The power generation options

The energy options

The sources for the production of mechanical and electricity can be classified into:

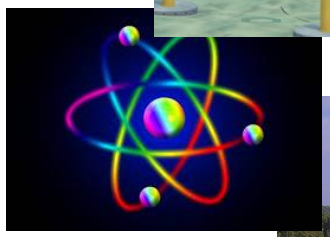
Traditional energy sources: are those that *use fossil fuels*. They are non-renewable sources of energy. They derive from the transformation of organic substances (coal, oil and natural gas) into more stable and carbon-rich forms. They are *non-renewable*, and their use at current rates jeopardizes their availability for future generations. *Currently, the largest share of energy is generated with these sources*.

Sustainable energy sources: are those that *use no fossil fuels*. Renewable energies are a subcategory of sustainable energy.

The energy options

- **Fossil energy sourses**
  - ✓ Coal
  - ✓ Oil
  - ✓ Natural Gas (fossil gas)

- **Sustainable energy sources**
  - Renewable energy sources
    - ✓ Solar (solar panel, photovoltaic cells)
    - ✓ Wind power
    - ✓ Hydropower
    - ✓ Geothermal
    - ✓ Marine energy (tidal power, wave power)
  - Non-renewable energy sources
    - ✓ Nuclear power (fission and fusion)
    - ✓ Biogas (methane and carbon dioxide produced from wastes
    - ✓ Biofuel (from biomass)



sugarcane plantation to produce ethanol

Units of ENERGY

Unit of Energy	Symbol	Equivalent amount of J
Kilojoule	kJ	10^3
Megjoule	MJ	10^6
Kilowatt-hour	kWh	3.6×10^6
Ton of Oil Equivalent*	toe	41.87×10^9
Kilocalorie	kcal	4.19×10^3
Electronvolt**	eV	1.6022×10^{-19}

The tonne of oil equivalent is the approximate energy that results by burning one tonne of crude oil. The tonne is a non-SI unit of mass equal to 1000 kilograms.

1 TOE → 11,639 MWh

The energy options

The mai use of the fossil fuels are:

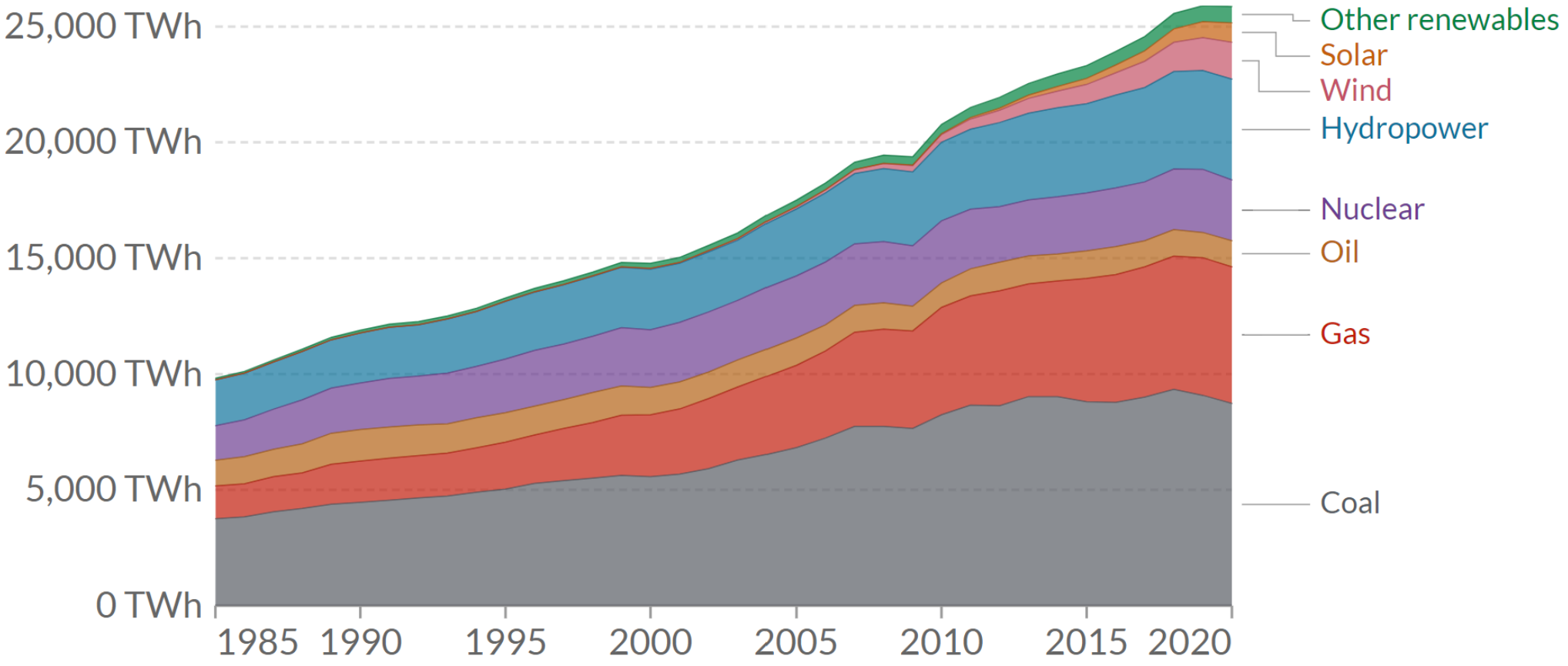
- Oil: transport fuels
- Gas: space heating and production of electricity
- Coal: production of electricity

The resources of fossil fuels are plentiful (at least those of coal), and they can satisfy our demand for at least another **hundred years**.

