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Strategies for Sustainable Energy

Lecture 6. Production Part II

ENG2110-01
College of Engineering
Yonsei University
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Strategies for Sustainable Energy

Lecture 6. Production Part II

Outline

8. Production: Hydroelectricity

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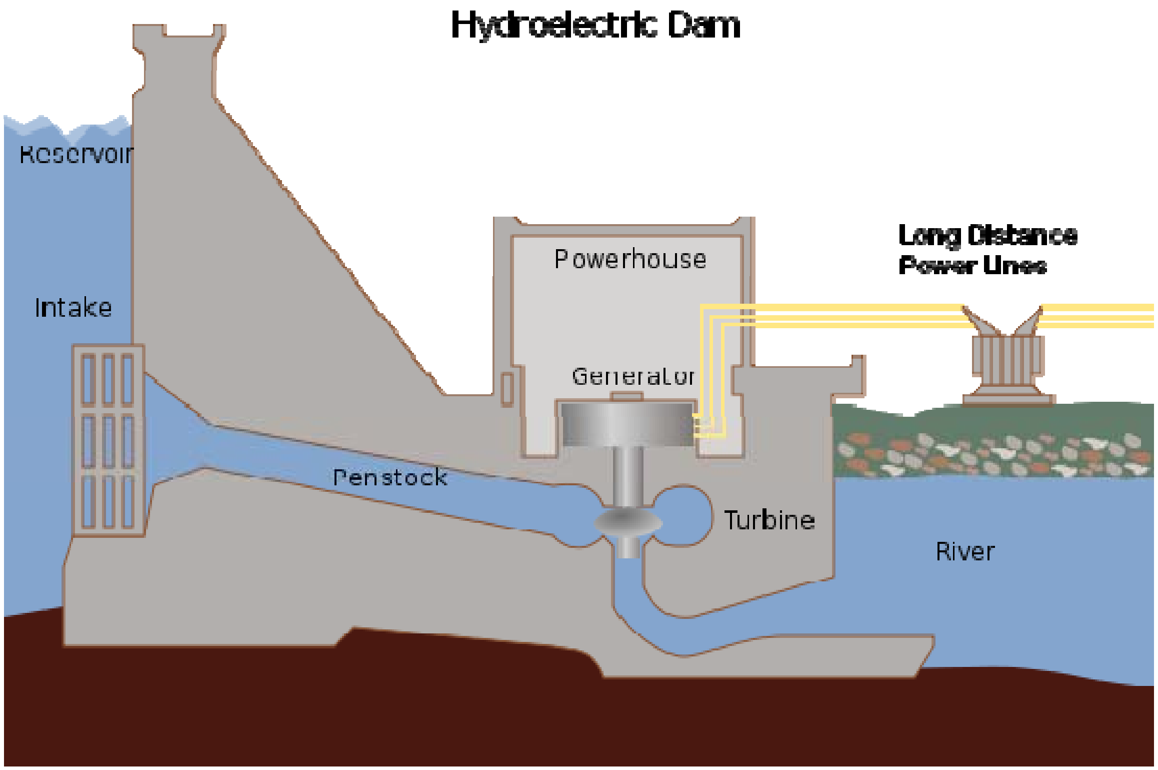
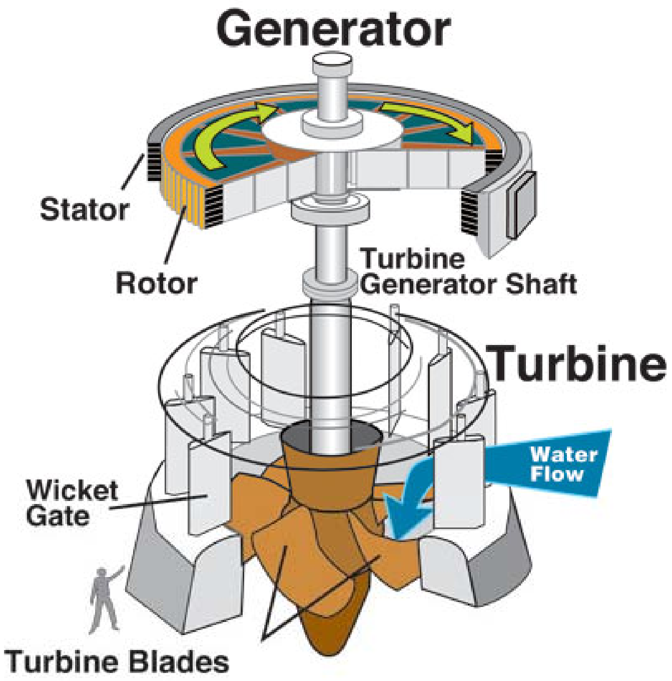
How it works: Converts gravitational potential energy of water to rotational kinetic energy of turbine and generator, which generates electricity.





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

8. Production: Hydroelectricity

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Estimating Energy Production from Hydroelectricity

To make hydroelectricity, you need

- altitude change
- rain

Two estimates for the UK:

- dry lowlands

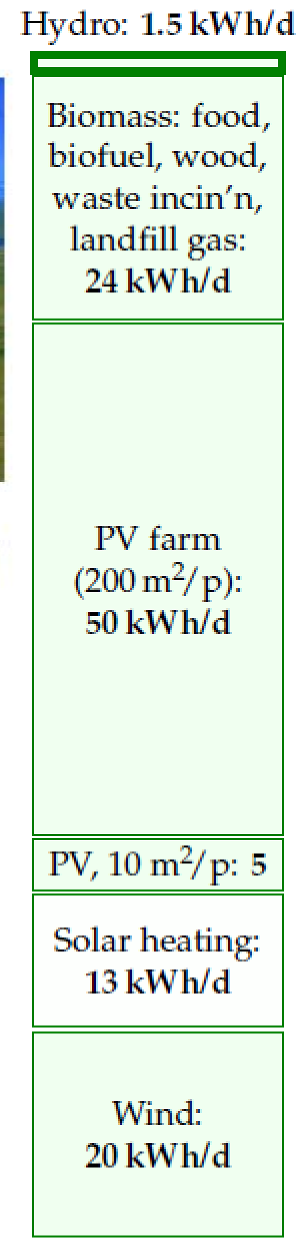
  rainfall = 584 mm/year
  gravity = 10 m/s^2
  density = 1000 kg/m^3
  altitude = 100 m
  maximum energy = 1 kWh/day/person
  if every river was dammed and every raindrop used

