Strategies for Sustainable Energy

Lecture 3. Energy Production

CBE 652
Sustainable Technology through Advanced Interdisciplinary Research (STAIR)

University of Tennessee, Knoxville
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Strategies for Sustainable Energy

Lecture 3. Production Part I

Outline

Section 1: Estimating Sustainable Energy Production from Wind
Section 2: Estimating Sustainable Energy Production from Solar
Section 3: Obstacles to Sustainable Energy Production from Wind
Section 4: Obstacles to Sustainable Energy Production from Solar

4. Production: Wind

Estimating Energy Production from Wind

How much wind power could we plausibly generate?

Three types of wind power
- **on-shore (land-based)**
- **shallow off-shore (shore-based)**
- **deep off-shore (sea-based)**

Power per person = wind power per unit area x area per person

If typical wind speed is 6 m/s = 13 miles/h = 22 km/h

The power per unit area of wind farm is 2 W/m^2.

Area per person = 4000 m^2/person

Power per person = 200 kWh/d/person if 100% of England was

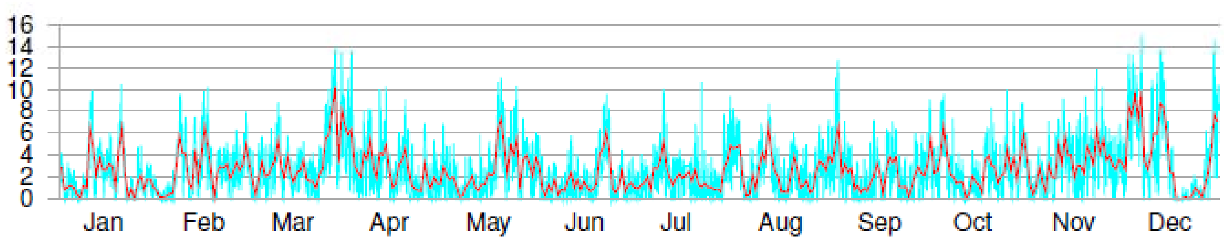


Figure 4.1. Cambridge mean wind speed in metres per second, daily (red line), and half-hourly (blue line) during 2006. See also figure 4.6.

4. Production: Wind

Estimating Energy Production from Wind

Power per person = 200 kWh/d/person if 100% of England was wind farms.

If 10% of England was wind farms, then 20 kWh/d/person.

This would require double the current global fleet of wind turbines.

Also remember the power per unit area. We will compare this with other technologies.

Conclusion: The maximum contribution of onshore wind is much less than our consumption.

Wind:
20 kWh/d

Power per unit area	
wind farm (speed 6 m/s)	2 W/m^2

Table 4.4. Facts worth remembering: wind farms.

Population density:
ROK: 2050 m^2/person
UK: 4000 m^2/person
China: 7200 m^2/person
USA: 31,250 m^2/person

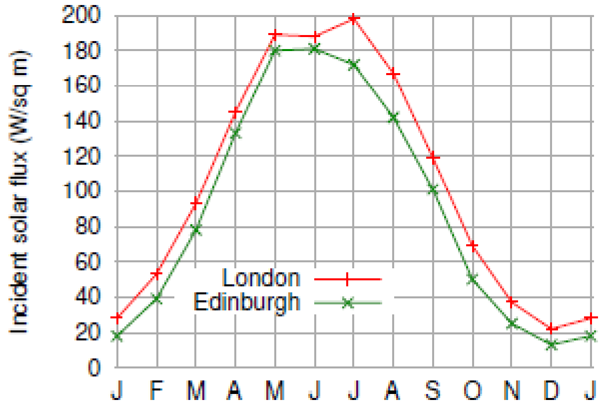
Strategies for Sustainable Energy

Lecture 5. Production Part I

Outline

6. Production: Solar

Estimating Energy Production from Solar Energy



Different types of Solar Power

- Solar Heating (or Solar Thermal)
- Solar Photovoltaic (generates electricity)
- Biomass (solar power generates "energy crops" via photosynthesis
- Food (energy for humans and other animals)

At noon on a cloudless day, the power of sunshine is 1 kW/m^2.
This applies to land oriented toward the sun.

You don't get all this power.
Due to the tilt of the Earth's rotational axis, the UK gets about 60% of this energy.
The average intensity over the course of the day is 32% of the maximum value at noon.
Some days are cloudy. In the UK, you only have good sun 34% of daylight hours.

So we have 110 W/m^2 that we could attempt to gather in the UK.

6. Production: Solar

Estimating Energy Production from Solar Energy

Solar Thermal (Solar Heating)

The simplest solar power technology is a panel making hot water.
If we cover all south-facing roof with solar thermal panels.
That's 10 m^2 per person.
50% efficiency turning sunlight into hot water.
This yields 13 kWh per day per person.

Solar heating:
13 kWh/d

Wind:
20 kWh/d

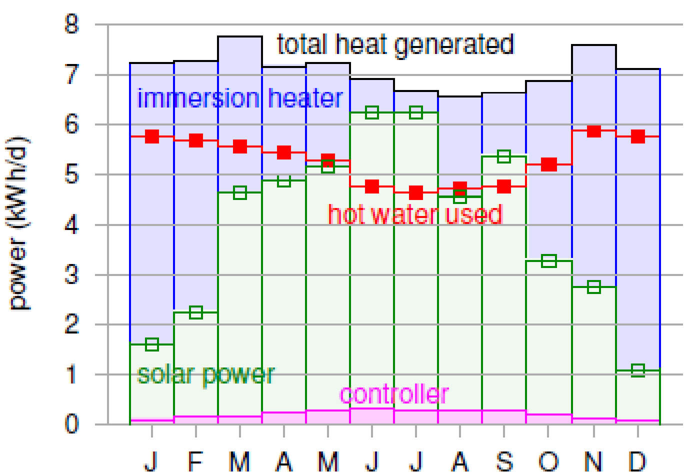


Figure 6.3. Solar power generated by a 3 m^2 hot-water panel (green), and supplementary heat required (blue) to make hot water in the test house of Viridian Solar. (The photograph shows a house with the same model of panel on its roof.) The average solar power from 3 m^2 was 3.8 kWh/d. The experiment simulated the hot-water consumption of an average European household – 100 litres of hot (60 °C) water per day. The 1.5–2 kWh/d gap between the total heat generated (black line, top) and the hot water used (red line) is caused by heat-loss. The magenta line shows the electrical power required to run the solar system. The average power per unit area of these solar panels is 53 W/m^2.

This is low-grade energy (heat).
Solar thermal is not generating electricity.

6. Production: Solar

Estimating Energy Production from Solar Energy

Solar Photovoltaic (electricity from solar energy)

Typical solar panels have a 10% efficiency.
Expensive panels have a 20% efficiency.
An average south-facing panel with an expensive panel could generate

$$20\% \times 110\ W/m^2 = 22\ W/m^2$$

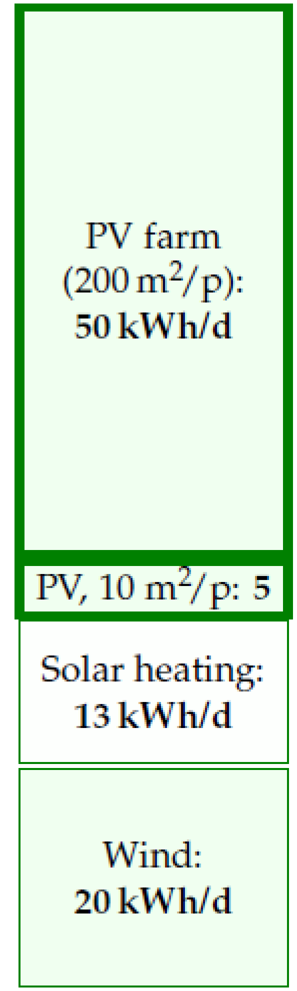
If every person had 10 m2 of expensive panels we would have

5 kWh/d/person

They cost four times as much as solar thermal and deliver half the power, but the power is in the form of high-grade energy--electricity.

If we had solar farms with cheaper panels (10% efficiency)
(Fantasy land)

$$10\% \times 110\ W/m^2 = 11\ W/m^2$$
$$11\ W/m^2 \times 200\ m^2/person = 50\ kWh/day/person$$



6. Production: Solar

Estimating Energy Production from Solar Energy

Manufacturing a solar panel consumes more energy than it will ever deliver.

False. The energy yield ratio (the ratio of energy delivered by a system over its lifetime, to the energy required to make it) of a roof-mounted, grid-connected solar system in Central Northern Europe is 4, for a system with a lifetime of 20 years (Richards and Watt, 2007); and more than 7 in a sunnier spot such as Australia. (An energy yield ratio bigger than one means that a system is A Good Thing, energy-wise.) Wind turbines with a lifetime of 20 years have an energy yield ratio of 80.