Main problems with burning fossil fuels

- **pollutants** released in the air and urban smog
- carbon dioxide (**CO_2**) due to coal enhancing green house effect
- Around 80% of the world's oil resources are located in the **Middle East**
- Most **European** gas resources are supposed to be depleted in about **30 years**

The electricity production by source

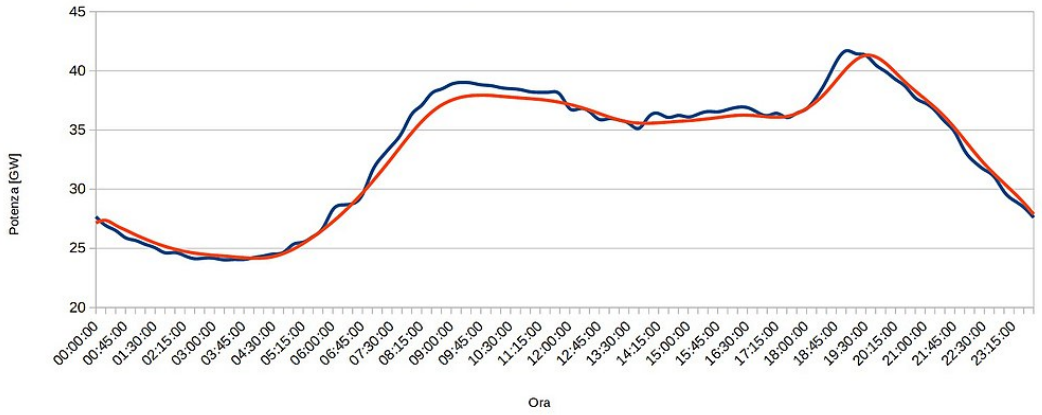


Source: Our World in Data based on BP Statistical Review of World Energy & Ember (2021)
Note: 'Other renewables' includes biomass and waste, geothermal, wave and tidal.

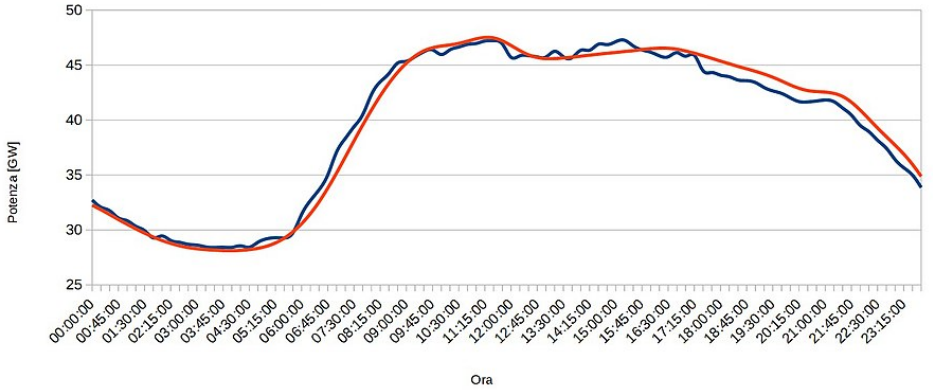
Electricity daily load diagram

Italian electricity ***base load***: about 25 GW

18 March 2020



15 July 2020



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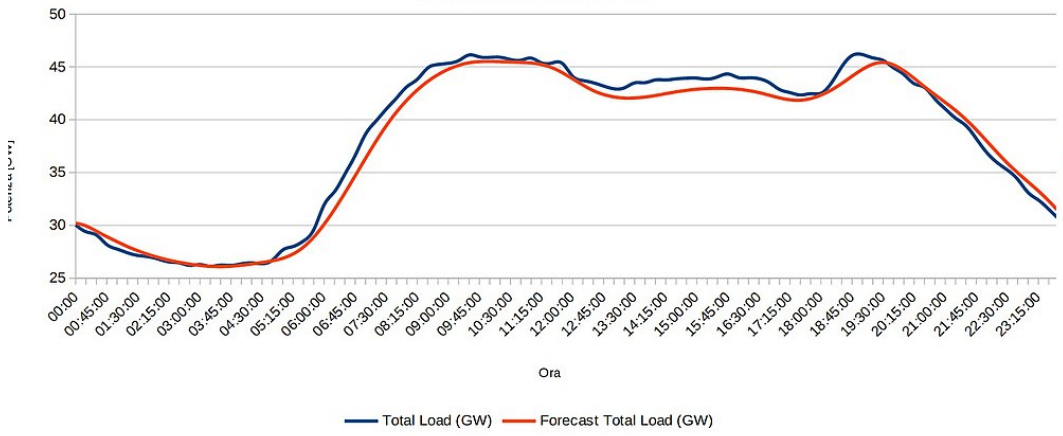

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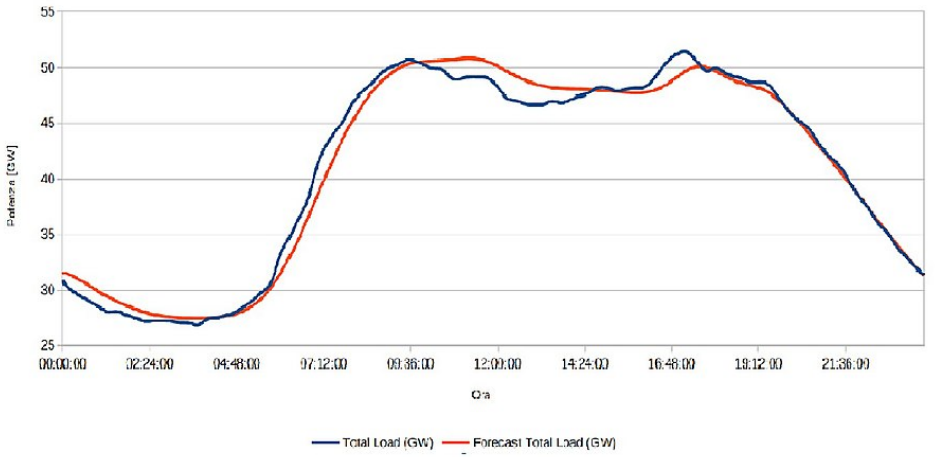
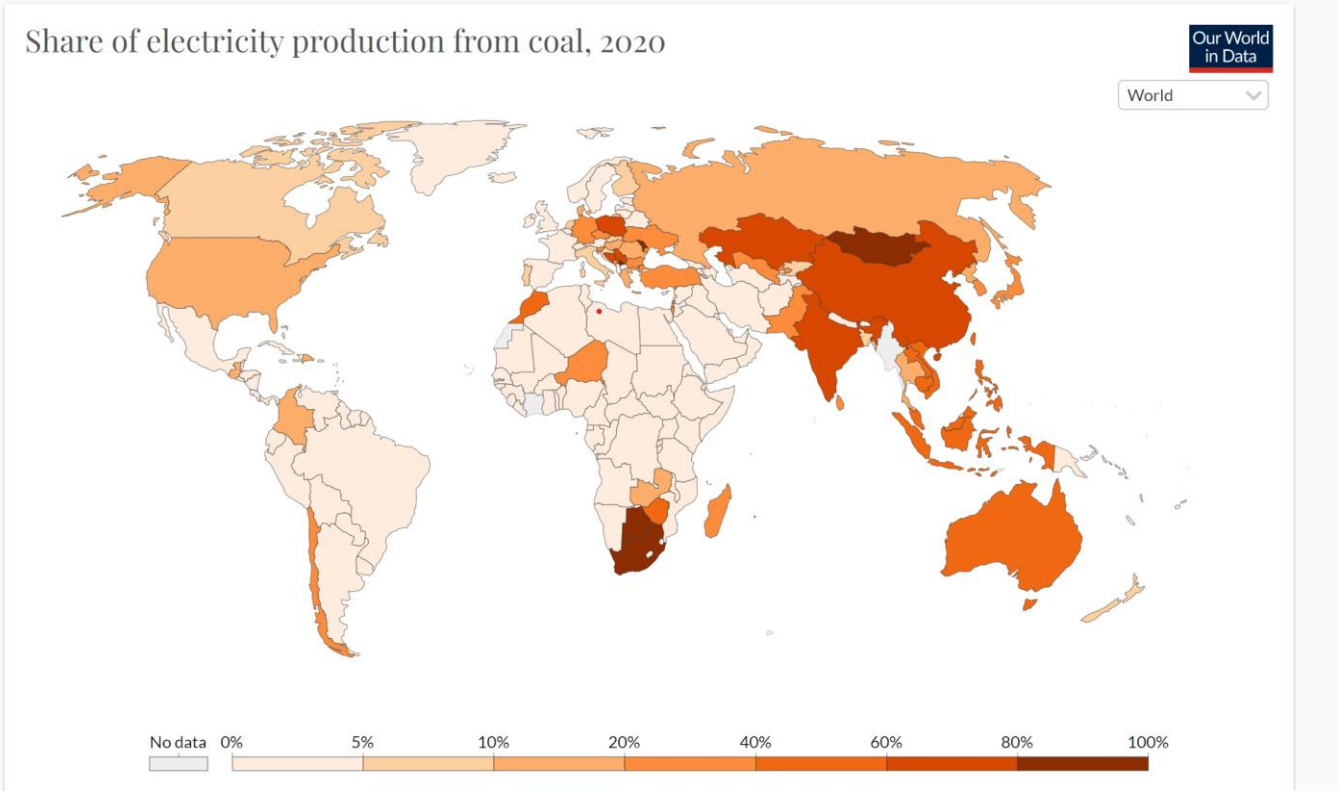


