Visions of a renewable future

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Introduction

Objects of our attention

- Scenarios for a >80% share of renewables in electricity or total energy ($\Longrightarrow$ 'fuel-saving' substitution of some fossil fuel is not sufficient)
- Must include some concept of balancing variability ($\Longrightarrow$ not interested in individual technologies or pre-industrial applications)
- Must be possible in at least 80% of countries worldwide ($\Longrightarrow$ hydroelectric dams excluded)
- Edge case: concentrated solar power (CSP) with built-in thermal storage (since needs good direct irradiation)

Hypotheses

- Consistent scenarios for 100% renewable energy across the economy are >100 years old
- Big flowering of scenarios across the world after the 1973 oil crisis
- We had the technology and understanding to switch to 100% renewable energy in 1970s
- It was clear early on that integrating electricity-gas-heat was critical
- It foundered on a lack of government support (subsidy and regulation), opposition from fossil and nuclear industries, cheap fossils
- The energy system modelling field has a bad case of historical amnesia

Hypotheses

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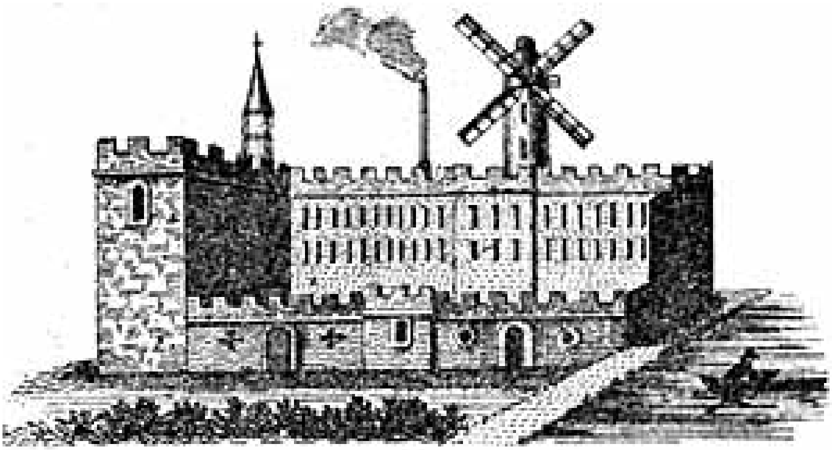
Question:

- Was the technology even ready in the 1970s? E.g. Could wind turbines produce sufficiently good power quality before modern power electronics? (DFIG and full converter)

Pre-1970

1780s: Unwin's Mill at Sutton

S. Unwin's cotton mill at Sutton in Ashfield used a windmill to pump water back to an upper pond for supplying a water wheel. First example of combining renewables for storage?



Source: Hills 'Power in the Industrial Revolution' (1970)

1833: Etzler: The Paradise within the Reach of all Men

The substance of this book is—

1. It is proved that there are powers at the disposal of man, million times greater than all human exertions could effect hitherto.

These powers are derived—

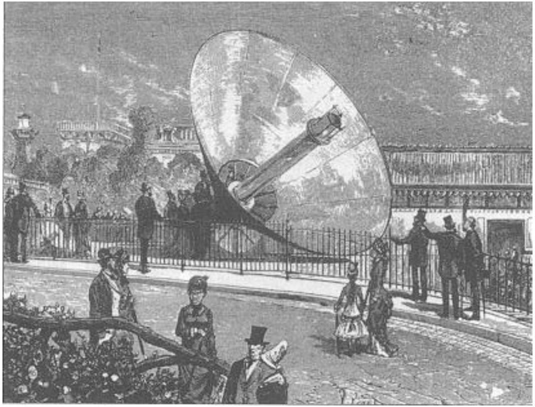
a. From wind.
b. From the tide.
c. From the waves of the sea, caused by wind.
d. From steam, generated by heat of the sun, by means of concentrating reflectors, or burning mirrors of a simple contrivance

The eternal promise of renewable energy from Etzler's 1833 "The Paradise within the Reach of all Men, without Labor, by Powers of Nature and Machinery: An Address to all intelligent men, in two parts".