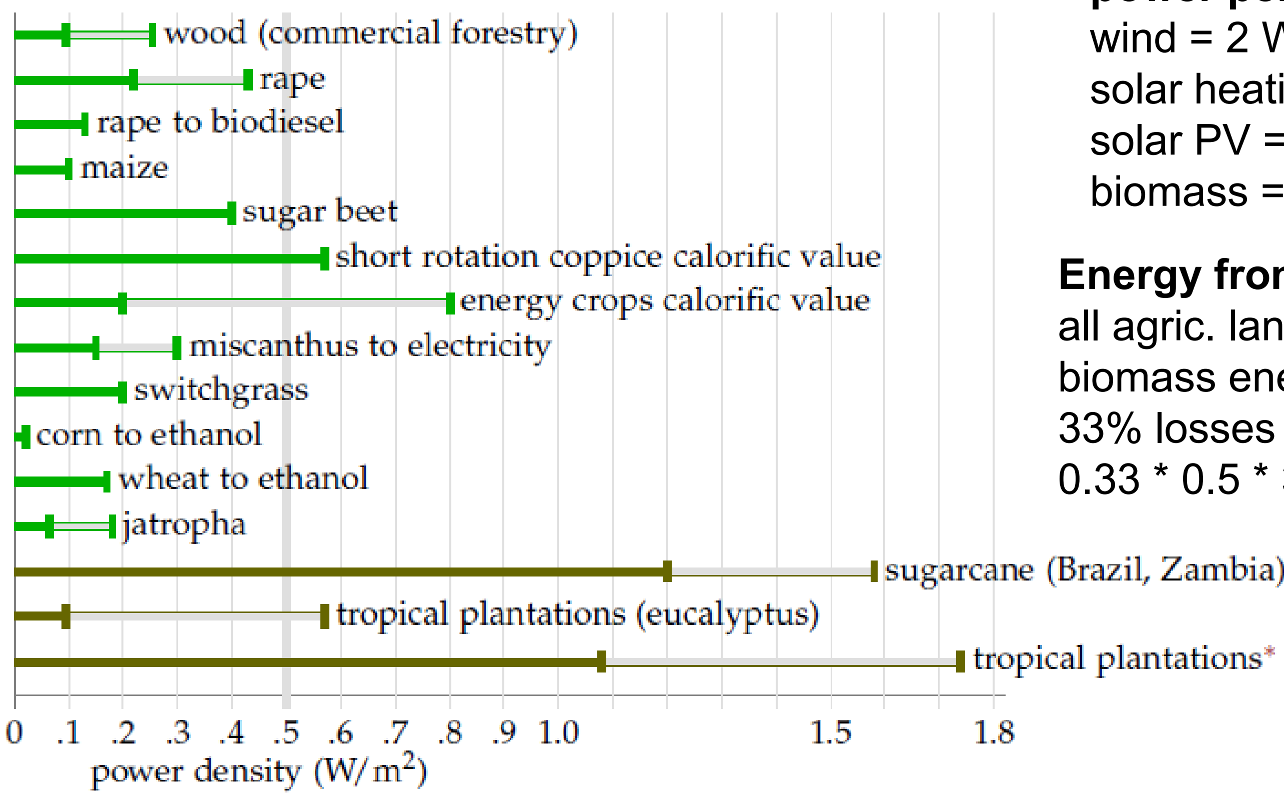
6. Production: Solar

Estimating Energy Production from Solar Energy

Solar Biomass

Options

1. Grow energy crops, which are burned for energy (coal substitution)
2. Grow energy crops, convert to biodiesel (petroleum substitution)
3. Grow food crops, burn waste products for energy (coal subs.)
4. Grow food, feed to humans and animals. (food)



power per area

wind = 2 W/m^2

solar heating = 50 W/m^2

solar PV = 20 W/m^2

biomass = < 2 W/m^2

Energy from biomass

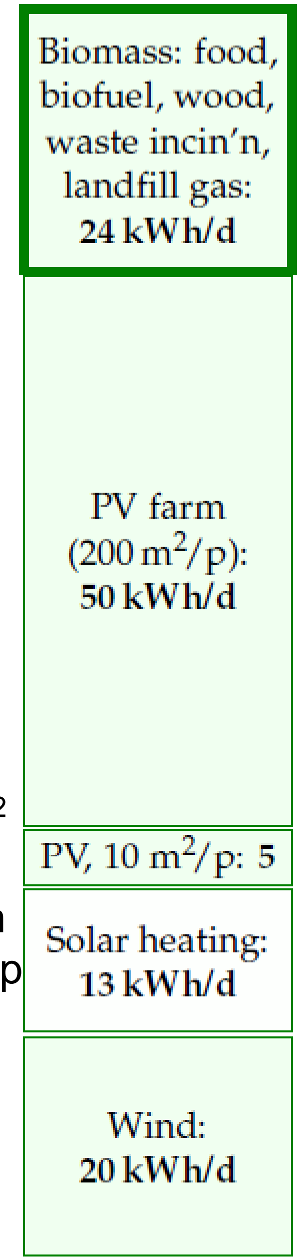
all agric. land for energy

biomass energy = 0.5 W/m^2

33% losses

0.33 * 0.5 * 3000 m^2/person

= 24 kWh/d/p



Strategies for Sustainable Energy

Lecture 5. Production Part I

Outline

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6. Production: Wind

Obstacles to Energy Production from Wind

Windmills kill birds!

Costs to birds

Do windmills kill "huge numbers" of birds? Wind farms recently got adverse publicity from Norway, where the wind turbines on Smola, a set of islands off the north-west coast, killed 9 white-tailed eagles in 10 months. I share the concern of BirdLife International for the welfare of rare birds. But I think, as always, it's important to do the numbers. It's been estimated that 30 000 birds per year are killed by wind turbines in Denmark, where windmills generate 9% of the electricity. Horror! Ban windmills! We also learn, moreover, that *traffic* kills *one million* birds per year in Denmark. Thirty-times-greater horror! Thirty-times-greater incentive to ban cars! And in Britain, 55 million birds per year are killed by *cats* (figure 10.6).

6. Production: Wind

Obstacles to Energy Production from Wind

Windmills are noisy!

Source/Activity	Indicative noise level dB (A)
Threshold of hearing	0
Rural night-time background	20-40
Quiet bedroom	35
Wind farm at 350m	35-45
Car at 40mph at 100m	55
Busy general office	60
Truck at 30mph at 100m	65
Pneumatic drill at 7m	95
Jet aircraft at 250m	105
Threshold of pain	140

http://www.bwea.com/ref/noise.html

6. Production: Wind

Obstacles to Energy Production from Wind

Windmills are a momentum sink! They will change the world's climate by draining momentum from the world's air currents.

Weather response to a large wind turbine array

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Received: 8 December 2008 – Published in Atmos. Chem. Phys. Discuss.: 29 January 2009
Revised: 8 January 2010 – Accepted: 15 January 2010 – Published: 26 January 2010

Abstract. Electrical generation by wind turbines is increasing rapidly, and has been projected to satisfy 15% of world electric demand by 2030. The extensive installation of wind farms would alter surface roughness and significantly impact the atmospheric circulation due to the additional surface roughness forcing. This forcing could be changed deliberately by adjusting the attitude of the turbine blades with respect to the wind, which would enable the "management" of a large array of wind turbines. Using a General Circulation Model (GCM), we represent a continent-scale wind farm as a distributed array of surface roughness elements. Here we show that initial disturbances caused by a step change in roughness grow within four and a half days such that the flow is altered at synoptic scales. The growth rate of the induced perturbations is largest in regions of high atmospheric instability. For a roughness change imposed over North America, the induced perturbations involve substantial changes in the track and development of cyclones over the North Atlantic, and the magnitude of the perturbations rises above the level of forecast uncertainty.