Coal power-plants

Coal is the main fossil fuel used to generate electricity, it supplies over **one-third of global electricity generation**. Large and remotely located *thermoelectrical* power plants provide the ***base load*** electricity. Coal is typically burned to *create steam*, which is then piped at high pressure over a turbine, causing it to rotate, producing electricity.



Advantages

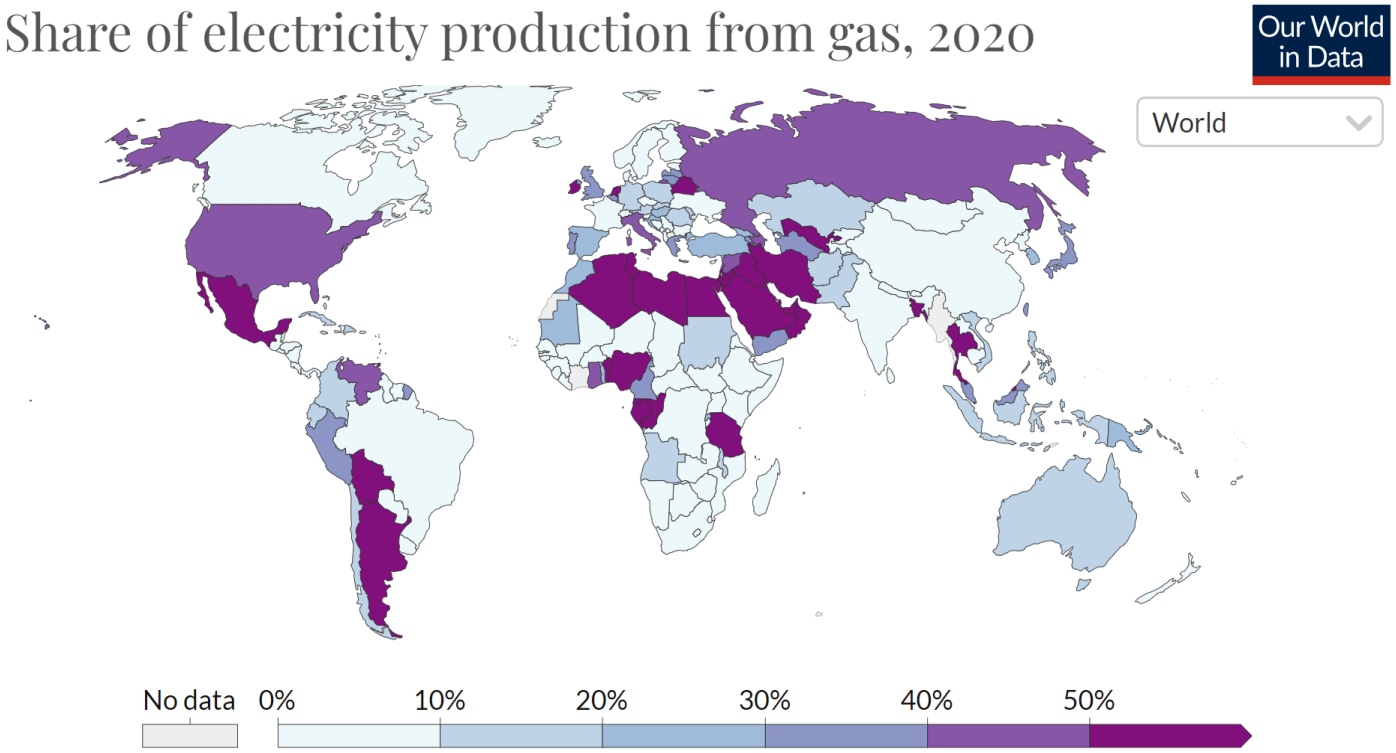
- There are ***substantial reserves*** in many countries capable of supplying electricity at the current usage rate ***for hundreds of years***
- Available continuously for *base load*
- *Low cost*

Environmental impacts

- *Pollutants* (SO_2, NO_x)
- Urban *smog*
- Huge quantities of *solid* waste
- *Green house* effect
- Environment deface due to the *mining* and *transporting*

Fossil gas power-plants

The fossil gas (natural gas) can be used as a fuel to produce high pressure *vapour in vapour electric plants, or in turbo-gas plants* directly exploiting the energy produced during methane combustion to spin a turbine. With reference to the performance, approximately *40% of the energy contained in the fuel is transformed into electricity, the remaining 60% is lost during energy conversion*. *Combined-cycle plants* associates a turbo-gas plant with a vapour group allowing to increase the performance by about 60%.