Source: Etzler (1833)

1860s: Augustine Mouchot: First concentrated solar engines

Mouchot's solar engine at 1878 Universal Exhibition in Paris:



In 1873 he wrote: "The time will arrive when the industry of Europe will cease to find those natural resources, so necessary for it. Petroleum springs and coal mines are not inexhaustible but are rapidly diminishing in many places. Will man, then, return to the power of water and wind? Or will he emigrate where the most powerful source of heat sends its rays to all? History will show what will come."

Others

In 1885, Werner von Siemens, commenting on the discovery of the photovoltaic effect in the solid state, wrote:

“In conclusion, I would say that however great the scientific importance of this discovery may be, its practical value will be no less obvious when we reflect that the supply of solar energy is both without limit and without cost, and that it will continue to pour down upon us for countless ages after all the coal deposits of the earth have been exhausted and forgotten.”

Max Weber mentioned the end of fossil fuel in the concluding paragraphs of his Die protestantische Ethik und der Geist des Kapitalismus (The Protestant Ethic and the Spirit of Capitalism), published in 1905.

Thomas Edison in 1931: “We are like tenant farmers chopping down the fence around our house for fuel when we should be using Natures inexhaustible sources of energy – sun, wind and tide. . . . I’d put my money on the sun and solar energy. What a source of power! I hope we don’t have to wait until oil and coal run out before we tackle that.”

Source: Wikipedia History of Renewable Energy

Other CSP pioneers

Frank Schuman: CSP for engines in 1913 in Egypt

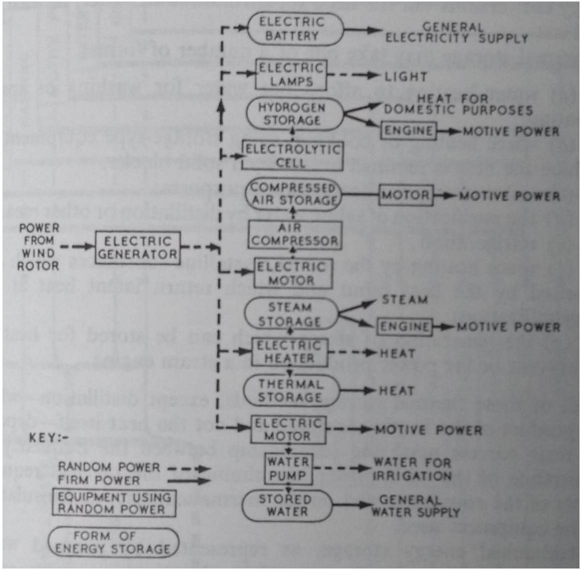
Marcel Perrot CSP in Algeria in 1940s-1960s - wanted to generated solar power in Algeria and export to France by sea cable, see book 'La Houille D'or Ou L'énergie Solaire' (1963)

1923: J.B.S. Haldane: Wind & Hydrogen Vision for Britain

Personally, I think that four hundred years hence the power question in England may be solved somewhat as follows: The country will be covered with rows of metallic windmills working electric motors which in their turn supply current at a very high voltage to great electric mains. At suitable distances, there will be great power stations where during windy weather the surplus power will be used for the electrolytic decomposition of water into oxygen and hydrogen. These gasses will be liquefied, and stored in vast vacuum jacketed reservoirs, probably sunk in the ground. If these reservoirs are sufficiently large, the loss of liquid due to leakage inwards of heat will not be great; thus the proportion evaporating daily from a reservoir 100 yards square by 60 feet deep would not be 1/1000 of that lost from a tank measuring two feet each way. In times of calm, the gasses will be recombined in explosion motors working dynamos which produce electrical energy once more, or more probably in oxidation cells. Liquid hydrogen is weight for weight the most efficient known method of storing energy, as it gives about three times as much heat per pound as petrol. On the other hand it is very light, and bulk for bulk has only one third of the efficiency of petrol. This will not, however, detract from its use in aeroplanes, where weight is more important than bulk. These huge reservoirs of liquified gasses will enable wind energy to be stored, so that it can be expended for industry, transportation, heating and lighting, as desired. The initial costs will be very considerable, but the running expenses less than those of our present system. Among its more obvious advantages will be the fact that energy will be as cheap in one part of the country as another, so that industry will be greatly decentralized; and that no smoke or ash will be produced.