(a)

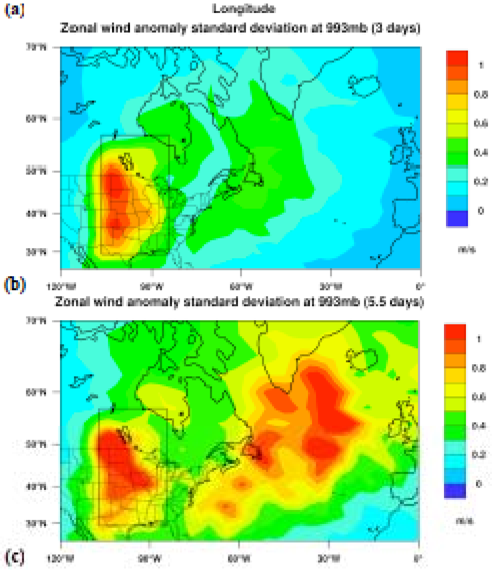

Fig. 3. Growth and propagation of anomalies. **(a)** A Hovmoller plot shows the standard deviation of anomalies versus forecast lead time and longitude, highlighting the growth rate and group velocity of perturbations. **(b)** The standard deviation over all cases of the anomalous lower tropospheric zonal wind field one half day after the roughness change is depicted. This plot is equivalent to a time slice of panel (a) at time day=3. The largest effects are confined to the wind farm. **(c)** Same as panel (b) except at time day=5.5. The largest effects are now located over the North Atlantic.

http://www.atmos-chem-phys.org/10/769/2010/acp-10-769-2010.pdf

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6. Production: Solar

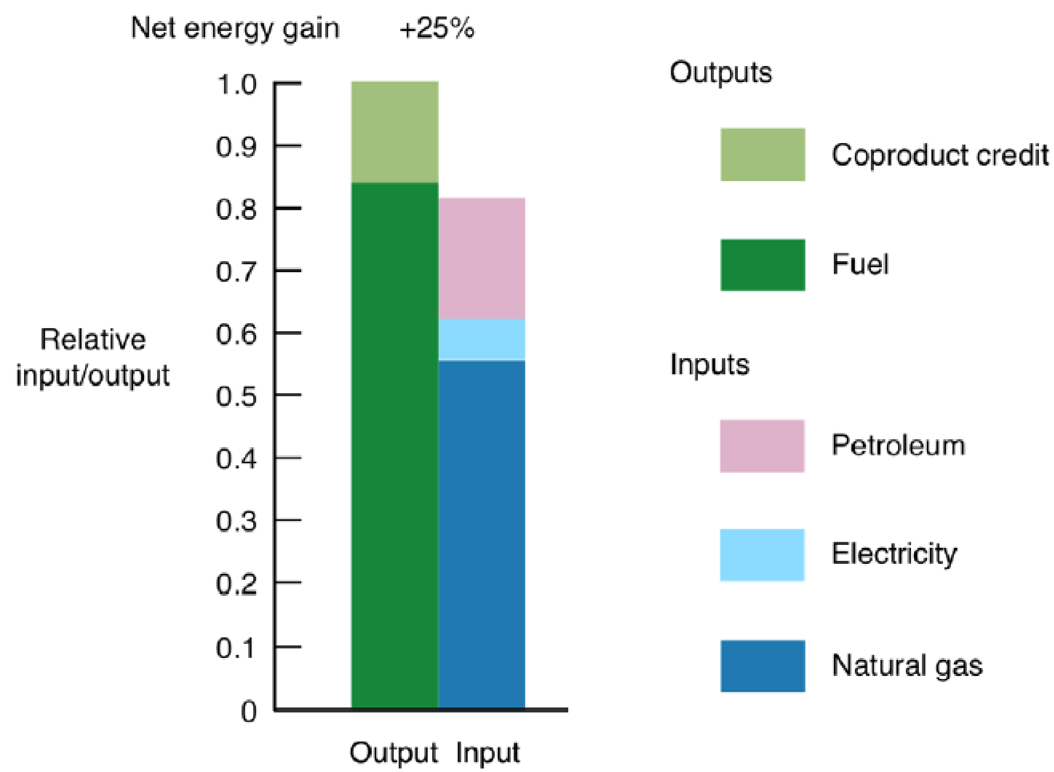
Obstacles to Energy Production from Solar Energy

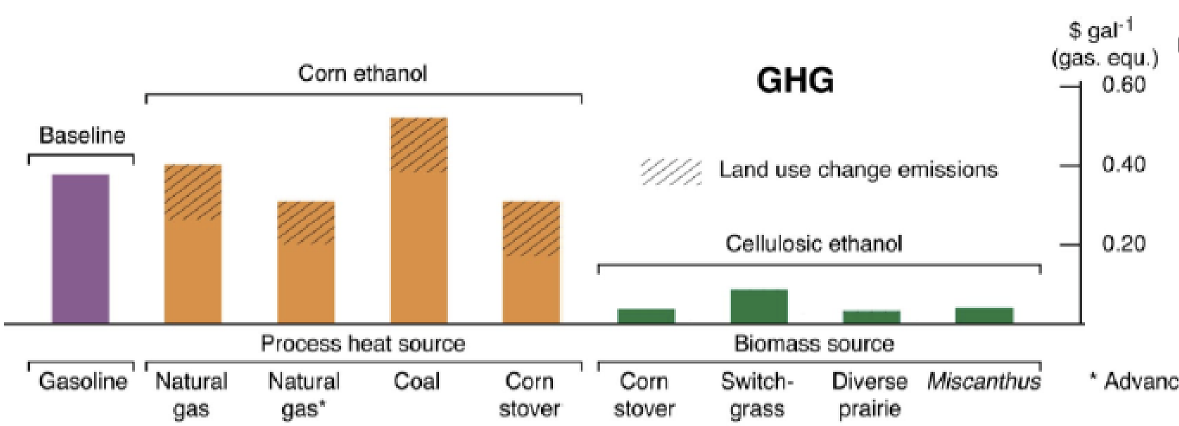
Does biomass generate net energy?

A little bit.

Does biomass lower CO_2 emissions?

Depends on what plant you use.





Corn ethanol

Slides from Dr. Jason Hill, University of MN, (2009).

6. Production: Solar

Obstacles to Energy Production from Solar Energy

Some people say:

When you use land that could be used to grow food to instead grow energy for those rich enough to pay for it, you are committing a crime against humanity!

BIOFUEL GENOCIDE

In summary, the world is facing a global food price crisis that threatens billions of people in the developing world with famine. Prices for major food commodities such as wheat, rice, corn and soybean have doubled in the last year or so. Global non-observance of basic human "entitlement" means that millions who cannot buy food will starve to death.


THE TIMES
THE SUNDAY TIMES

Archive Article Please enjoy this article from The Times & The Sunday Times

From The Sunday Times

June 10, 2007

Top scientist says biofuels are scam

Jonathan Leake and Steven Swinford

EXPLORE UK NEW

http://sites.google.com/site/biofuelgenocide/

6. Production: Solar

Obstacles to Energy Production from Solar Energy

Photovoltaics are expensive!

Typical kWh usage by homes in three selected US average homes is shown below. For example, in a Sacramento, California home, it would cost around $16-$20,000 (depending on 8-10,000 above that you may change) to satisfy around 25% of that homes energy needs.

Detroit, Michigan (Edison)	7000 kWh/year	19 kWh/day
Sacramento, California (SMUD)	8485 kWh/year	23 kWh/day
Gainsville, Alabama	11,127 kWh/year	30 kWh/day

Guideline electricity generation costs today (cents/kWh)

Combined cycle gas turbine	3-5
Wind	4-7
Biomass gasification	7-9
Remote diesel generation	20-40
Solar PV central station	20-30
Solar PV distributed	20-50

http://www.solarbuzz.com/StatsCosts.htm

Commercial electricity ~ 9 cents/kWh (Knoxville, TN, November, 2010)

Strategies for Sustainable Energy

Lecture 6. Production Part II

Outline

Section 1: Estimating Sustainable Energy Production from Hydroelectricity
Section 2: Estimating Sustainable Energy Production from Offshore Wind
Section 3: Estimating Sustainable Energy Production from Waves
Section 4: Estimating Sustainable Energy Production from Tides
Section 5: Estimating Sustainable Energy Production from Geothermal
Section 6: Obstacles to Sustainable Energy Production

8. Production: Hydroelectricity

Estimating Energy Production from Hydroelectricity

To make hydroelectricity, you need

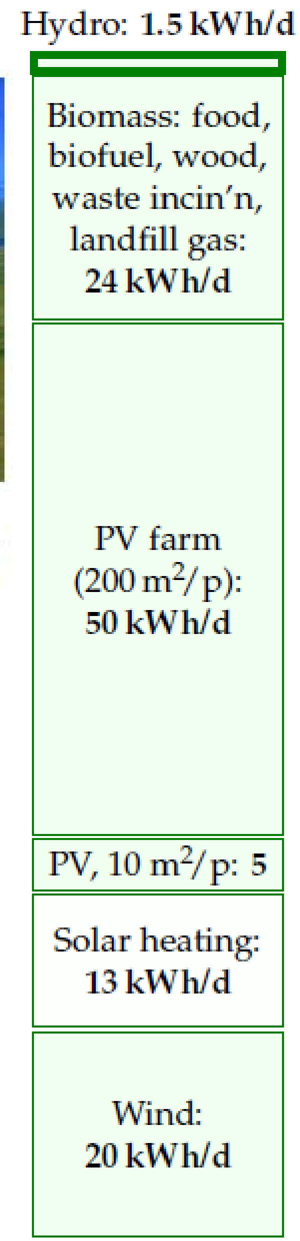
- altitude change
- rain

Two estimates for the UK:

- dry lowlands
  - rainfall = 584 mm/year
  - gravity = 10 m/s^2
  - density = 1000 kg/m^3
  - altitude = 100 m
  - maximum energy = 1 kWh/day/person
  - if every river was dammed and every raindrop used
- wet highlands
  - rainfall = 2278 mm/year
  - altitude change = 300 m
  - maximum energy = 7 kWh/day/person
  - conceivable energy = 1.5 kWh/day/person

Currently in England, 0.2 kWh/day/person from hydroelectric energy

Figure 8.1. Nant-y-Moch dam, part of a 55 MW hydroelectric scheme in Wales. Photo by Dave Newbould, www.origins-photography.co.uk.

