Sustainable Energy

How to wean ourselves off fossil fuels and maintain quality of life

Reading: Ch. 1, 2 in Sustainable Energy – Without the Hot Air, by David MacKay

http://www.withouthotair.com/Contents.html
Fossil fuel CO₂ emissions: Burning buried sunshine
Carbon emissions rising faster than estimates
Global C emissions map

Where emissions come from
Atmospheric CO$_2$: Last 50 years

(2.0 ppm/year increase, or 0.5%)
1769: James Watt patents the steam engine

Sustainable Energy – Without the Hot Air, by David MacKay
IPCC Emissions Scenarios: Carbon Dioxide

Concentration (ppmv)
Preindustrial: 280
In 2000: 368

Emissions (GtC / yr)
How much is a gigaton (Gt)?

- One billion metric tons (10^{12} kg)
- It is about 2750 Empire State Buildings.
- Global CO₂ emissions are about \textbf{32 Gt} as of 2012.
Carbon Emissions (year 2000)

Global emissions are 32 Gt CO2 per year
Per capita emissions: ~5.5 tons CO2 per year

Sustainable Energy – Without the Hot Air, by David MacKay
74% emissions from “energy” rest is from agriculture, deforestation

Figure 1.9. Breakdown of world greenhouse-gas emissions (2000) by cause and by gas. “Energy” includes power stations, industrial processes, transport, fossil fuel processing, and energy-use in buildings. “Land use, biomass burning” means changes in land use, deforestation, and the burning of un-renewed biomass such as peat. “Waste” includes waste disposal and treatment. The sizes indicate the 100-year global warming potential of each source. Source: Emission Database for Global Atmospheric Research.

*Sustainable Energy – Without the Hot Air*, by David MacKay
Energy and Power

**Energy** is measured in kilowatt-hours (kWh)

*Example*, a 40 Watt bulb left on all day (24 hours) is about 1000 Wh or 1 kWh

**Power** is the *rate* of energy use, measured in kWh per day
- Average European uses 125 kWh per day per person (total energy)
- Average American uses 250 kWh per day per person.
Energy sources

US average =
250 kWh per day per person

Estimated U.S. Energy Use in 2009: ~94.6 Quads

Source: LBNL 2010. Data is based on DOE/EA-0484(2008), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory.
Some Observations on US energy use

1) We waste a lot of energy
2) We use a lot of oil for getting around
3) Natural gas is increasing
4) Renewables are nowhere (for now)

US energy use is diverse

U.S. Energy Consumption by Sector

- Buildings: 49%
- Industry: 23%
- Transportation: 28%

Source: US Energy Information Administration (2011)
Can we live without fossil fuels?

Sustainable
Energy use < renewable sources

Unsustainable
Energy use > renewable sources

Wind • solar • hydro • wave • tidal • geothermal • nuclear
Sustainable energy components

- Land wind turbines
- Offshore wind turbines
- Solar: Thermal and PV
- Biomass
- Hydroelectricity
- Wave energy
- Tidal energy
- Geothermal
- Nuclear
Assumptions

• This is only an exercise to see IF renewables can meet current total energy demand (not just electricity).
• Book focuses on United Kingdom.
• US per capita consumption is twice that of UK!
• No attempt to HOW this can be done. MacKay did not address cost, social impact, community values, priorities
WIND

Figure 18.1. The state of play after we added up all the traditional renewables.
Solar

Figure 18.1. The state of play after we added up all the traditional renewables.
Hydroelectricity

Figure 18.1. The state of play after we added up all the traditional renewables.
Tidal and Wave

Figure 18.1. The state of play after we added up all the traditional renewables.
Geothermal

Geothermal Reservoir

Figure 18.1. The state of play after we added up all the traditional renewables.
Theoretical vs. Practical renewable resource plans for UK

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>My estimates</th>
<th>IEE</th>
<th>Tyndall</th>
<th>IAG</th>
<th>PIU</th>
<th>CAT</th>
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<tbody>
<tr>
<td>Geothermal</td>
<td>1 kWh/d</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>[Tide: 11 kWh/d]</td>
<td>Tide: 10 kWh/d</td>
<td>Tide: 2.4</td>
<td>Tide: 3.9</td>
<td>Tide: 3.4</td>
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<td></td>
<td></td>
<td>Wave: 4 kWh/d</td>
<td>Wave: 2.3</td>
<td>Wave: 2.4</td>
<td>Wave: 1.5</td>
<td>Wave: 2.4</td>
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<tr>
<td></td>
<td></td>
<td>Deep offshore wind: 32 kWh/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallow offshore wind: 16 kWh/d</td>
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<td>Offshore: 6.4</td>
<td>Offshore: 4.6</td>
<td>Offshore: 4.6</td>
<td>Offshore: 4.6</td>
<td>Offshore: 21 kWh/d</td>
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<tr>
<td>Biomass: food, biofuel, wood, waste incineration, landfill gas: 24 kWh/d</td>
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<td>Hydro: 0.08</td>
<td>Energy crops, waste: 2</td>
<td>Energy crops, waste, landfill gas: 31 kWh/d</td>
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<tr>
<td>PV farm (200 m²/p): 50 kWh/d</td>
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<td>PV: 0.3</td>
<td>PV: 0.2</td>
<td>PV: 12</td>
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<td>PV: 1.4</td>
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<tr>
<td>PV, 10 m²/p: 5</td>
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<td>Wind: 2</td>
<td>Wind: 2.6</td>
<td>Wind: 2.6</td>
<td>Wind: 2.5</td>
<td>Wind: 1.3</td>
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<tr>
<td>Solar heating: 13 kWh/d</td>
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<td>Wind: 20 kWh/d</td>
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Actual “plans” are quite modest and don’t meet demand.
The NIMBY effect