Advantages

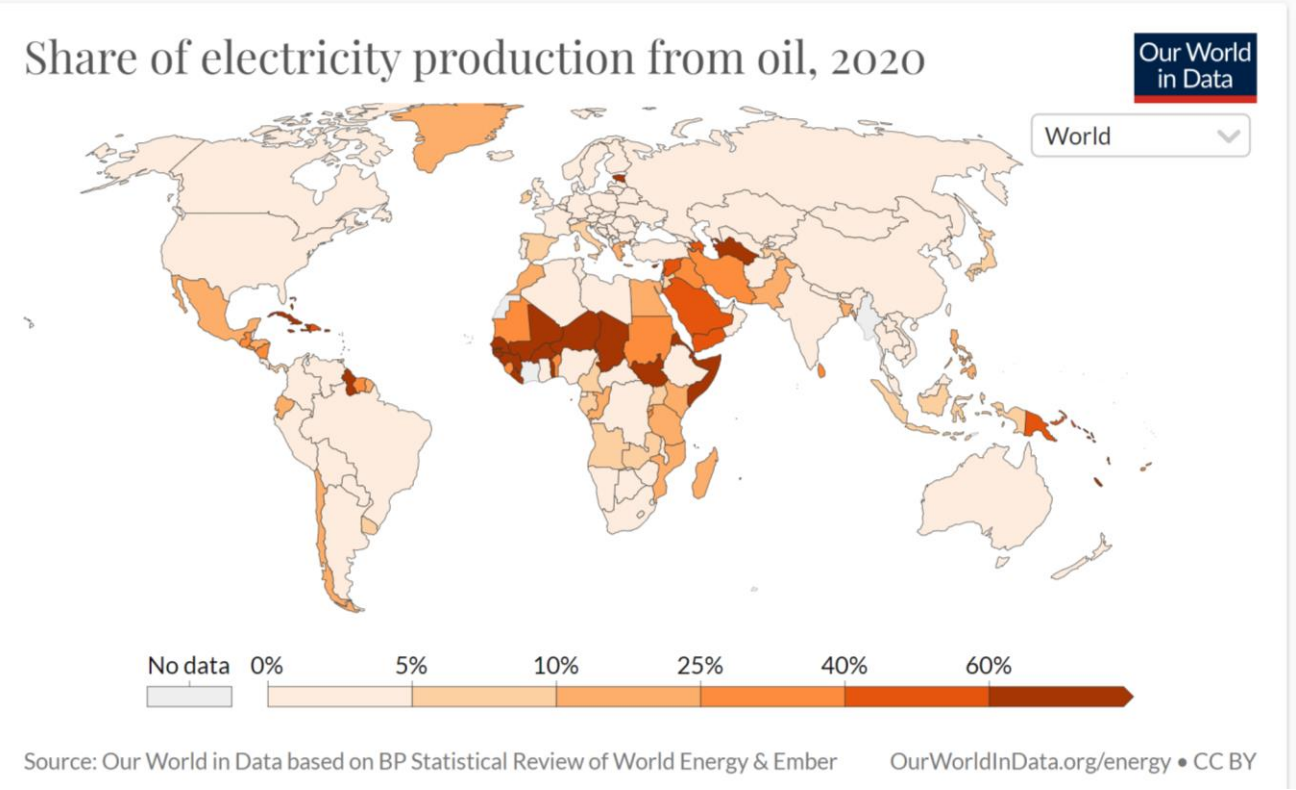
- The *cleanest* fossil fuels
- *Available continuously* for base load
- Power plants can be built in *smaller units (100 MW)*
- much *less* CO_2 emissions (*vapour electric plants*)

Environmental impacts

- increase in *CO_2 emissions in turbo-gas and combined-cycle plants*
- significant *impacts on water resources* for steam-cooling

Oil power-plants

Three technologies are used to convert oil into electricity, it can be burned to create *steam in conventional steam power plant*. Or is burned under pressure to produce hot exhaust gases to generate *electricity by Combustion turbine*. Also *Combined-cycle technology* can be used, where oil is first combusted in a combustion turbine, using the heated exhaust gases to generate electricity. The exhaust gases are recovered, to heat water creating steam to drive a second turbine.



Advantages

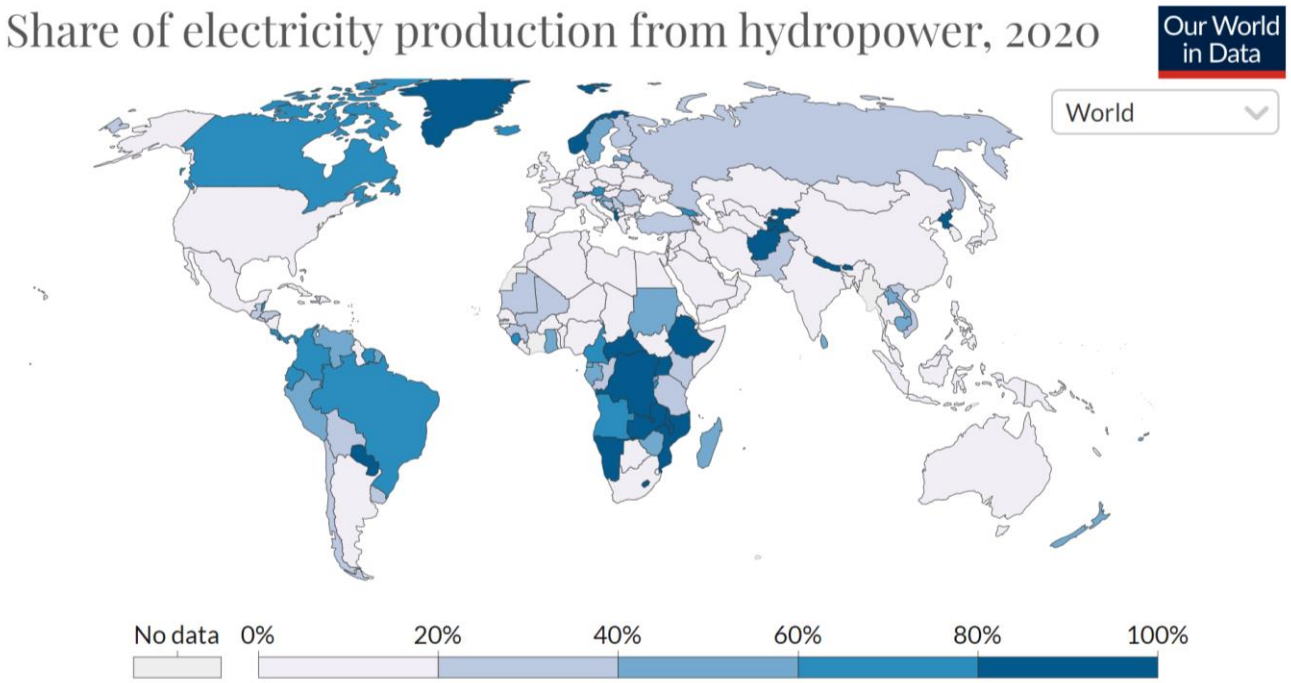
- Available *continuously* for base load