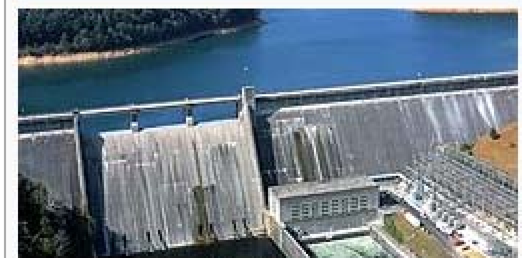


8. Production: Hydroelectricity

Estimating Energy Production from Hydroelectricity

Norris Dam, Tennessee, USA

Norris Dam



Norris Dam

Official name	Norris Dam
Locale	Anderson County and Campbell County, Tennessee, USA
Coordinates	36°13′27″N 84°05′29″W
Construction began	October 1, 1933
Opening date	March 4, 1936
Dam and spillways	
Length	1,860 feet (570 m)
Height	265 feet (81 m)
Impounds	Clinch River
Reservoir	
Creates	Norris Lake
Power station	
Turbines	2
Installed capacity	131.4 MW

10. Production: Off-shore Wind

Estimating Energy Production from Off-shore wind

Winds are stronger and more consistent at sea. Consider two kinds of off-shore wind energy

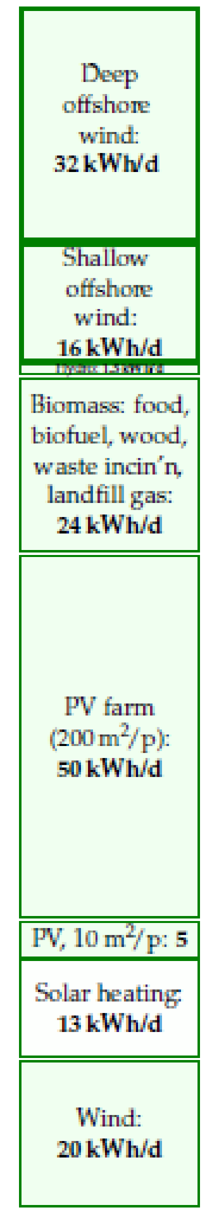
- near off-shore

Using the Kentish Flats wind farm in the Thames estuary 8.5 km from land, which began operation in 2005, generated about 3 W/m^2.
There is 40,000 km^2 of shallow water in British waters.
This could generate 48 kWh/d, but would cut off shipping.
If one third of this area was used, there could be 16 kWh/d production.
Requires 44,000 3MW turbines. 15 per km for 3000 km of coast.

- deep off-shore

Consists of water that is 25 and 50 m deep.
There is 80,000 km^2 of deep water in British waters.
If one third of this area was used, there could be 32 kWh/d production.
Requires 88,000 3MW turbines. 15 per km for 3000 km of coast.

But…some experts believe that deep off shore is too expensive to become a reality.



10. Production: Off-shore Wind

Estimating Energy Production from Off-shore wind

Is it humanly possible to build this many wind turbines?
What are the material demands?

To create 48 kWh per day of offshore wind per person in the UK would require 60 million tons of concrete and steel – one ton per person. Annual world steel production is about 1200 million tons, which is 0.2 tons per person in the world. During the second world war, American shipyards built 2751 Liberty ships, each containing 7000 tons of steel – that's a total of 19 million tons of steel, or 0.1 tons per American. So the building of 60 million tons of wind turbines is not off the scale of achievability; but don't kid yourself into thinking that it's easy. Making this many windmills is as big a feat as building the Liberty ships.

For comparison, to make 48 kWh per day of nuclear power per person in the UK would require 8 million tons of steel and 0.14 million tons of concrete. We can also compare the 60 million tons of offshore wind hardware that we're trying to imagine with the existing fossil-fuel hardware already sitting in and around the North Sea (figure 10.4). In 1997, 200 installations and 7000 km of pipelines in the UK waters of the North Sea contained 8 million tons of steel and concrete. The newly built Langeled gas pipeline from Norway to Britain, which will convey gas with a power of 25 GW (10 kWh/d/p), used another 1 million tons of steel and 1 million tons of concrete (figure 10.5).

Figure 10.1. Kentish Flats – a shallow offshore wind farm. Each rotor has a diameter of 90 m centred on a hub height of 70 m. Each "3 MW" turbine weighs 500 tons, half of which is its foundation.

12. Production: Waves

Estimating Energy Production from Waves

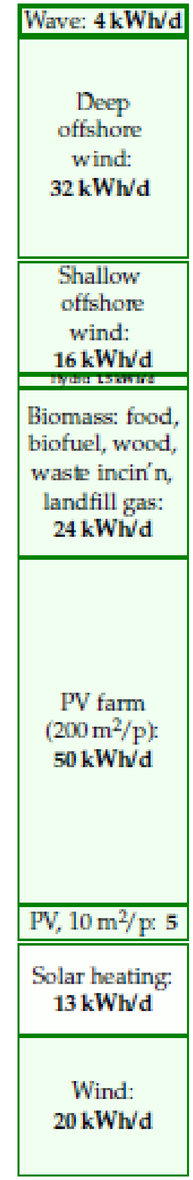
Where do waves come from?
The sun creates wind. Wind creates waves.

Waves deliver a power per unit length of coast, whereas solar/wind/biomass was measured as power per unit area.

Waves in the Atlantic ocean possess 40 kW/m of coast.
Britain has 1000 km of Atlantic coast, or 1/60 m/person.
Total energy is 16 kWh/day/person.

If wave machines that are 50% efficient are lined up along 50% of the coast, then we can obtain 4 kWh/d/person of wave energy.

Figure 12.1. A Pelamis wave energy collector is a sea snake made of four sections. It faces nose-on towards the incoming waves. The waves make the snake flex, and these motions are resisted by hydraulic generators. The peak power from one snake is 750 kW; in the best Atlantic location one snake would deliver 300 kW on average. Photo from Pelamis wave power www.pelamiswave.com.



14. Production: Tides

Estimating Energy Production from Tides

Where do tides come from?
Gravitational interactions between the moon and earth (and to a lesser extent) the sun and the earth give rise to tides.

One places “wind mills for water” (waterwheels) underwater where they are powered by the tidal movement of water in and out of a tidal pool.

These waterwheels provide 3 W/m^2.
Is there a large enough tidal pool to provide a country with energy? What about the North Sea?

This tidal pools contains 100 kWh/d/person. (English person)
If we tap into 10% of this energy with 50% efficiency, we would obtain 5 kWh/day/person.

Figure 14.6. The average incoming power of lunar tidal waves crossing these two lines has been measured to be 250 GW. This raw power, shared between 60 million people, is 100 kWh per day per person.