Hard choices to make
Other people’s renewables...

Desertec – ambitious plan to power Europe
Any renewable energy plan must provide the energy you need

- For the UK, the per capita energy draw is 125 kWh per day.
- USA is DOUBLE this!
- MacKay outlines 5 plans for 5 constituencies (Diversity, NIMBYs, Greens, Economically viable)
Sustainable Energy – Without the Hot Air, by David MacKay
A renewables plan that meets ALL of current UK energy needs

Ballpark cost: $1.4 trillion
Per capita cost: $22,000

Plan M

Solar in deserts: 16 kWh/d
Clean coal: 3
Nuclear: 16 kWh/d
Tide: 3.7
Wave: 0.3
Hydro: 0.2
Waste: 1.1
Pumped heat: 12 kWh/d
Wood: 5 kWh/d
Solar HW: 1
Biofuels: 2
PV: 2
Wind: 8

Sustainable Energy – Without the Hot Air, by David MacKay
Efficiency gains – the simplest, cheapest (partial) solution

Infrastructure ideas:
- Electrify Transport
- Solar and heat pumps for hot water

MacKay’s home efficiency gains
Sustainable energy lessons

• It’s hard to meet UK energy needs with renewables only, it’s doubly hard for US.
• Any viable sustainable energy plan involves hard choices.
• It’s expensive, but within the range of other major initiatives (wars, space program).
• It quickly exposes waste and inefficiencies.
• What’s lacking is not technology, but social and political will.
Increasing renewable energy investment

Global new investment in renewable energy


- Small Distributed Capacity, RD&D
- Financial New Investment

(Billion USD)

<table>
<thead>
<tr>
<th>Year</th>
<th>Small Distributed Capacity</th>
<th>Financial New Investment</th>
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<tbody>
<tr>
<td>2004</td>
<td>14</td>
<td>33</td>
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<tr>
<td>2005</td>
<td>43</td>
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<td>2008</td>
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<td>159</td>
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<td>2009</td>
<td>122</td>
<td>160</td>
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<tr>
<td>2010</td>
<td>143</td>
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</table>
Some welcome good news!

- Renewable investment and deployment are increasing.
- Costs are decreasing rapidly.
- Market penetration is high in some economies (Europe).
- Grid parity (with coal) is imminent.
- Once grid parity is achieved, renewables will increase.
- Decarbonized global economy is the (long-term) goal.
Lots of room for growth!

Global renewable power capacities (excluding hydro)
Data source: REN21, Renewables Global Status Report (2006-2012)
Solar Grid Parity In All 50 US States By 2016, Predicts Deutsche Bank

Solar PV industry outlook

Electricity prices ($/kw-hr)

US - Average price of electricity in 2005: 8.6 cents/kWh

Convergence

WaferNews source: Stephen O'Rourke/Deutsche Bank

Market Penetration...

Proportion of renewable energy (in %)

Levelized Cost of Energy (LCOE) calculation

Accounts for:

- Initial investment
- Operations and maintenance
- Cost of fuel
- Cost of Capital
- 20-40 year lifetime
- No tax credits, incentives included

\[
LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}
\]

- Average lifetime levelized electricity generation cost
- Investment expenditures in the year \(t\)
- Operations and maintenance expenditures in the year \(t\)
- Fuel expenditures in the year \(t\)
- Electricity generation in the year \(t\)
- Discount rate
- Life of the system

Pro: Formally accounts for life cycle energy investment (but not envir. costs!)
Con: Ignores cyclical (daily to seasonal) energy pricing fluctuations

http://www.eia.gov/forecasts/aeo(er/early_elecgen.cfm
LCOE – 2014 estimates

LEVELISED COST OF ELECTRICITY, H1 2014 ($/MWH)

PV projects as low as $80/MWh
Onshore wind as low as $37/MWh

http://www.greentechmedia.com/articles/read/3-signs-clean-tech-is-booming-in-2014