Environmental impacts

- Significant air pollution in the forms of nitrogen oxides, *greenhouse gases* and heavy metals
- negatively impact *local water* resources and aquatic habitats
- *solid waste* disposal
- drilling produces a long list of air pollutants, *toxic and hazardous materials*, and emissions of hydrogen sulphide and toxic gas

Hydroelectric power-plants

In hydroelectric plants the mechanical energy of the water is converted in electricity. The Water is released through hydraulic turbines to produce electricity. The plant's power mainly depends on the speed of the water through turbine. Mainly, three type of system are used, run-of-river power stations, conventional hydropower stations and pumped storage power stations. The run-of-river power stations take advantage of the natural flow of a water course between different levels. In conventional hydropower stations, penstocks convey the water from the dam toward hydraulic turbines. Pumped storage power stations have two reservoirs at different altitudes, use off-peak electricity to pump water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity.



Advantages

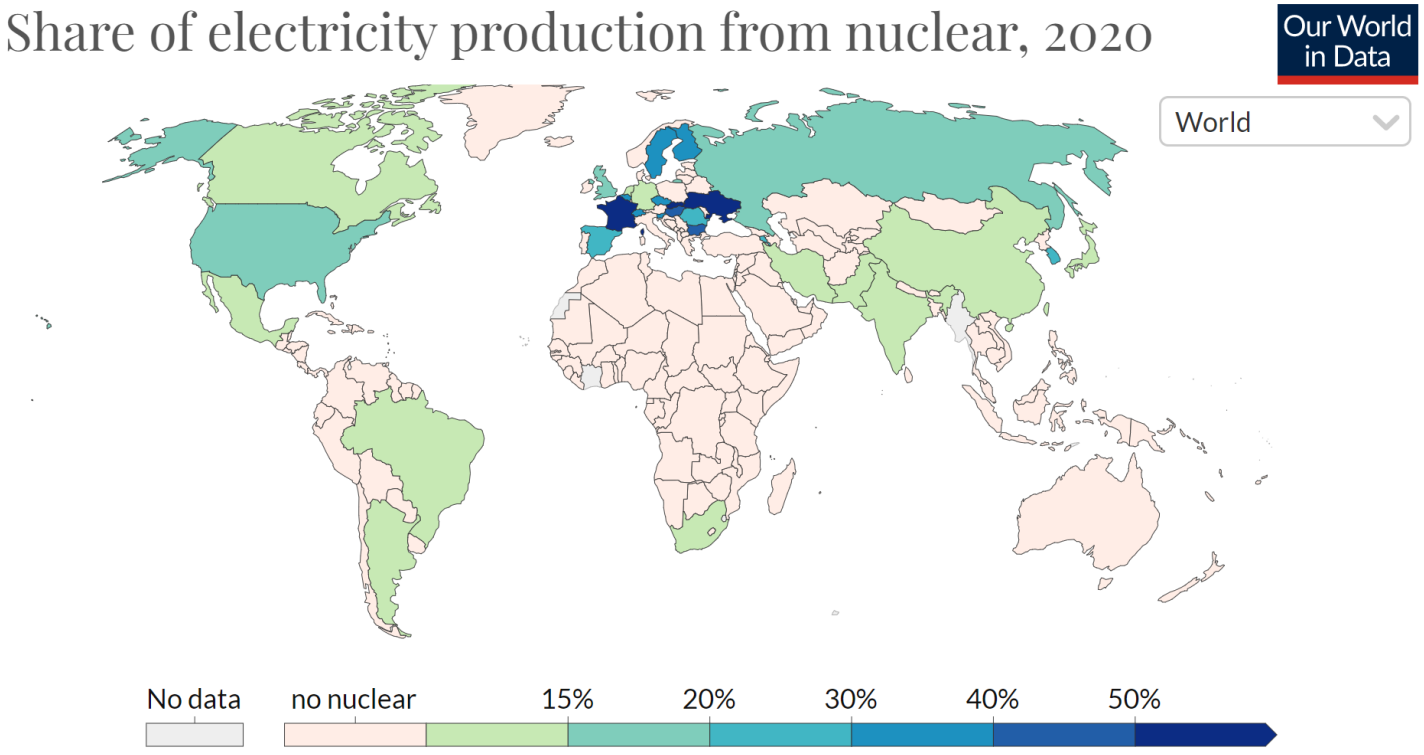
- No CO_2 or other serious pollutants
- Efficient conversion (no steam cycle is involved)
- Available continuously for base load

Environmental impacts

- few technologically attractive site available
- changes in river conditions, land and vegetation
- alteration of river and riverside habitat
- alteration of water quality

Nuclear power-plants

A nuclear power plant is a ***thermal power station*** where thermal power is got by fissioning nuclei of atoms in the reactor core. The heat generated by the reactor converts water into ***steam***, which spins a turbine. The ***uranium 235*** is the dominant choice of fuel in the world. The uranium fuel is formed into ceramic pellets, each ceramic pellet produces about the same amount of energy as ***150 gallons of oil***. It has been estimated that even factoring ***in costs such as managing radioactive wastes and disposal nuclear plants, the nuclear plants cost is between 33 to 50% of a coal plant and 20 to 25% of a gas combined-cycle plant***.