14. Production: Tides

Estimating Energy Production from Tides

Three technologies

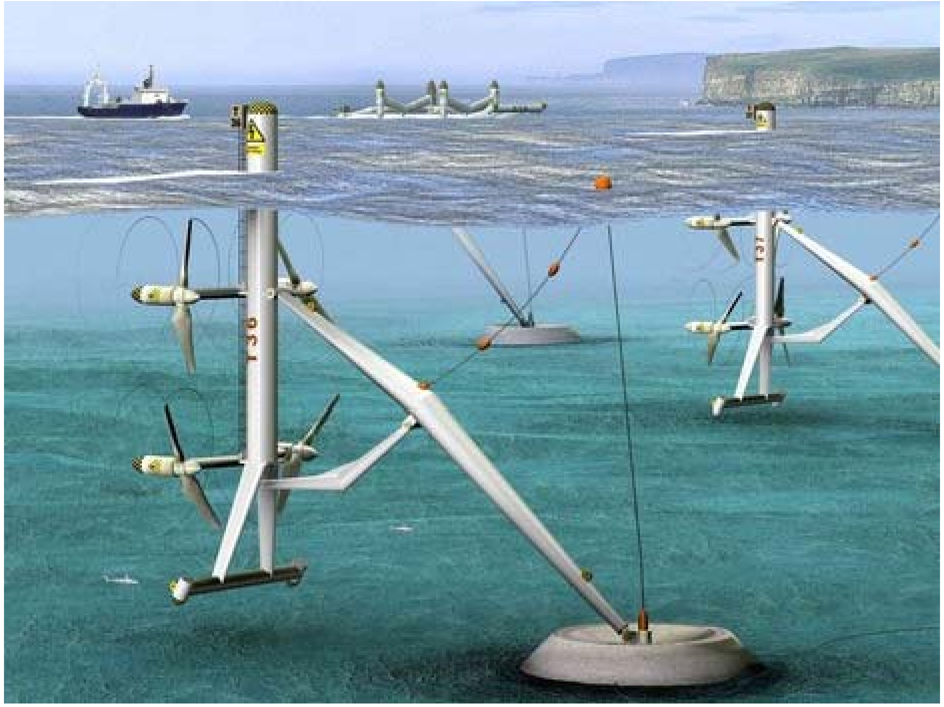
- tidal farms
- tidal barrages
- tidal lagoons

Tidal farms

1 exists in Hammerfest, Norway.

Power density of 6 W/m^2

Without concern for economics, upper estimates say that 9 kWh/day/person could be provided by Tidal farms.



14. Production: Tides

Estimating Energy Production from Tides

Three technologies

- tidal farms
- tidal barrages
- tidal lagoons

Tidal Barrages

Famous barrage at La Rance in France where the tidal range is 8 meters and has produced an average power of 60 MW since 1966.

A Tidal barrage is a dam-like structure used to capture the energy from masses of water moving in and out of a bay or river due to tidal forces.
Instead of damming water on one side like a conventional dam, a tidal barrage first allows water to flow into the bay or river during high tide, and releasing the water back during low tide. This is done by measuring the tidal flow and controlling the sluice gates at key times of the tidal cycle. Turbines are then placed at these sluices to capture the energy as the water flows in and out.

http://en.wikipedia.org/wiki/Tidal_barrage

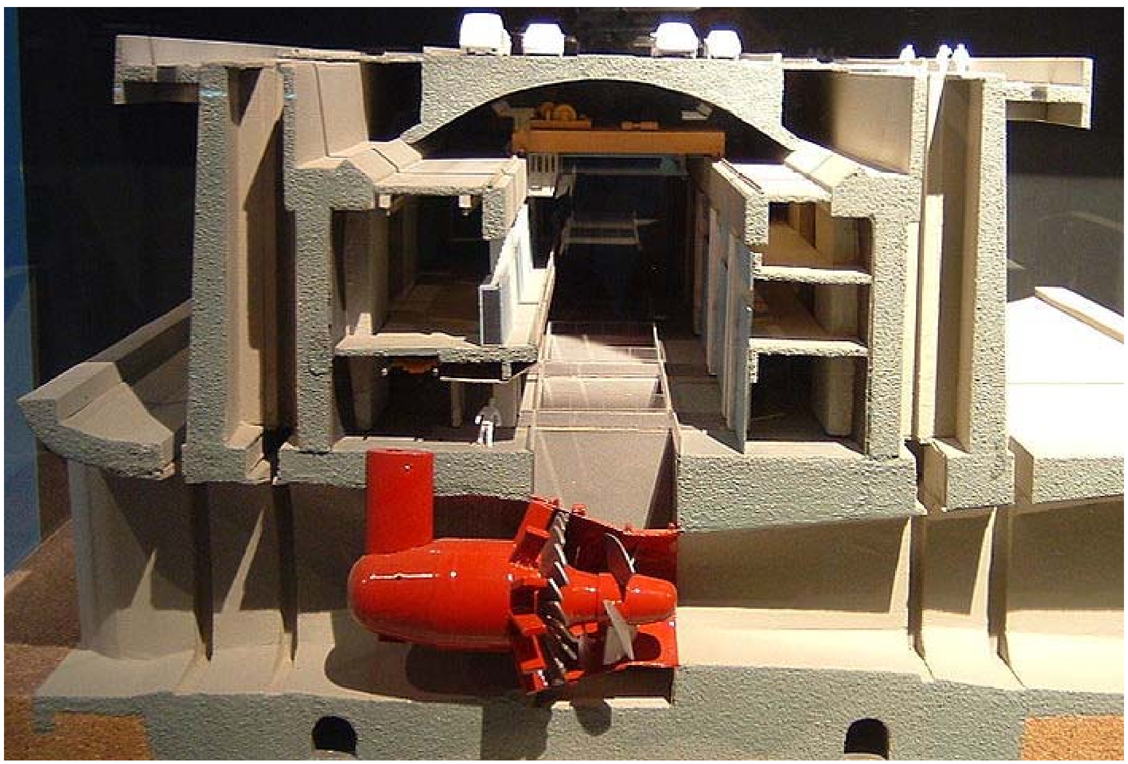
14. Production: Tides

Estimating Energy Production from Tides

Three technologies

- tidal farms
- tidal barrages
- tidal lagoons

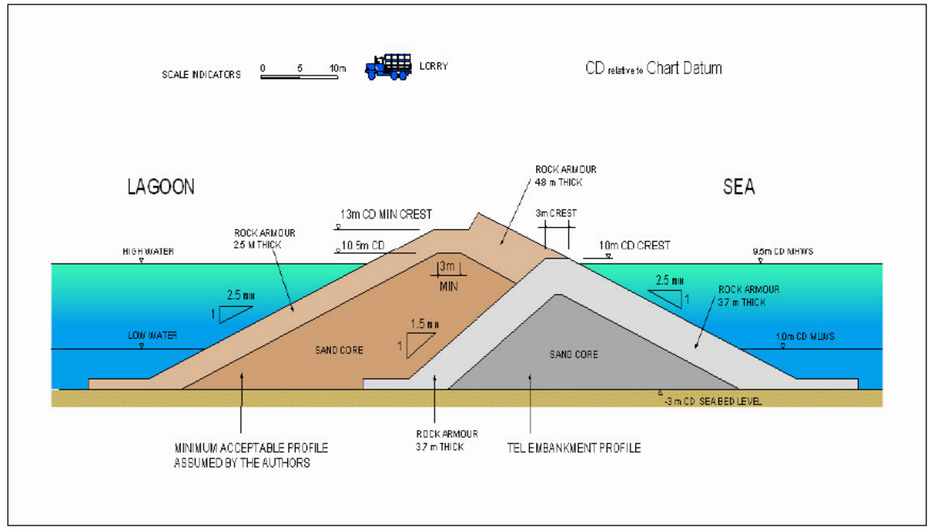
A similar barrage proposed at Cardiff (in England) would generate 0.8 kWh/day/person on average.



Country	France
Locale	Brittany
Coordinates	48°37′05″N 02°01′24″W
Status	Operational
Construction began	26 July 1963
Opening date	26 November 1966
Construction cost	₣620 million
Owner(s)	Électricité de France
Dam and spillways	
Type of dam	Barrage
Length	700 m (2,300 ft)
Reservoir	
Tidal range	8 m (26 ft)
Power station	
Type	Tidal barrage
Turbines	24
Installed capacity	240 MW
Annual generation	600 GWh