- 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

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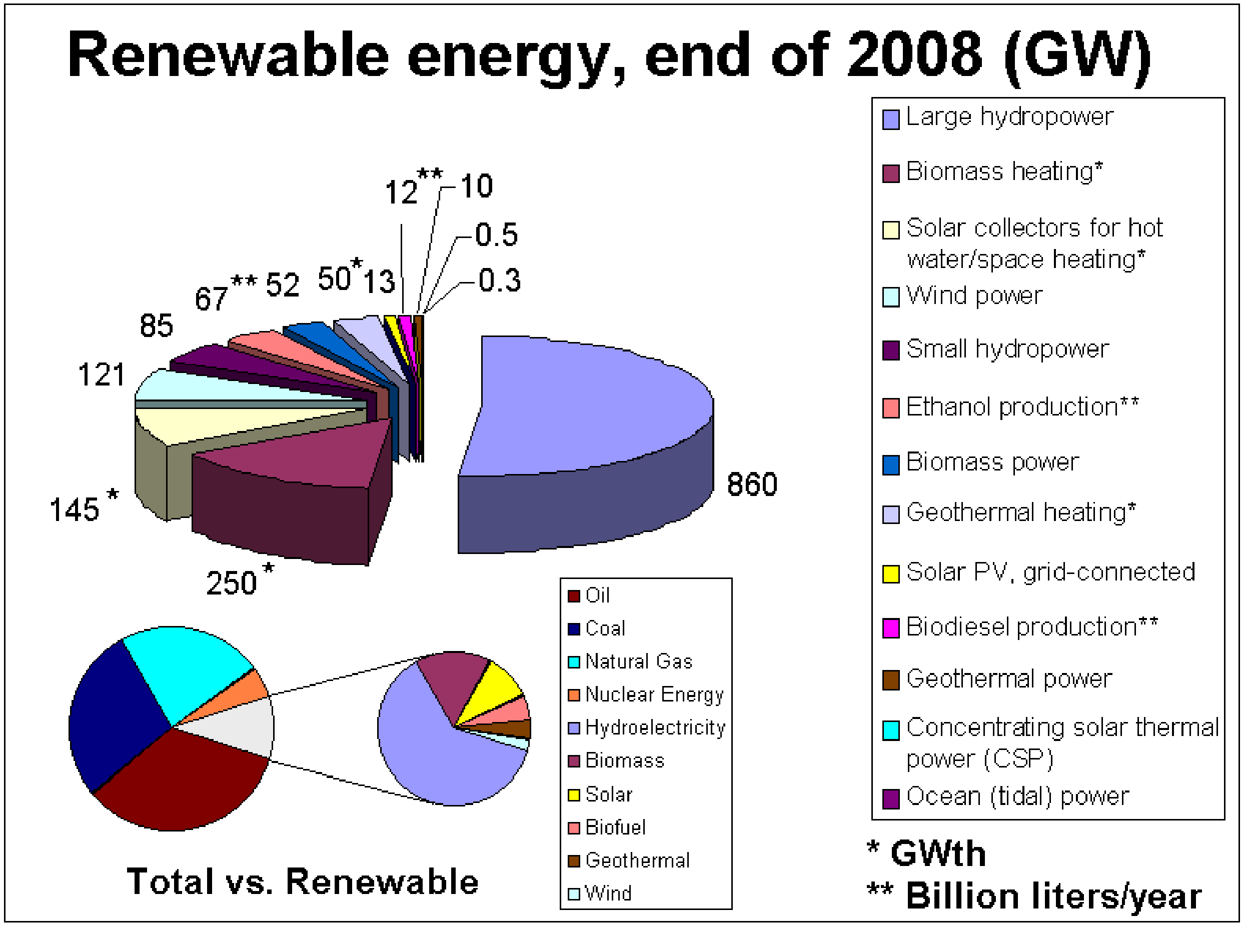
Worldwide, an installed capacity of 777 GWe (giga Watt electrical) supplied 2998 TWh of hydroelectricity in 2006.

This was approximately 20% of the world's electricity, and accounted for about 88% of electricity from renewable sources.