Source: J.B.S. Haldane ‘Daedalus’ (1923)

1955: E.W. Golding: Wind for remote communities



In his 1955 book 'The Generation of Electricity by Wind Power' E.W. Golding sketched an energy system for remote communities that seems very modern:

- Electrify as much as possible to avoid conversion losses
- Then use thermal, hydrogen and compressed air energy storage to balance wind variations

Source: Golding (1955)

Others

1875: Jules Verne on fuel cell and hydrogen economy in ‘Mysterious Island’

1912: Wilhelm Ostwald in ‘Der energetische Imperativ’

1920s: Pre-DESERTEC ideas, see Breyer et al (2016) e.g. Atlantropa by Herman Sörgel (damming the Mediterranean at Strait of Gibraltar)

1955: Eduard Justi ideas for solar power in Sahara exported to Europe as hydrogen in ‘Probleme und Wege der zukünftigen Energieversorgung der Menschheit’

1968: Buckminster-Fuller in Operating Manual for Spaceship Earth: we “must operate exclusively on our vast daily energy income from the powers of wind, tide, water, and the direct Sun radiation energy” using global grid - ideas fed Global Energy Network Institute (GENI)

1970: Aden and Marjorie Meinel’s plan for 1000 GW, 5000 square mile CSP ‘National Solar Power Facility’ in US

1970: Bockris: solar-hydrogen economy

1970s

1973 oil crisis

In 1972, 92% of Denmark's energy consumption came from imported oil.

1973: Organization of Arab Petroleum Exporting Countries proclaimed an oil embargo.

Oil price jumps from 4 to 12 USD/barrel.

Catalyst for many people (mostly physicists - that's another story) to rethink energy supply: Amory Lovins ('Soft Energy Paths' 1976-7); Art Rosenfeld on Energy Efficiency; Union of Concerned Scientists report 'Energy Strategies: Toward a Solar Future' (1980); Bent Sørensen; Swedish Secretariat for Futures Studies; Le Groupe de Bellevue, ALTER: A Study of a Long-Term Energy Future for France based on 100% Renewable Energies (Paris, 1978); Wolf Häfele, Jeanne Anderer, A. McDonald and Nebojsa Nakicenoviç, Energy in a Finite World (Cambridge, MA: Ballinger, 1981), many others...

1975: Bent Sørensen: 1st consistent 100% RE scenario

In 1975 Bent Sørensen published a scenario for 100% renewable energy in Denmark. He dealt with the variability of wind (with hydrogen) & solar thermal (with TES).

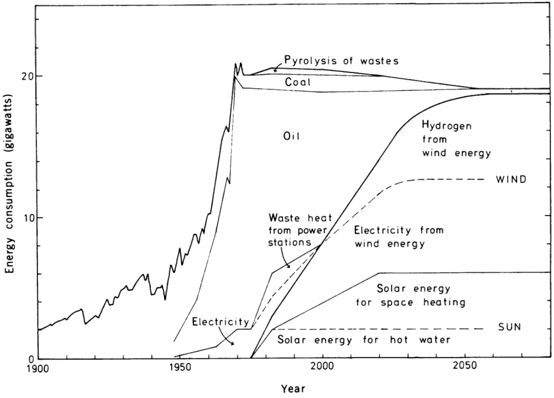


Fig. 4. Net energy consumption in Denmark, shown according to sources. Up to 1974, actual data are shown (*14*); data after 1974 indicate the proposed plan. The relative weighting between solar and wind energy shares might be altered, for example, if a major breakthrough occurred in the devel-opment of solar cells, making them competitive to wind-produced electricity under Danish condi-tions. The heavy, solid line indicates the proposed total share of solar and wind energy.