Advantages

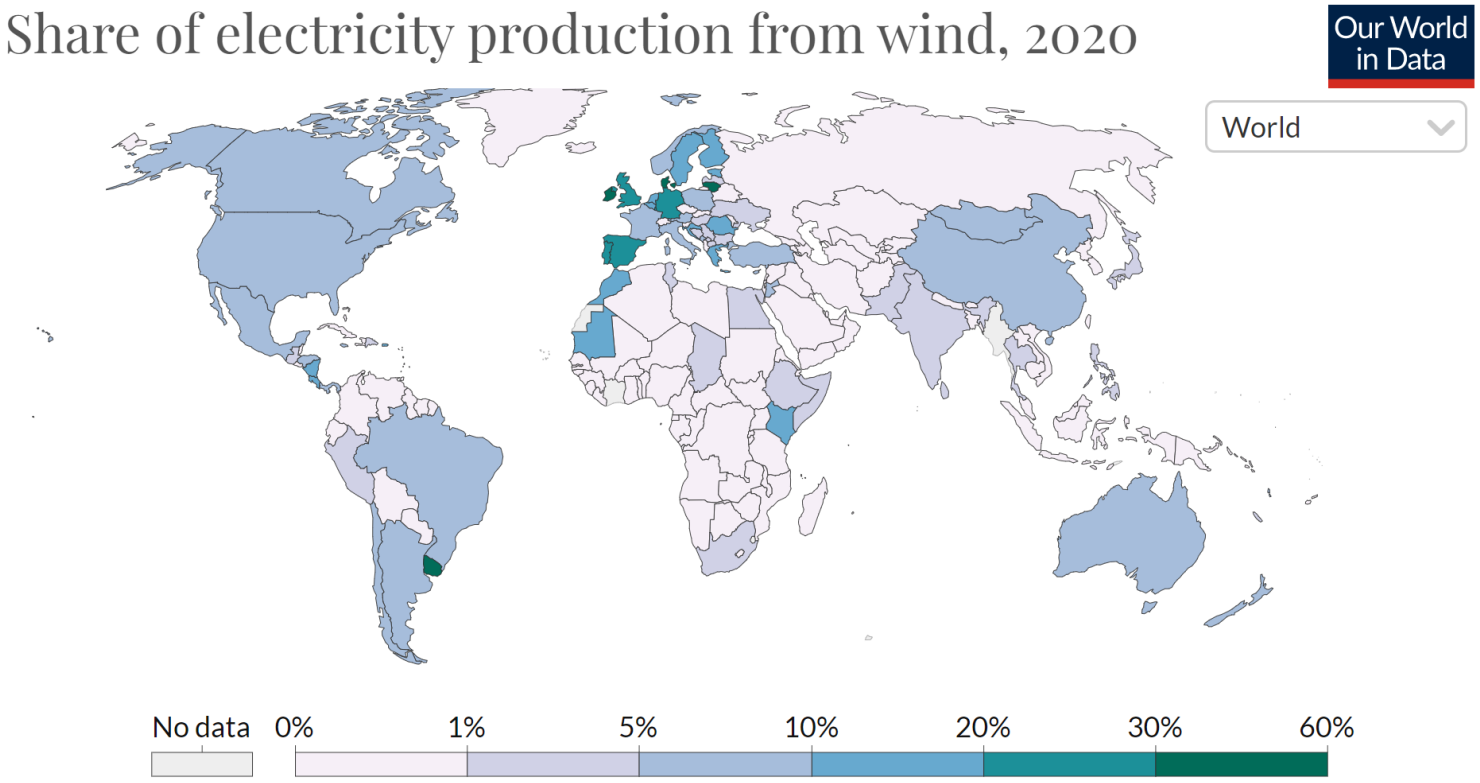
- ***No CO_2*** or other serious pollutants
- Available ***continuously*** for base load
- Fuel available ***for hundred year***
- High power output

Environmental impacts

- ***Radiative nuclear waste***
- reprocessing spent fuel is the production of nearly pure plutonium
- Expensive ***upfront Cost***

Wind power-plants

In a wind power station is a group of wind turbines covering an extensive area. The electricity is got by converting kinetic wind energy into rotating energy of the turbine blades around a rotor. The turbine is mounted on a tower to provide better access to stronger winds. Modern wind turbines produce up to few MW and it can be categorized in land-based WIND and off-shore WIND. Off-shore farm are able to capture larger amounts of energy.



Advantages

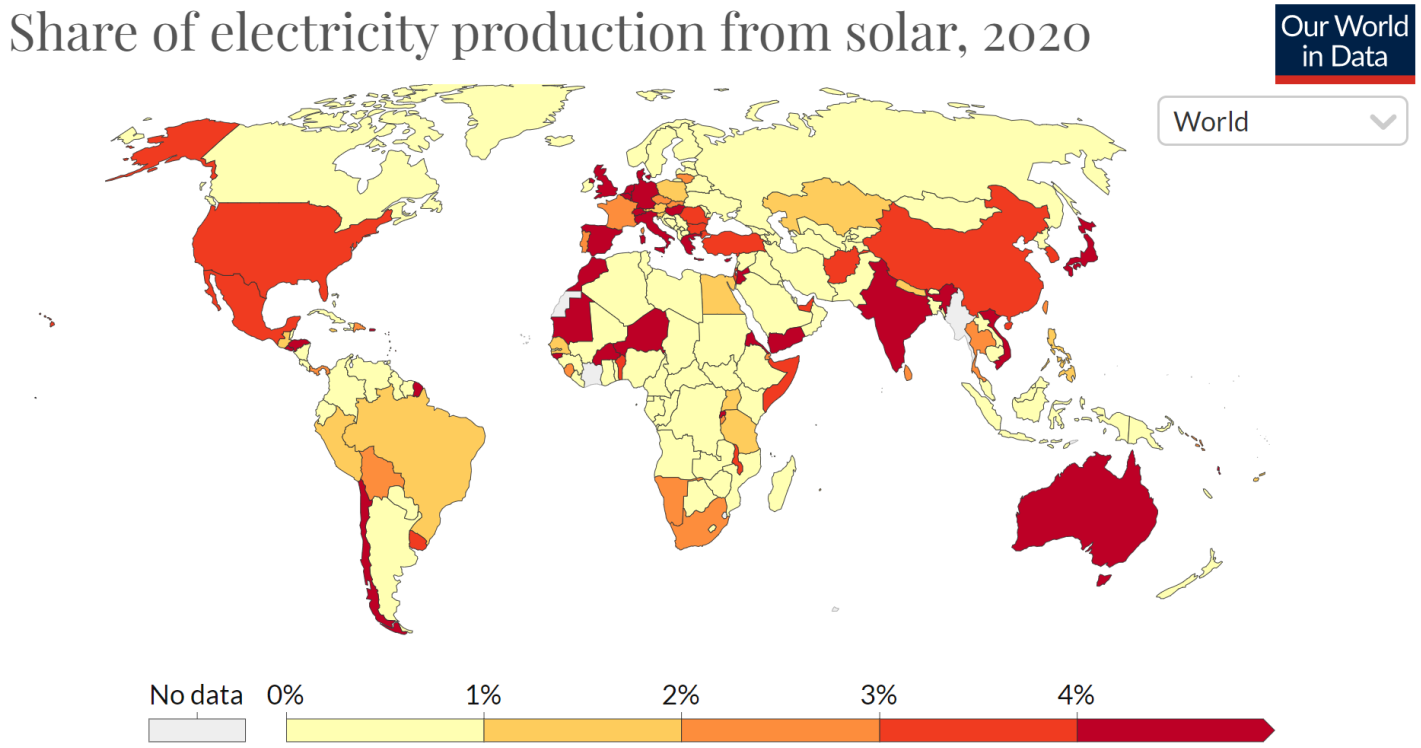
- *Free* and renewable fuel
- *No* CO_2 or other serious pollutants
- *Few running* costs