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

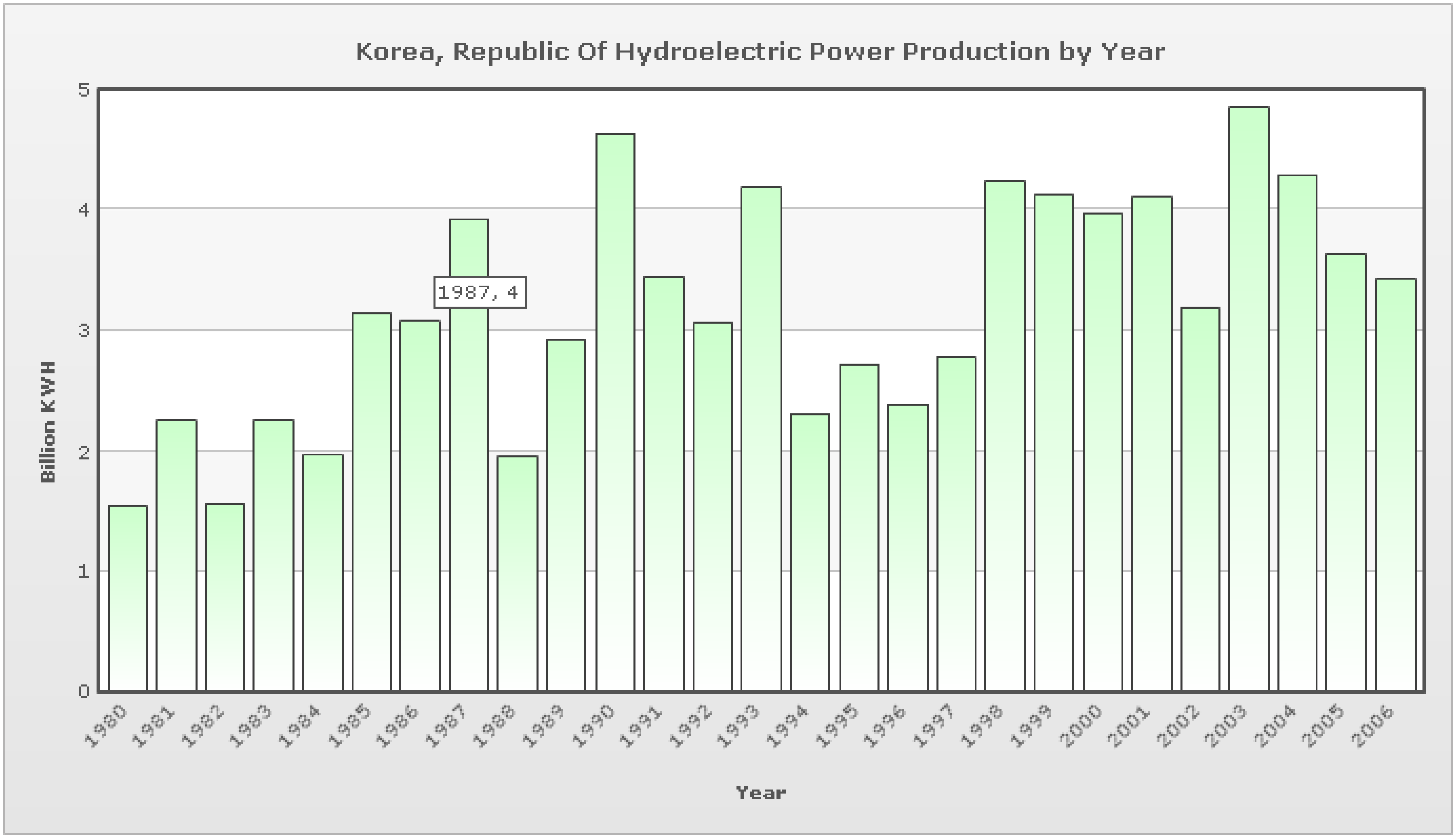
8. Production: Hydroelectricity

Ten of the largest hydroelectric producers as at 2009.[30][31]

Country	Annual hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total capacity
China	652.05	196.79	0.37	22.25
Canada	369.5	88.974	0.59	61.12
Brazil	363.8	69.080	0.56	85.56
United States	250.6	79.511	0.42	5.74
Russia	167.0	45.000	0.42	17.64
Norway	140.5	27.528	0.49	98.25
India	115.6	33.600	0.43	15.80
Venezuela	85.96	14.622	0.67	69.20
Japan	69.2	27.229	0.37	7.21
Sweden	65.5	16.209	0.46	44.34

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

8. Production: Hydroelectricity



http://www.indexmundi.com/energy.aspx?country=kr&product=hydro&graph=production

8. Production: Hydroelectricity

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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

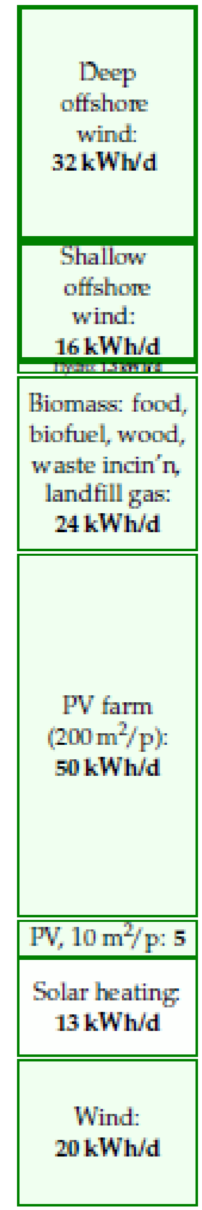
- near off-shore

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

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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.

10. Production: Off-shore Wind

Aerial view of Lillgrund Wind Farm, Sweden

http://en.wikipedia.org/wiki/File:Sund_mpazdziora.JPG

10. Production: Off-shore Wind

World's largest offshore wind farms

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned	References
Thanet	300	United Kingdom	100 × Vestas V90-3MW	2010	[14][15]
Horns Rev II	209	Denmark	91 × Siemens 2.3-93	2009	[16]
Rødsand II	207	Denmark	90 × Siemens 2.3-93	2010	[17]
Lynn and Inner Dowsing	194	United Kingdom	54 × Siemens 3.6-107	2008	[18][19][20][21]
Robin Rigg (Solway Firth)	180	United Kingdom	60 × Vestas V90-3MW	2010	[22][23]
Gunfleet Sands	172	United Kingdom	48 × Siemens 3.6-107	2010	[23][24]
Nysted (Rødsand I)	166	Denmark	72 × Siemens 2.3	2003	[18][25][26]

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

10. Production: Off-shore Wind

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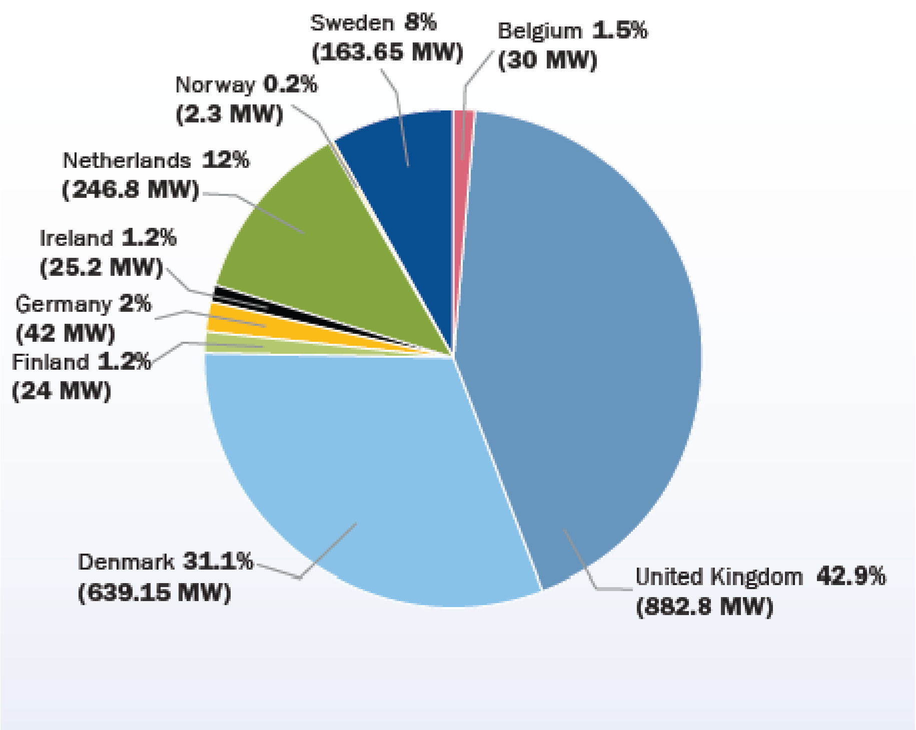
INSTALLED CAPACITY: CUMULATIVE SHARE BY COUNTRY END 2009 IN MW