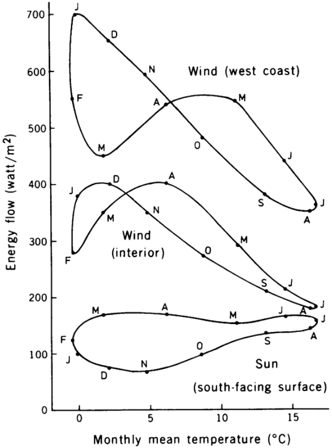
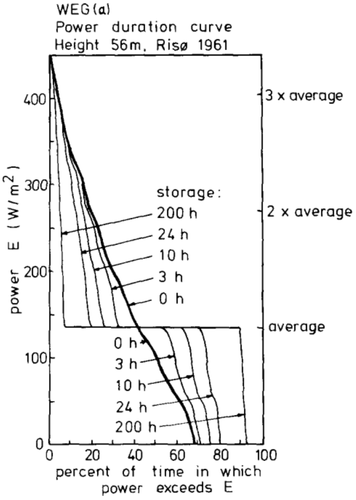


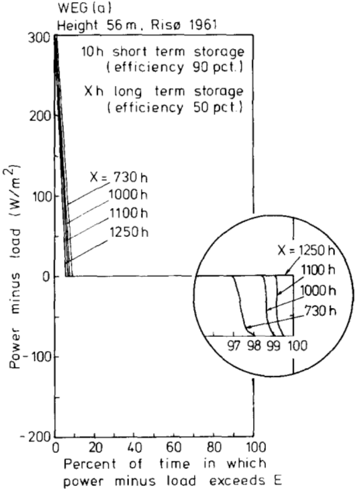
Fig. 2. Monthly average energy flow from con-tinuous sources through a vertical square meter in Denmark, as function of the monthly mean

Source: Sørensen (1975) Science

1978: Bent Sørensen: Balancing the wind

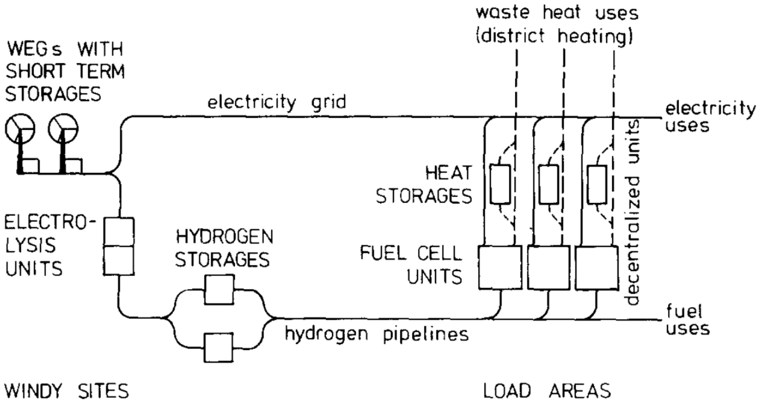
He analysed the residual load duration curve for wind and load with short-term storage (left) and with long-term storage (right) with high conversion losses (i.e. hydrogen storage).





1978: Bent Sørensen: Coupled electricity-heat-gas

He already sketched a 'Smart Energy System', which is quite close to current plans for Denmark: lots of wind, CHP and waste heat in district heating.