Disadvantages

- Dangerous to some wildlife
- *Noisy*
- *Intermittency* due to inconsistency of the wind
- Expensive *upfront Cost*
- *Large area* required
- *Lower amount of energy*

solar power-plants

Solar power station converts the electromagnetic power of the sun radiation into electrical energy by means **photovoltaic** or **thermodynamic** effects. Photovoltaic plants take advantage of the ability of some *semiconductor* materials to generate electricity when exposed to light rays. Instead, thermodynamic solar *plants mirrors or lens* are used to concentrate ray heat on a working fluid, which then heats steam to operate a conventional generation power block with a steam turbine.



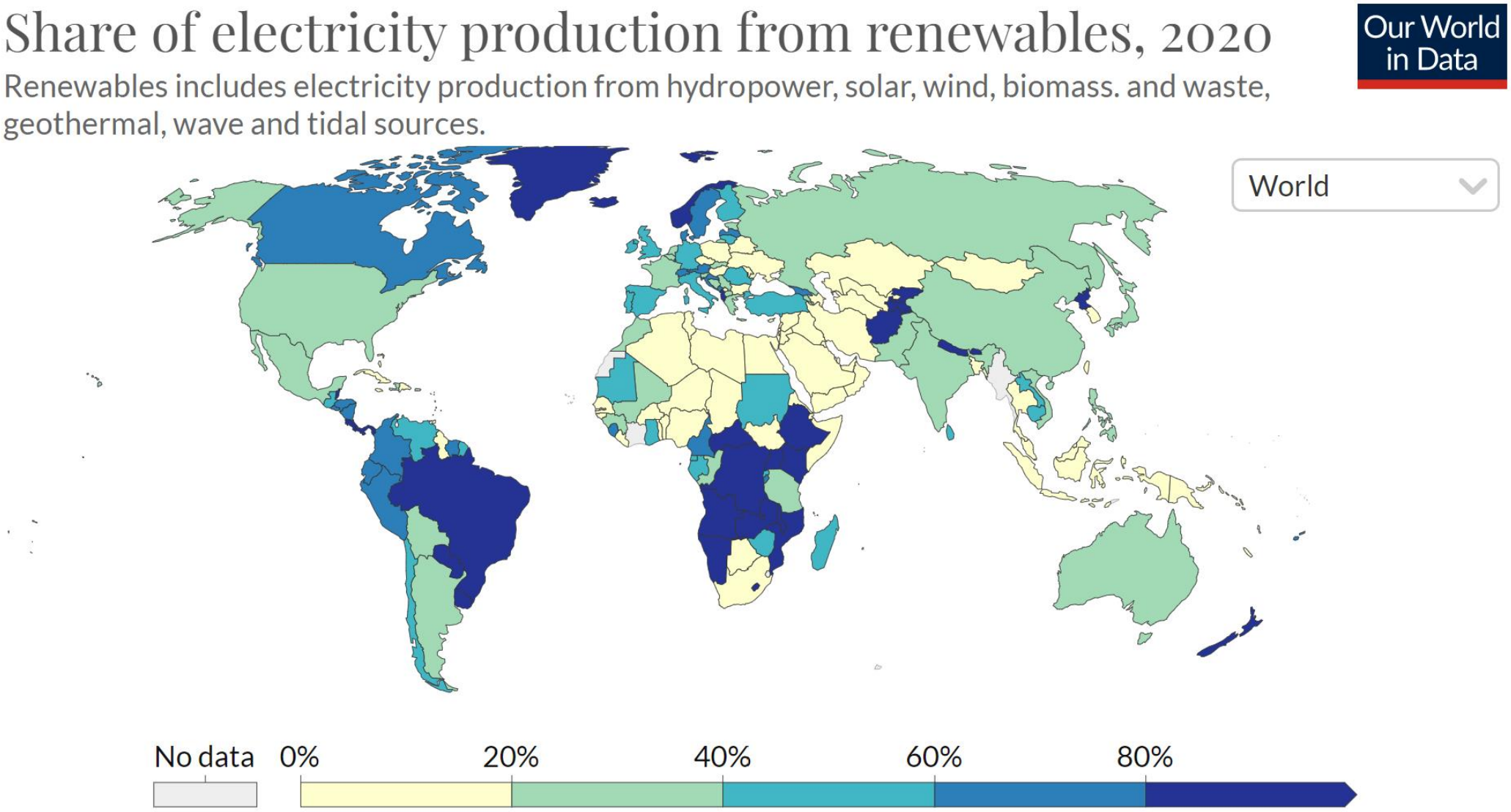
Advantages

- *Free* and renewable fuel
- *No* CO_2 or other serious pollutants
- *Few running* costs

Disadvantages:

- Dangerous to some wildlife
- *Weather* dependent
- Expensive *upfront* cost
- *Large area* required