FIGURE 3.2



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

12. Production: Waves

Estimating Energy Production from Waves

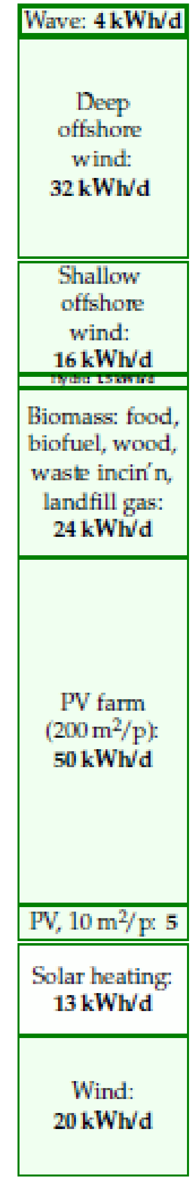
Where do waves come from?
The sun creates wind. Wind creates waves.

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.



12. Production: Waves

No commercial energy production

In the United States, the Pacific Northwest Generating Cooperative is funding the building of a commercial wave-power park at Reedsport, Oregon.[22] The project will utilize the PowerBuoy technology Ocean Power Technologies which consists of modular, ocean-going buoys. The rising and falling of the waves moves hydraulic fluid with the buoy; this motion is used to spin a generator, and the electricity is transmitted to shore over a submerged transmission line. A 150 kW buoy has a diameter of 36 feet (11 m) and is 145 feet (44 m) tall, with approximately 30 feet of the unit rising above the ocean surface. Using a three-point mooring system, they are designed to be installed one to five miles (8 km) offshore in water 100 to 200 feet (60 m) deep.[23]

An example of a surface following device is the Pelamis Wave Energy Converter. The sections of the device articulate with the movement of the waves, each resisting motion between it and the next section, creating pressurized oil to drive a hydraulic ram which drives a hydraulic motor.[24] The machine is long and narrow (snake-like) and points into the waves; it attenuates the waves, gathering more energy than its narrow profile suggests. Its articulating sections drive internal hydraulic generators (through the use of pumps and accumulators).

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

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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

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Estimating Energy Production from Tides

Three technologies

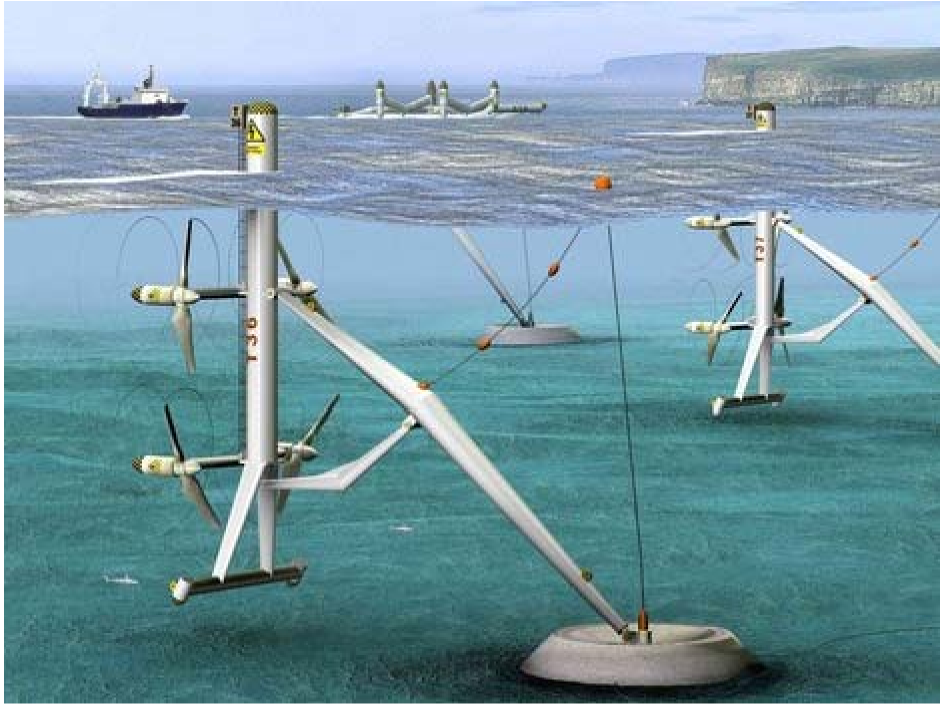
- tidal farms
- tidal barrages
- tidal lagoons

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

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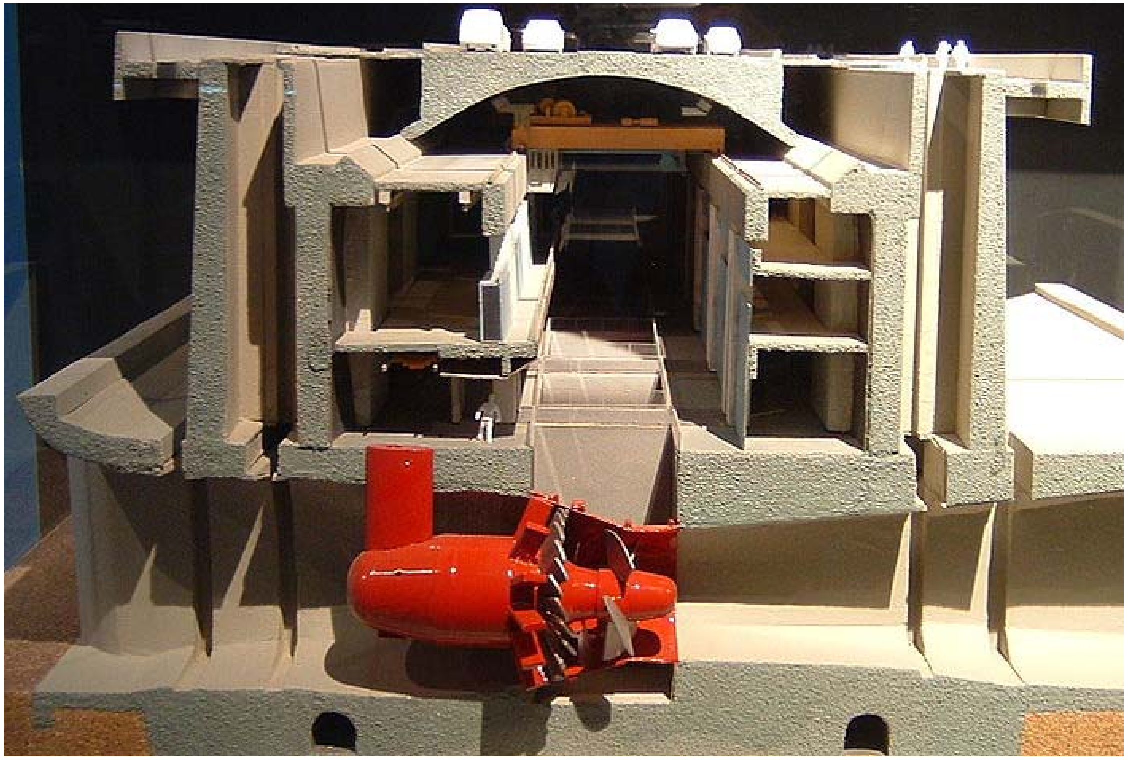
Estimating Energy Production from Tides