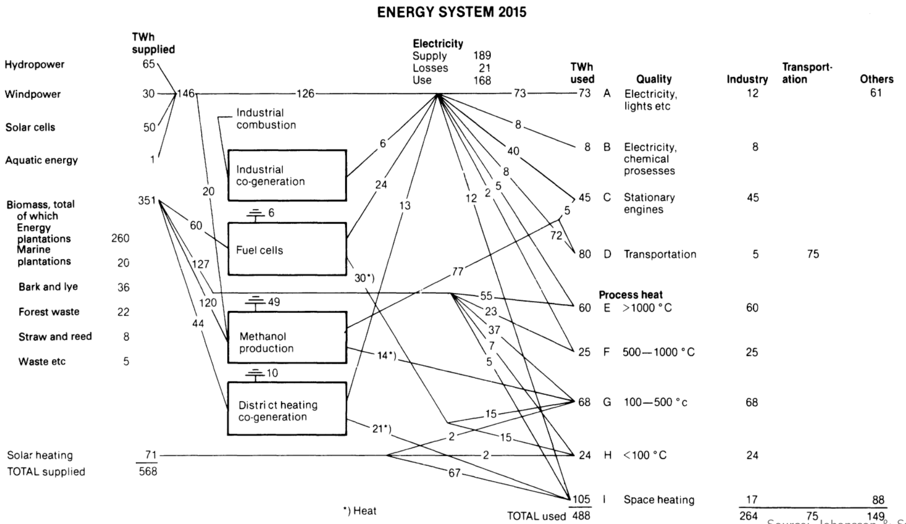


Finally, Fig. 21 shows that an electricity producing WEG system with hydrogen storage may be integrated into the complete energy supply system in a way, which substantially diminishes the losses associated with the hydrogen cycle. This is possible partly by using some of the hydrogen directly as fuel (process heat in industry, transportation, etc.), partly by utilizing the fuel cell waste heat (initially in the form of hot air[14]) for heating purposes, e.g. district heating, using a heat storage facility (e.g. hot water) as a buffer. One advantage of this system is, that the WEG and electrolysis unit can be placed at the wind-favored sites, and the fuel-cells for regeneration of electricity plus heat production near to the heat-load areas. In many cases not only the electric grid, but also the necessary hydrogen pipelines will already exist (previously in use for distributing natural gas). In this way the fuel cell/district heating units can be of any suitable size and can be placed in a decentralized fashion according to the distribution of load areas.

Source: Sørensen (1978) Solar Energy

1977: Swedish Secretariat for Futures Studies ‘Sol Sverige’

1977 ‘Sol Sverige’ report: a mixture of renewables, but quite biomass heavy.



Source: Johansson & Steen (1978) Ambio

2000s: Renaissance

Spurred by climate change and health impacts of air pollution. Again, mostly physicists:

- Henrik Lund and group at Aalborg University
- Gregor Czisch scenarios for wind in EUMENA
- Mark Z. Jacobson, Mark A. Delucchi and group
- Martin Greiner and group
- Christian Breyer and group
- Many others....

Lessons?

- Many of the ideas we consider ‘modern’ (100% renewables, sector coupling) are old
- Idea of balancing variability by coupling electricity-gas-heat is old (also necessary for variability of demand)
- It may actually be ‘different this time’ because solar and wind are so far down the learning curve
- Warning from history of nuclear power in Alvin Weinberg’s ‘The First Nuclear Era’ (1994): “It never occurred to us that we not only had to engineer a nuclear system that was sound technically, but also one that was ‘right’ politically” (hat tip A. Madrigal) - socio-political aspects are also important

Open Questions

- Was the technology **really** there in the 1970s - e.g. power quality of early wind turbines?
- Did any of the early 100% renewable scenarios have any policy effect - e.g. Sørensen's influence on build up of wind and district heating in Denmark?
- Which effect dominated failure of renewables in 1980s and 1990s - lack of policy support, opposition from fossil and nuclear industries, or low cost of fossil fuels?
- What lessons should we learn from all of this?

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