14. Production: Tides

Estimating Energy Production from Tides

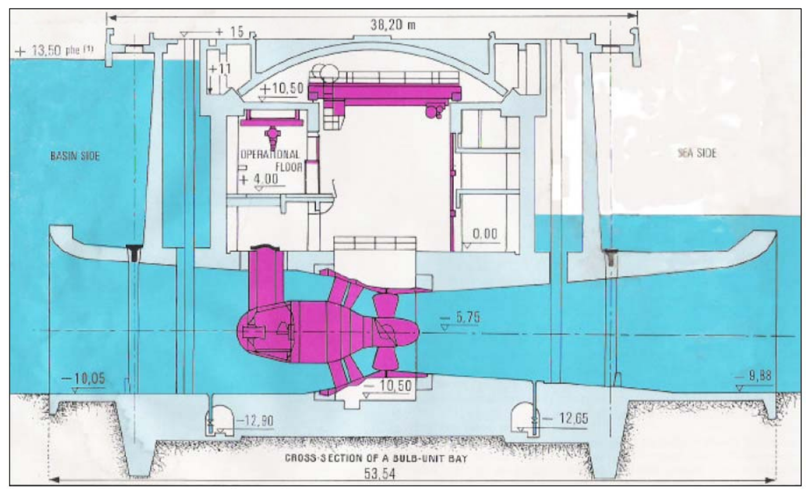


Three technologies

- tidal farms
- tidal barrages
- tidal lagoons

Tidal Lagoons

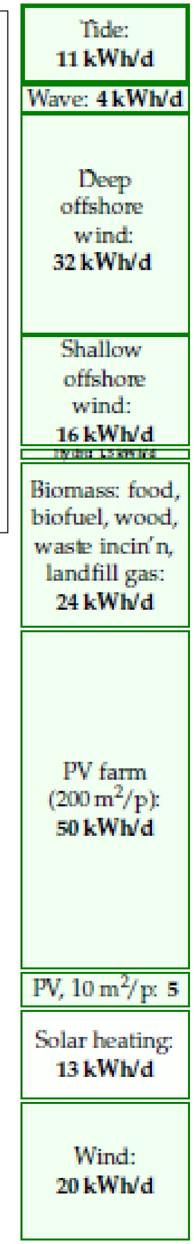
Building walls in shallow water can trap water that enters at high tide. This trapped water can be released through a turbine to generate power.



In the UK proposed tidal lagoons have an estimated power density of 4.5 W/m^2 with an area of 800 km^2, yielding 1.5 kWh/d/person.

Total from tides = 11 kWh/d/person

http://www.inference.phy.cam.ac.uk/sustainable/refs/tide/file30617.pdf



Estimating Energy Production from Geothermal

Figure 16.3. Geothermal power in Iceland. Average geothermal electricity generation in Iceland (population, 300 000) in 2006 was 300 MW (24 kWh/d per person). More than half of Iceland's electricity is used for aluminium production. Photo by Gretar Ívarsson.

Where does geothermal power come from?

- Radioactive decay in the crust of the earth 40 mW/m^2
- Heat trickling from the Earth's core 10 mW/m^2

16. Production: Geothermal

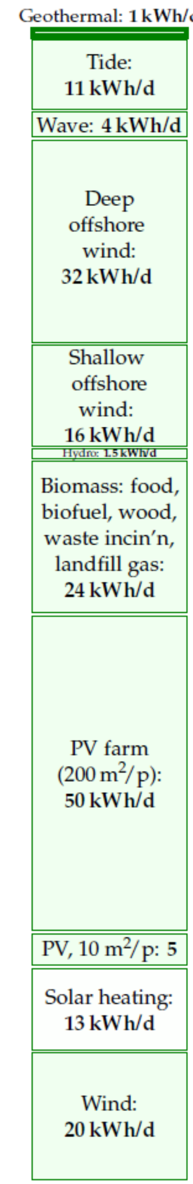
Estimating Energy Production from Geothermal

How do you get geothermal energy?
Dig holes in the ground.
Pump cold water in.
Get hot water out.

This can be done in 2 ways:

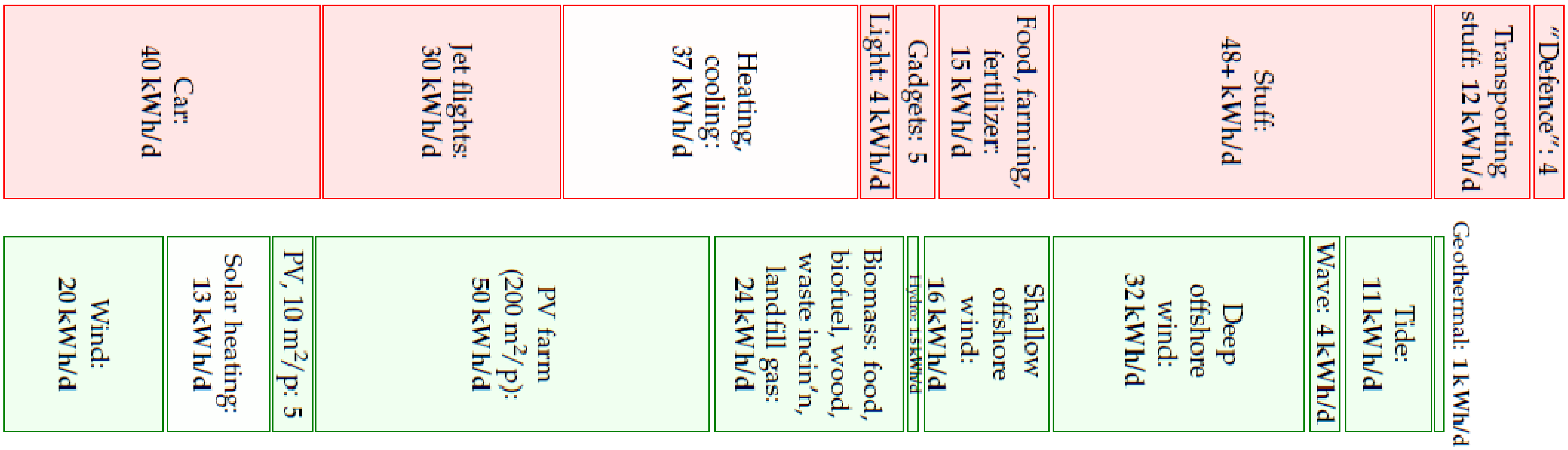
- unsustainably
  extract heat from the rock faster than it can be replenished
  "mining" the earth for heat
- sustainably
  extract heat only as fast as it is naturally generated

Sustainable plan
Dig holes 15 km deep.
Here a heat engine would yield 17 mW/m^2.
Use all available land.
2 kWh/d/person in the UK.



18. Production: Total

Estimating Total Energy Production from Sustainable Sources



The total energy consumption estimated = 195 kWh/day
The total conceivable sustainable energy production = 180 kWh/day

All economic, social and environmental considerations were ignored.