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.



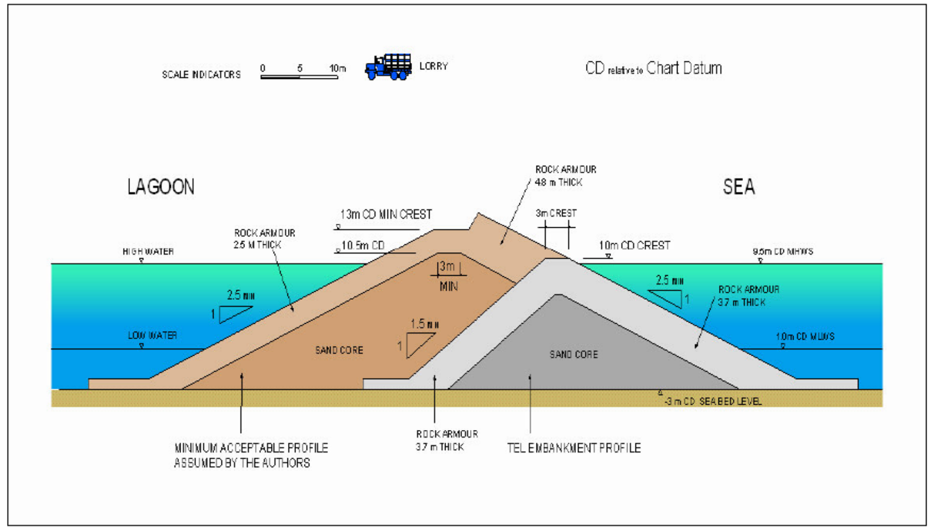
Country	France
Locale	Brittany
Coordinates	48°37′05″N 02°01′24″W
Status	Operational
Construction began	26 July 1963
Opening date	26 November 1966
Construction cost	₣620 million
Owner(s)	Électricité de France
Dam and spillways	
Type of dam	Barrage
Length	700 m (2,300 ft)
Reservoir	
Tidal range	8 m (26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

14. Production: Tides

Estimating Energy Production from Tides

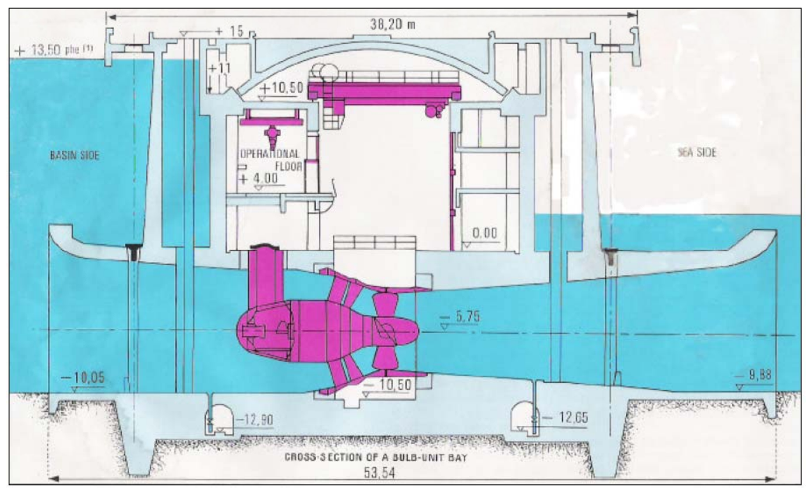
Three technologies

- tidal farms
- tidal barrages
- tidal lagoons



Tidal Lagoons

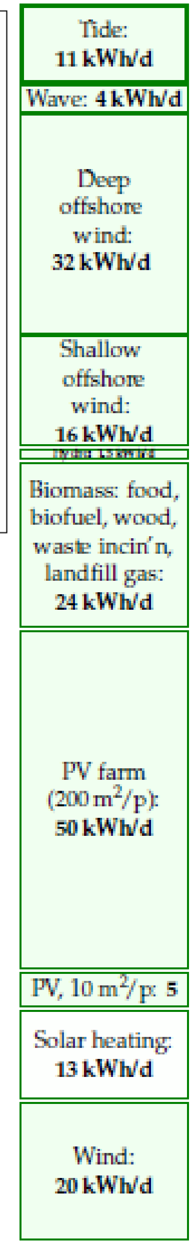
Building walls in shallow water can trap water that enters at high tide. This trapped water can be released through a turbine to generate power.



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



14. Production: Tides

Sihwa Lake Tidal Power Station is a large tidal power station currently under construction. When completed the plant will operate with a total power output capacity of 254 MW, surpassing the 240 MW Rance Tidal Power Station to become the world's largest tidal power installation.

The tidal barrage makes use of a seawall constructed in 1994 for flood mitigation and agricultural purposes. Ten 25.4 MW submerged bulb turbines are driven in an unpumped flood generation scheme; power is generated on tidal inflows only and the outflow is sluiced away. This slightly unconventional and relatively inefficient approach has been chosen to balance a complex mix of existing land use, water use, conservation, environmental and power generation considerations.

