news in 2006. Kindled by tidings of great climate change and a tripling in the price of natural gas in just six years, the flames of debate are raging. How should Britain handle its energy needs? And how should the world?

“Wind or nuclear?”, for example. Greater polarization of views among smart people is hard to imagine. During a discussion of the proposed expansion of nuclear power, Michael Meacher, former environment minister, said “if we’re going to cut greenhouse gases by 60% . . . by 2050 there is no other possible way of doing that except through renewables;” Sir Bernard Ingham, former civil servant, speaking in favour of nuclear expansion, said “anybody who is relying upon renewables to fill the [energy] gap is living in an utter dream world and is, in my view, an enemy of the people.”

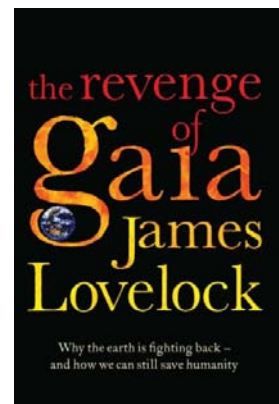
Similar disagreement can be heard within the ecological movement. All agree that *something* must be done urgently, but *what*? Jonathan Porritt, chair of the Sustainable Development Commission, writes: “there is no justification for bringing forward plans for a new nuclear power programme at this time, and . . . any such proposal would be incompatible with [the Government’s] sustainable development strategy;” and “a non-nuclear strategy could and should be sufficient to deliver all the carbon savings we shall need up to 2050 and beyond, and to ensure secure access to reliable sources of energy.” In contrast, environmentalist James Lovelock writes in his book, *The Revenge of Gaia*: “Now is much too late to establish sustainable development.” In his view, power from nuclear fission, while



David Goodstein’s *Out of Gas* (2004).



Bjørn Lomborg’s *The Skeptical Environmentalist* (2001).



*The Revenge of Gaia: Why the earth is fighting back – and how we can still save humanity.*  
James Lovelock (2006). © Allen Lane.

not recommended as the long-term panacea for our ailing planet, is “the only effective medicine we have now.” Onshore wind turbines are “merely . . . a gesture to prove [our leaders’] environmental credentials.”

This heated debate is fundamentally about numbers. How much energy could each source deliver, at what economic and social cost, and with what risks? But actual numbers are rarely mentioned. In public debates, people just say “Nuclear is a money pit” or “We have a *huge* amount of wave and wind.” The trouble with this sort of language is that it’s not sufficient to know that something is huge: we need to know how the one “huge” compares with another “huge,” namely *our huge energy consumption*. To make this comparison, we need numbers, not adjectives.

Where numbers are used, their meaning is often obfuscated by enormity. Numbers are chosen to impress, to score points in arguments, rather than to inform. “Los Angeles residents drive 142 million miles – the distance from Earth to Mars – every single day.” “Each year, 27 million acres of tropical rainforest are destroyed.” “14 billion pounds of trash are dumped into the sea every year.” “British people throw away 2.6 billion slices of bread per year.” “The waste paper buried each year in the UK could fill 103 448 double-decker buses.”

If all the ineffective ideas for solving the energy crisis were laid end to end, they would reach to the moon and back. . . . I digress.

The result of this lack of meaningful numbers and facts? We are inundated with a flood of crazy innumerate codswallop. The BBC doles out advice on how we can do our bit to save the planet – for example “switch off your mobile phone charger when it’s not in use;” if anyone objects that mobile phone chargers are not *actually* our number one form of energy consumption, the mantra “every little helps” is wheeled out. Every little helps? A more realistic mantra is:

*if everyone does a little, we’ll achieve only a little.*

Companies also contribute to the daily codswallop as they tell us how wonderful they are, or how they can help us “do our bit.” BP’s website, for example, celebrates the reductions in carbon dioxide (CO<sub>2</sub>) pollution they hope to achieve by changing the paint used for painting BP’s ships. Does anyone fall for this? Surely everyone will guess that it’s not the exterior paint job, it’s the stuff *inside* the tanker that deserves attention, if society’s CO<sub>2</sub> emissions are to be significantly cut? BP also created a web-based carbon absolution service, “targetneutral.com,” which claims that they can “neutralize” all your carbon emissions, and that it “doesn’t cost the earth” – indeed, that your CO<sub>2</sub> pollution can be cleaned up for just £40 per year. How can this add up? – if the true cost of fixing climate change were £40 per person then the government could fix it with the loose change in the Chancellor’s pocket!

Even more reprehensible are companies that exploit the current concern for the environment by offering “water-powered batteries,” “biodegrad-

For the benefit of readers who speak American, rather than English, the translation of “every little helps” into American is “every little bit helps.”



able mobile phones,” “portable arm-mounted wind-turbines,” and other pointless tat.

Campaigners also mislead. People who want to promote renewables over nuclear, for example, say “offshore wind power could power all UK homes;” then they say “new nuclear power stations will do little to tackle climate change” because 10 new nuclear stations would “reduce emissions only by about 4%.” This argument is misleading because the playing field is switched half-way through, from the “number of homes powered” to “reduction of emissions.” The truth is that the amount of electrical power generated by the wonderful windmills that “could power all UK homes” is *exactly the same* as the amount that would be generated by the 10 nuclear power stations! “Powering all UK homes” accounts for just 4% of UK emissions.

Perhaps the worst offenders in the kingdom of codswallop are the people who really should know better – the media publishers who promote the codswallop – for example, New Scientist with their article about the “water-powered car.”\*

In a climate where people don’t understand the numbers, newspapers, campaigners, companies, and politicians can get away with murder.

We need simple numbers, and we need the numbers to be comprehensible, comparable, and memorable.

With numbers in place, we will be better placed to answer questions such as these:

1. Can a country like Britain conceivably live on its own renewable energy sources?
2. If everyone turns their thermostats one degree closer to the outside temperature, drives a smaller car, and switches off phone chargers when not in use, will an energy crisis be averted?
3. Should the tax on transportation fuels be significantly increased? Should speed-limits on roads be halved?
4. Is someone who advocates windmills over nuclear power stations “an enemy of the people”?
5. If climate change is “a greater threat than terrorism,” should governments criminalize “the glorification of travel” and pass laws against “advocating acts of consumption”?
6. Will a switch to “advanced technologies” allow us to eliminate carbon dioxide pollution without changing our lifestyle?
7. Should people be encouraged to eat more vegetarian food?
8. Is the population of the earth six times too big?

\*See this chapter’s notes (p19) for the awful details. (Every chapter has endnotes giving references, sources, and details of arguments. To avoid distracting the reader, I won’t include any more footnote marks in the text.)



Figure 1.1. This Greenpeace leaflet arrived with my junk mail in May 2006. Do beloved windmills have the capacity to displace hated cooling towers?

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