18. Produc

Estimating Total Energy Production from Sustainable Sources

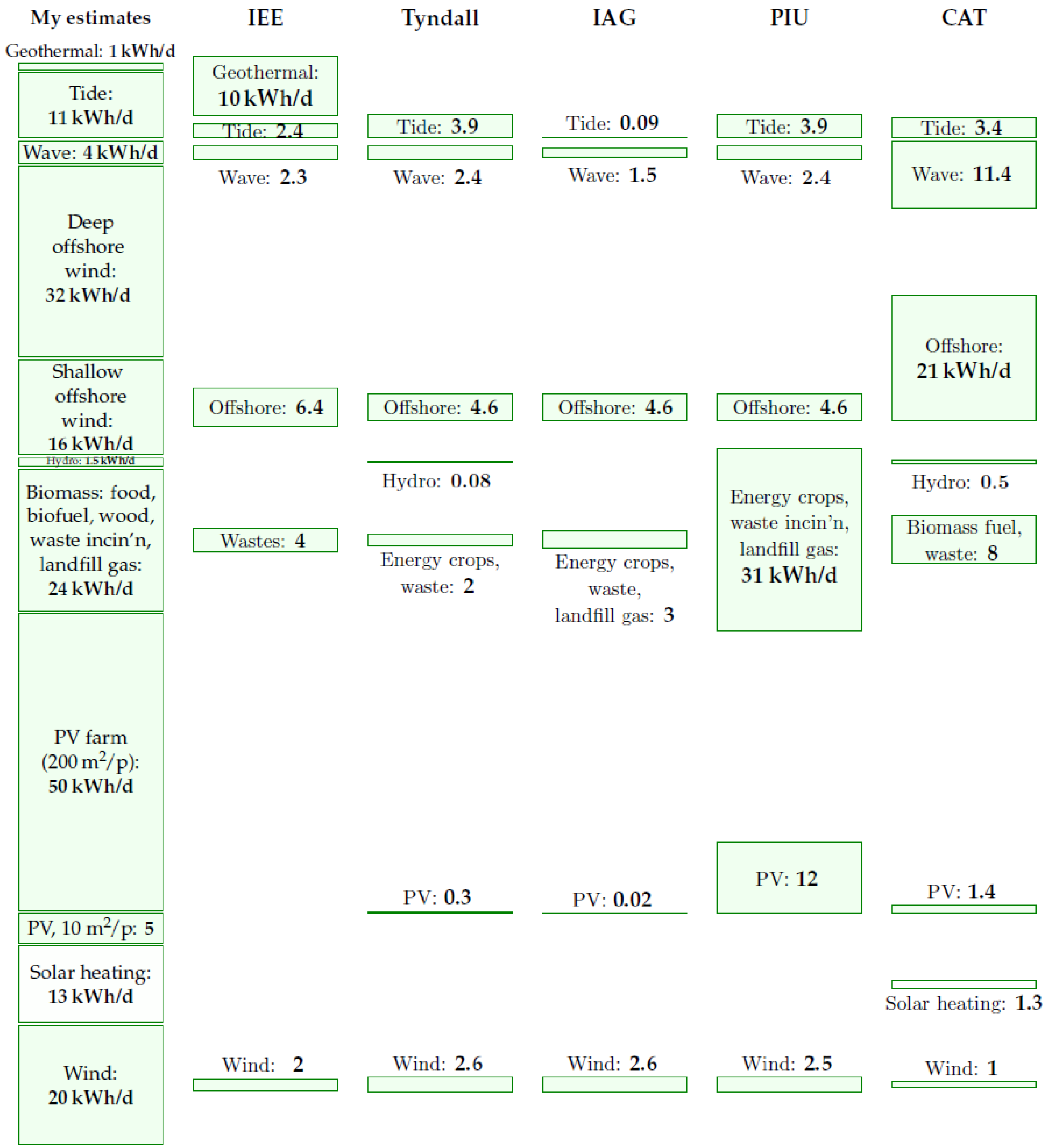
Totals

book
180 kWh/d/p

IEE
27 kWh/d/p

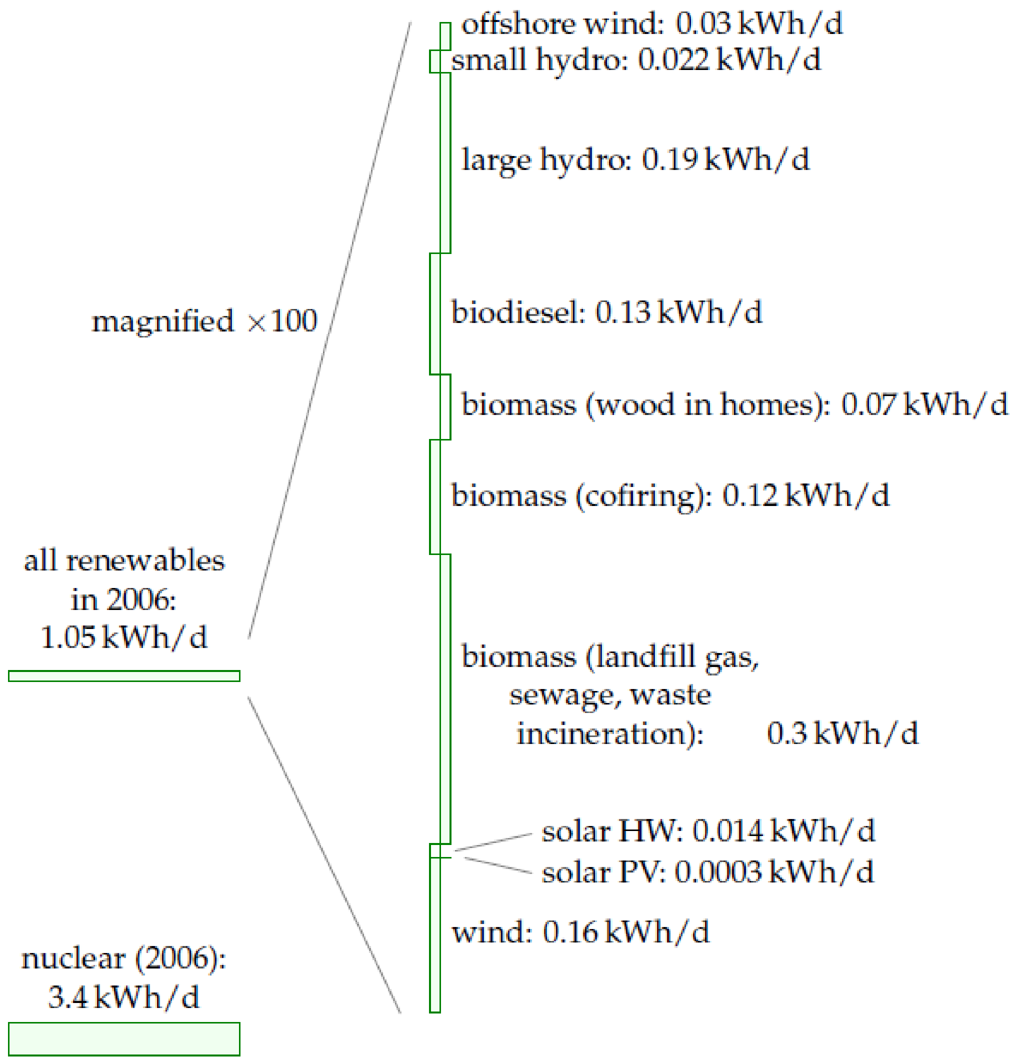
Tyndall
15 kWh/d/p

IAG
12 kWh/d/p



18. Production: Total

Current Total Energy Production from Sustainable Sources in the UK



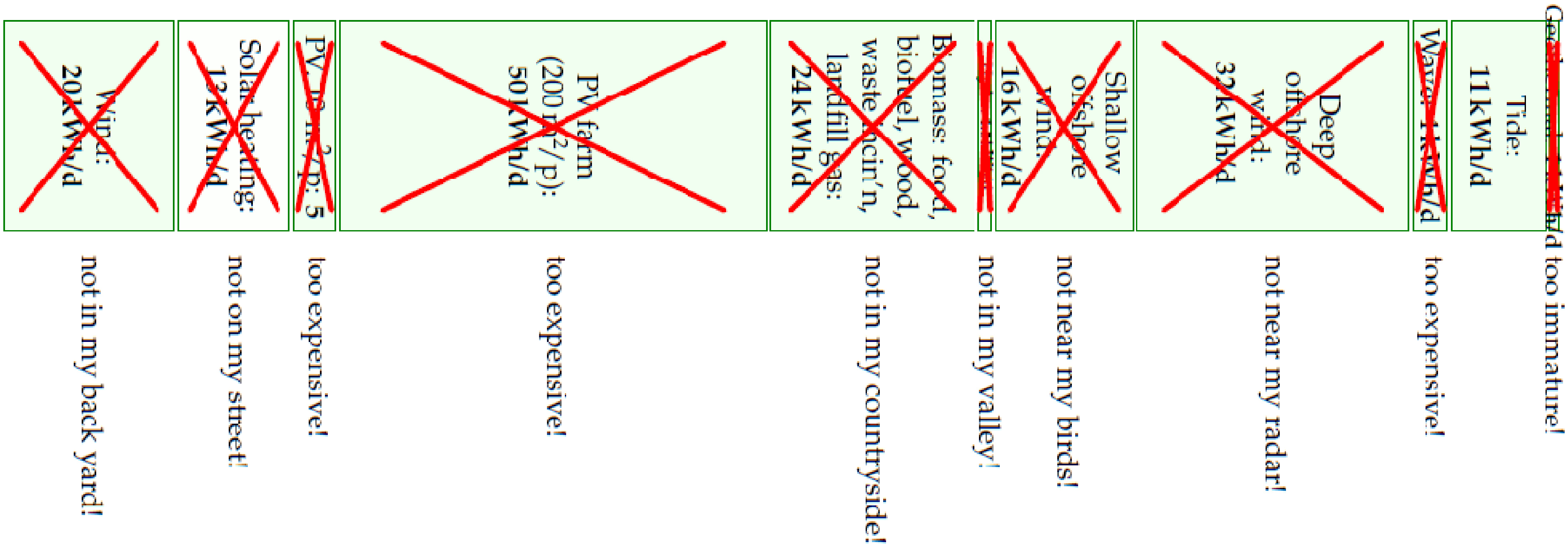
Strategies for Sustainable Energy

Lecture 6. Production Part II

Outline

Section 1: Estimating Sustainable Energy Production from Hydroelectricity
Section 2: Estimating Sustainable Energy Production from Offshore Wind
Section 3: Estimating Sustainable Energy Production from Waves
Section 4: Estimating Sustainable Energy Production from Tides
Section 5: Estimating Sustainable Energy Production from Geothermal
Section 6: Obstacles to Sustainable Energy Production

Production: Obstacles



Rivers No More: The Environmental Effects of Large Dams

The two main categories of environmental impacts of dams are those which are inherent to dam construction and those which are due to the specific mode of operation of each dam.

The most significant consequence of this myriad of complex and interconnected environmental disruptions is that they tend to fragment the riverine ecosystem, isolating populations of species living up and downstream of the dam and cutting off migrations and other species movements.