The tidal power station should provide indirect environmental benefits as well as renewable energy generation. After the seawall was built, pollution built up in the newly created Sihwa Lake reservoir, making its water useless for agriculture. In 2004, seawater was reintroduced in the hope of flushing out contamination; future inflows from the tidal barrage are envisaged as a complementary permanent solution.[1]

The working basin area was originally intended to be 43 km^2 (17 sq mi)[4] although this already been reduced by land reclamation and freshwater dykes. The basin will eventually be only around 30 km^2 (12 sq mi).

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

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

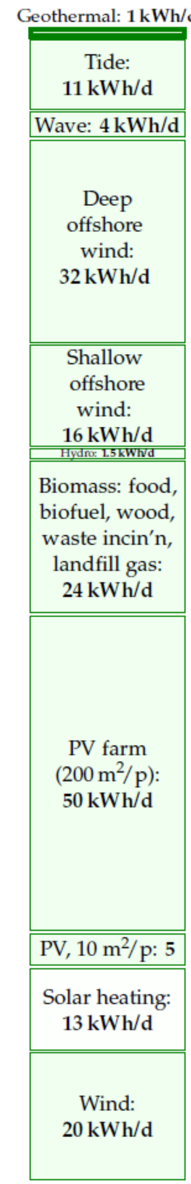
Estimating Energy Production from Geothermal

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.



16. Production: Geothermal

The International Geothermal Association (IGA) has reported that 10,715 megawatts (MW) of geothermal power in 24 countries is online, which is expected to generate 67,246 GWh of electricity in 2010. This represents a 20% increase in geothermal power online capacity since 2005. IGA projects this will grow to 18,500 MW by 2015, due to the large number of projects presently under consideration, often in areas previously assumed to have little exploitable resource.

In 2010, the United States led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants;[3] the largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California. The Philippines follows the US as the second highest producer of geothermal power in the world, with 1,904 MW of capacity online; geothermal power makes up approximately 18% of the country's electricity generation.

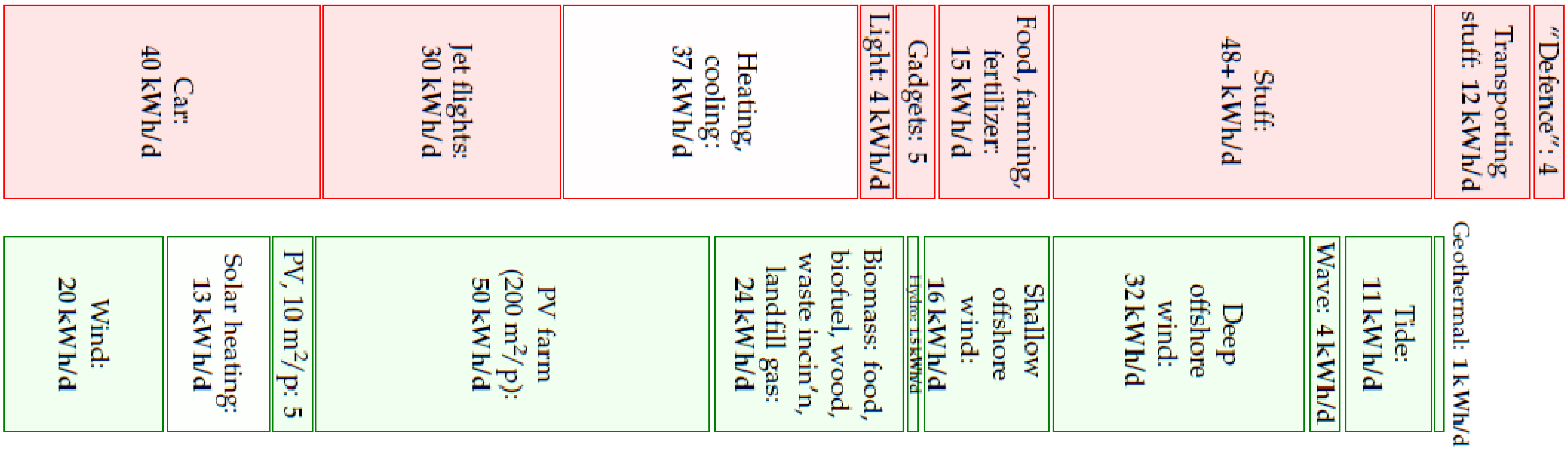
http://en.wikipedia.org/wiki/Geothermal_electricity

Installed geothermal electric capacity

Country	Capacity (MW) 2007[6]	Capacity (MW) 2010[28]	percentage of national production
USA	2687	3086	0.3%
Philippines	1969.7	1904	27%
Indonesia	992	1197	3.7%
Mexico	953	958	3%
Italy	810.5	843	
New Zealand	471.6	628	10%
Iceland	421.2	575	30%
Japan	535.2	536	0.1%
El Salvador	204.2	204	14%
Kenya	128.8	167	11.2%
Costa Rica	162.5	166	14%
Turkey	38	94	0.3%
Nicaragua	87.4	88	10%
Russia	79	82	
Papua-New Guinea	56	56	
Guatemala	53	52	
Portugal	23	29	
China	27.8	24	
France	14.7	16	
Ethiopia	7.3	7.3	
[illegible]	[illegible]	[illegible]	