Because almost all dams reduce normal flooding, they also fragment ecosystems by isolating the river from its floodplain, turning what fish biologists term a 'floodplain river' into a 'reservoir river'. The elimination of the benefits provided by natural flooding may be the single most ecologically damaging impact of a dam.

This fragmentation of river ecosystems has undoubtedly resulted in a massive reduction in the number of species in the world's watersheds.

http://www.internationalrivers.org/en/node/1636

Production: Obstacles

Alliance to Protect Nantucket Sound (from wind turbines)

Esthetic concerns
The proposed turbines for Nantucket Sound constitute "wind factories," a gigantic industrial development in the waters between mainland Cape Cod and the Islands.

Is this the character of the region Cape Codders really want? And are they ready to embrace turbines, with all their accompanying noise, light flicker and visual blight?

Economic Concerns
The DPU approved an electricity rate deal between Cape Wind and National Grid that could force consumers and businesses to pay $1.4 billion extra on their energy bills over 15 years.

“This decision will not only raise costs for our members, but also establishes a dangerous precedent of regulatory rubber-stamping of renewable energy contracts with absolutely no concern for the ratepayer.”

http://www.saveoursound.org/

Production: Obstacles

Wind turbines disrupt radar

Wind turbines, with tip speeds of 6-7 times the wind speed, can create clutter interference and possibly significant Doppler interference with the very sensitive radars fielded by the FAA, DOD, NOAA, and other agencies. Aircraft targets and, to some extent, weather features seen by NOAA radars, can be temporarily lost, fail to be located, shadowed by the radar signature of the turbine farm, or misidentified, and the wind turbines may also lead to false detection of aircraft. These problems have led the FAA to issue a number of Notices of Presumed Hazard, stalling further work on the installation of several thousand MW of wind turbine power

http://www.fas.org/irp/agency/dod/jason/wind.pdf

Production: Obstacles

Tidal Barrages damage the environment

The placement of a barrage into an estuary has a considerable effect on the water inside the basin and on the ecosystem. Many governments have been reluctant in recent times to grant approval for tidal barrages. Through research conducted on tidal plants, it has been found that tidal barrages constructed at the mouths of estuaries pose similar environmental threats as large dams. The construction of large tidal plants alters the flow of saltwater in and out of estuaries, which changes the hydrology and salinity and possibly negatively affects the marine mammals that use the estuaries as their habitat [5] The La Rance plant, off the Brittany coast of northern France, was the first and largest tidal barrage plant in the world. It is also the only site where a full-scale evaluation of the ecological impact of a tidal power system, operating for 20 years, has been made [6]
French researchers found that the isolation of the estuary during the construction phases of the tidal barrage was detrimental to flora and fauna, however; after ten years, there has been a "variable degree of biological adjustment to the new environmental conditions" [6]
Some species lost their habitat due to La Rance's construction, but other species colonized the abandoned space, which caused a shift in diversity. Also as a result of the construction, sandbanks disappeared, the beach of St. Servan was badly damaged and high-speed currents have developed near sluices, which are water channels controlled by gates [7]

http://en.wikipedia.org/wiki/Tidal_barrage#Environmental_impact

Does tidal power slow the rotation of the Earth?

Tidal power, while clean and green, should not be called renewable. Extracting power from the tides slows down the earth's rotation. We definitely can't use tidal power long-term.

False. The natural tides already slow down the earth's rotation. The natural rotational energy loss is roughly 3 TW (Shepherd, 2003). Thanks to natural tidal friction, each century, the day gets longer by 2.3 milliseconds. Many tidal energy extraction systems are just extracting energy that would have been lost anyway in friction. But even if we *doubled* the power extracted from the earth–moon system, tidal energy would still last more than a billion years.

Geothermal Wells Cause Earthquakes!

Plant construction can adversely affect land stability. Subsidence (sinking of the land) has occurred in the Wairakei field in New Zealand and in Staufen im Breisgau, Germany. Enhanced geothermal systems can trigger earthquakes as part of hydraulic fracturing. The project in Basel, Switzerland was suspended because more than 10,000 seismic events measuring up to 3.4 on the Richter Scale occurred over the first 6 days of water injection.

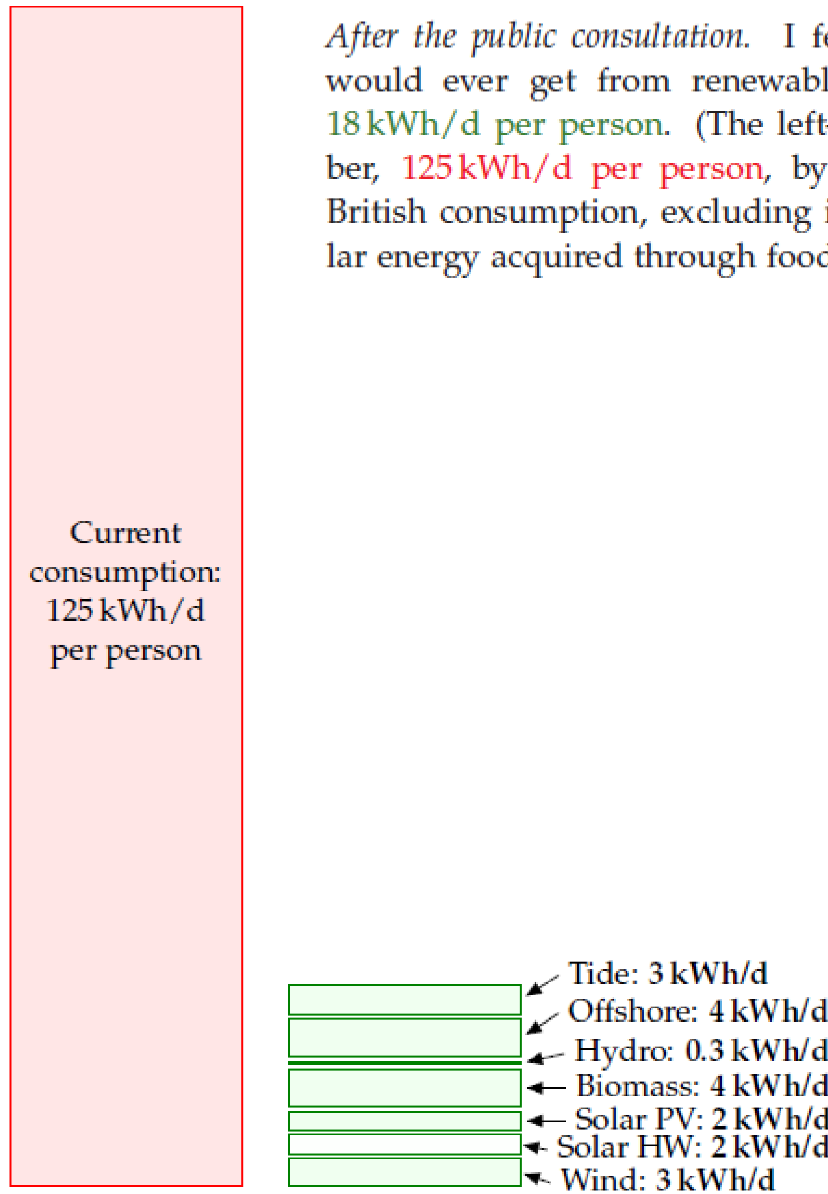
Fluids drawn from the deep earth carry a mixture of gases, notably carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4) and ammonia (NH_3). These pollutants contribute to global warming, acid rain, and noxious smells if released. Existing geothermal electric plants emit an average of 122 kilograms (269 lb) of CO_2 per megawatt-hour (MW·h) of electricity, a small fraction of the emission intensity of conventional fossil fuel plants. Plants that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust.

http://en.wikipedia.org/wiki/Geothermal_energy#Environmental_effects

18. Production: Total

Estimating Total Energy Production from Sustainable Sources

After the public consultation. I fear the maximum Britain would ever get from renewables is in the ballpark of 18 kWh/d per person. (The left-hand consumption number, 125 kWh/d per person, by the way, is the average British consumption, excluding imports, and ignoring solar energy acquired through food production.)



18. Production: Total

Estimating Total Energy Production from Sustainable Sources

Two Conclusions

1. To make a difference, renewable energy facilities have to be country sized.

2. It's not going to be easy.

Power per unit land or water area	
Wind	2 W/m^2
Offshore wind	3 W/m^2
Tidal pools	3 W/m^2
Tidal stream	6 W/m^2
Solar PV panels	5–20 W/m^2
Plants	0.5 W/m^2
Rain-water (highlands)	0.24 W/m^2
Hydroelectric facility	11 W/m^2
Geothermal	0.017 W/m^2

Table 18.10. Renewable facilities have to be country-sized because all renewables are so diffuse.