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

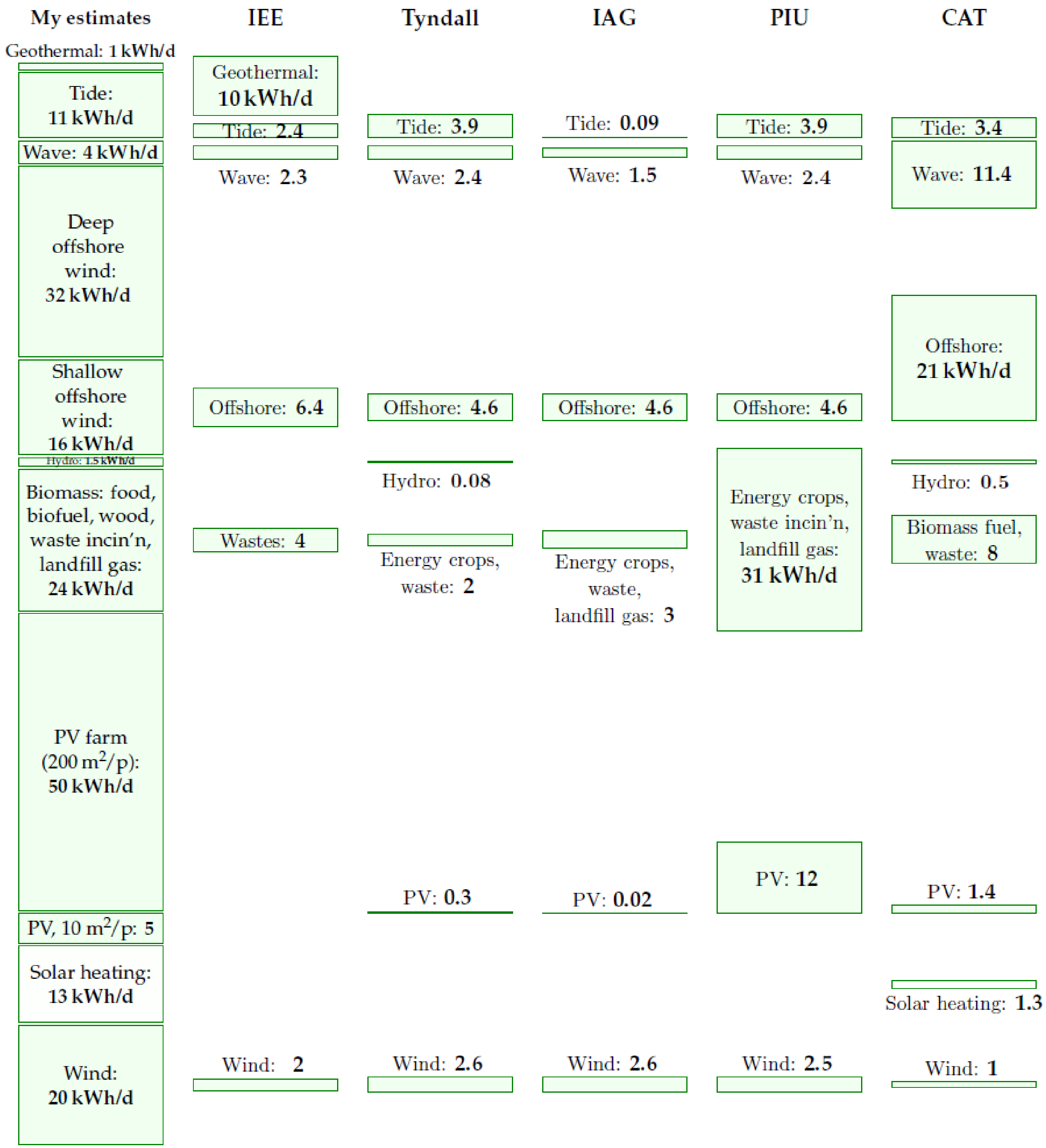
Totals

book
180 kWh/d/p

IEE
27 kWh/d/p

Tyndall
15 kWh/d/p

IAG
12 kWh/d/p



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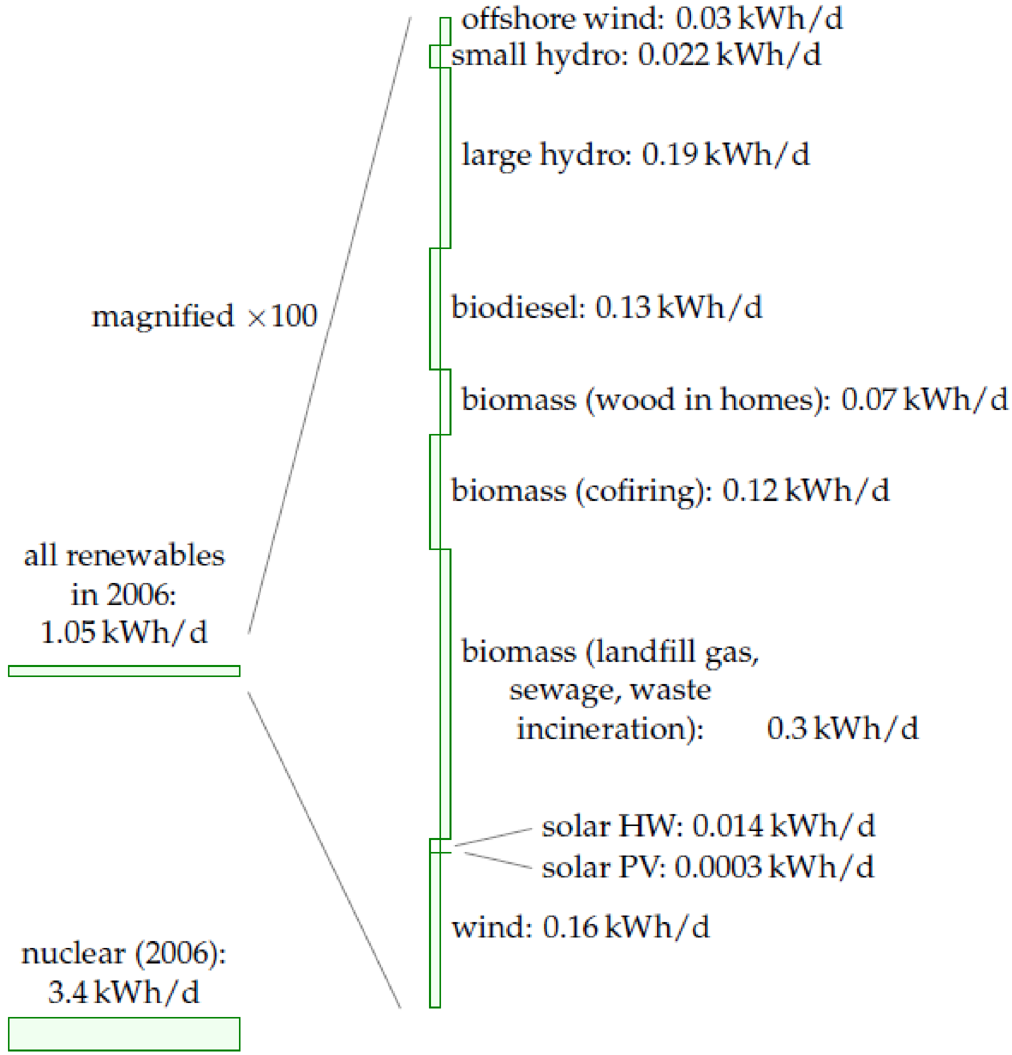
Current Total Energy Production from Sustainable Sources in the UK



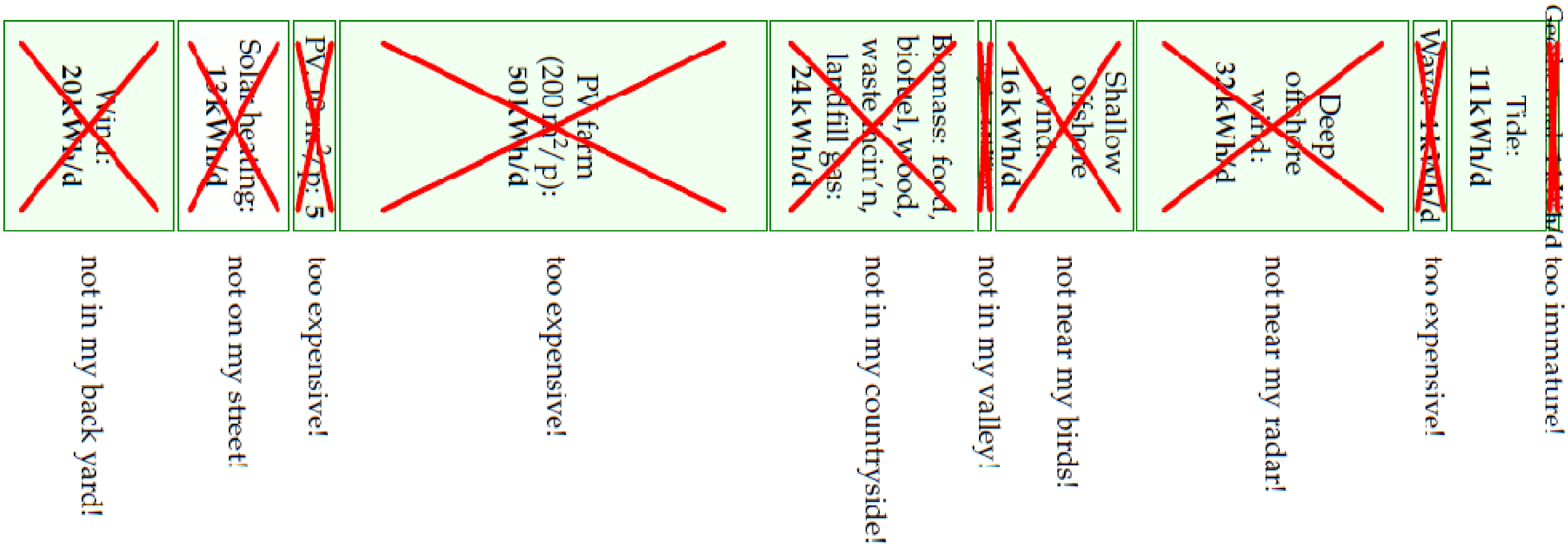
Strategies for Sustainable Energy

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

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/

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

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 ($CO2$), hydrogen sulfide ($H2S$), methane ($CH4$) and ammonia ($NH3$). 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 $CO2$ 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

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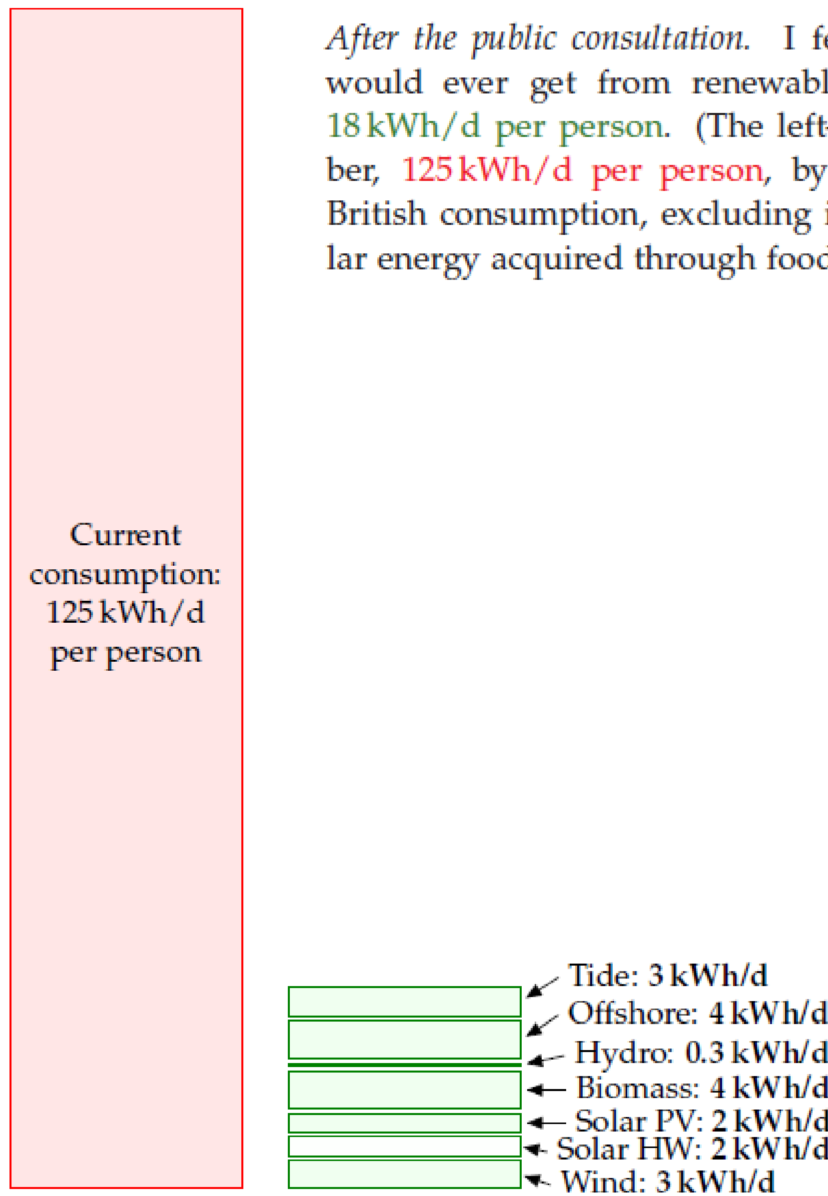
Estimating Total Energy Production from Sustainable Sources

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

YONSEI UNIVERSITY

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.