Renewable energy rate



Renewable energy

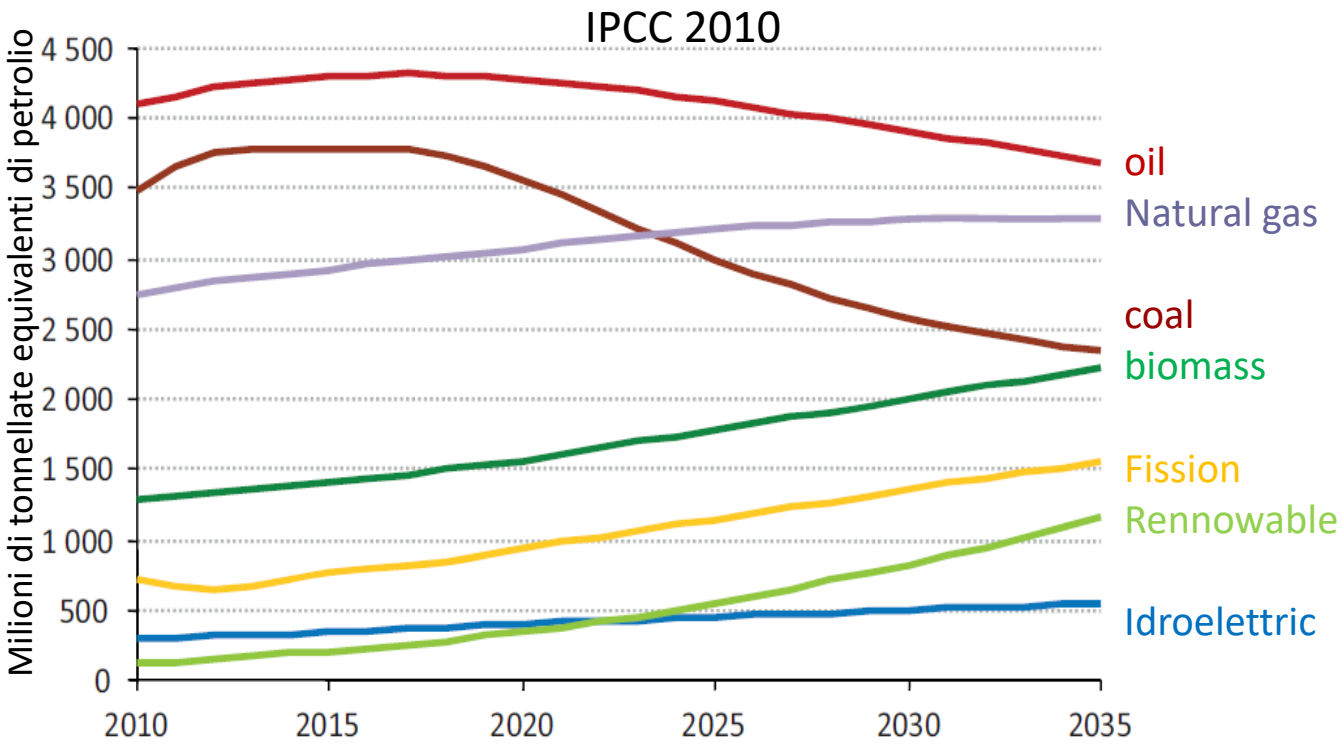
Fuel requirements

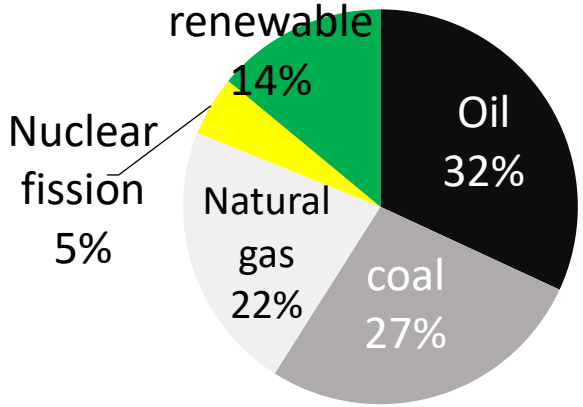
Fuel needed by energy sources for *1 GW power plant for one year*

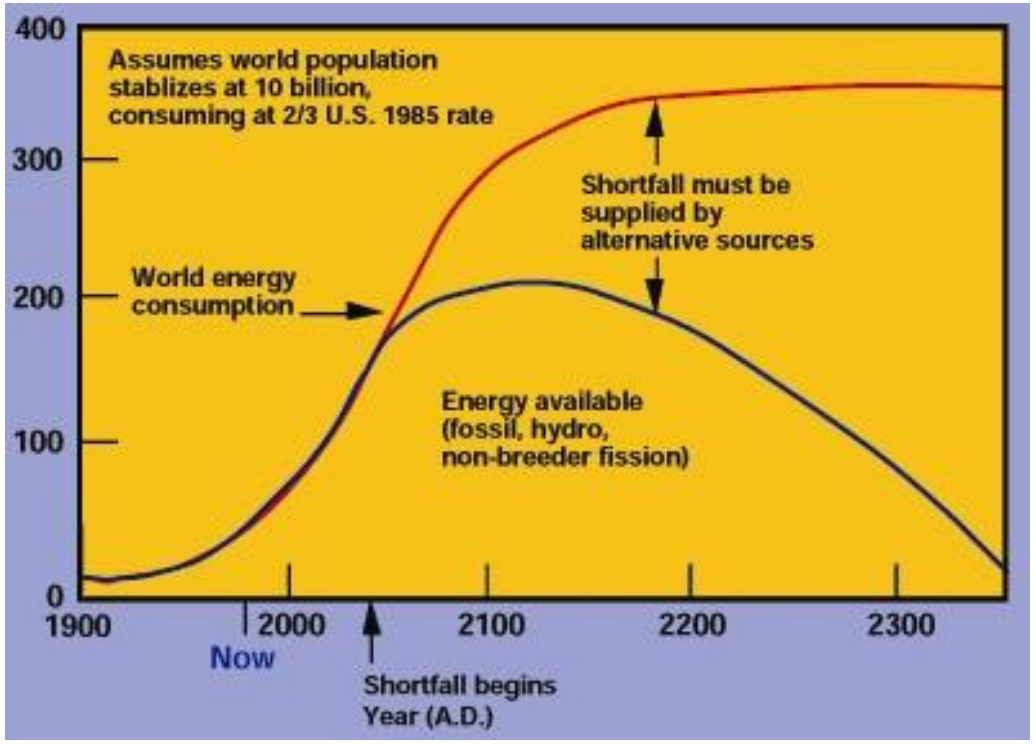
Energy source	Fuel needed	Land use [km^2]	Comments
Coal	2.5×10^6 tons	1+ mines	26260 train wagon loads
Gas	1.2×10^9 m^3	1	
Oil	1.4×10^6 tons	1	10×10^6 oil barrels or 100 oil tankers
Nuclear fission	35 tons of uranium oxide	1+ mines	from 210 tons of uranium ore
Nuclear fusion	100 kg deuterium + 150 kg tritium	1+ mines	from 2850 m^3 of sea water and 10 tons of lithium ore
Wind	2700 wind turbines (1.5MW each)	490	η=25%
Solar PV	23 km^2 of solar panels 50 km^2 of solar panels	23 50	Country near the equator Our latitude
Biomass	30000 km^2 of woods	30000	

Fossil source impact

81% of global energy consumption is meet by fossil fuels

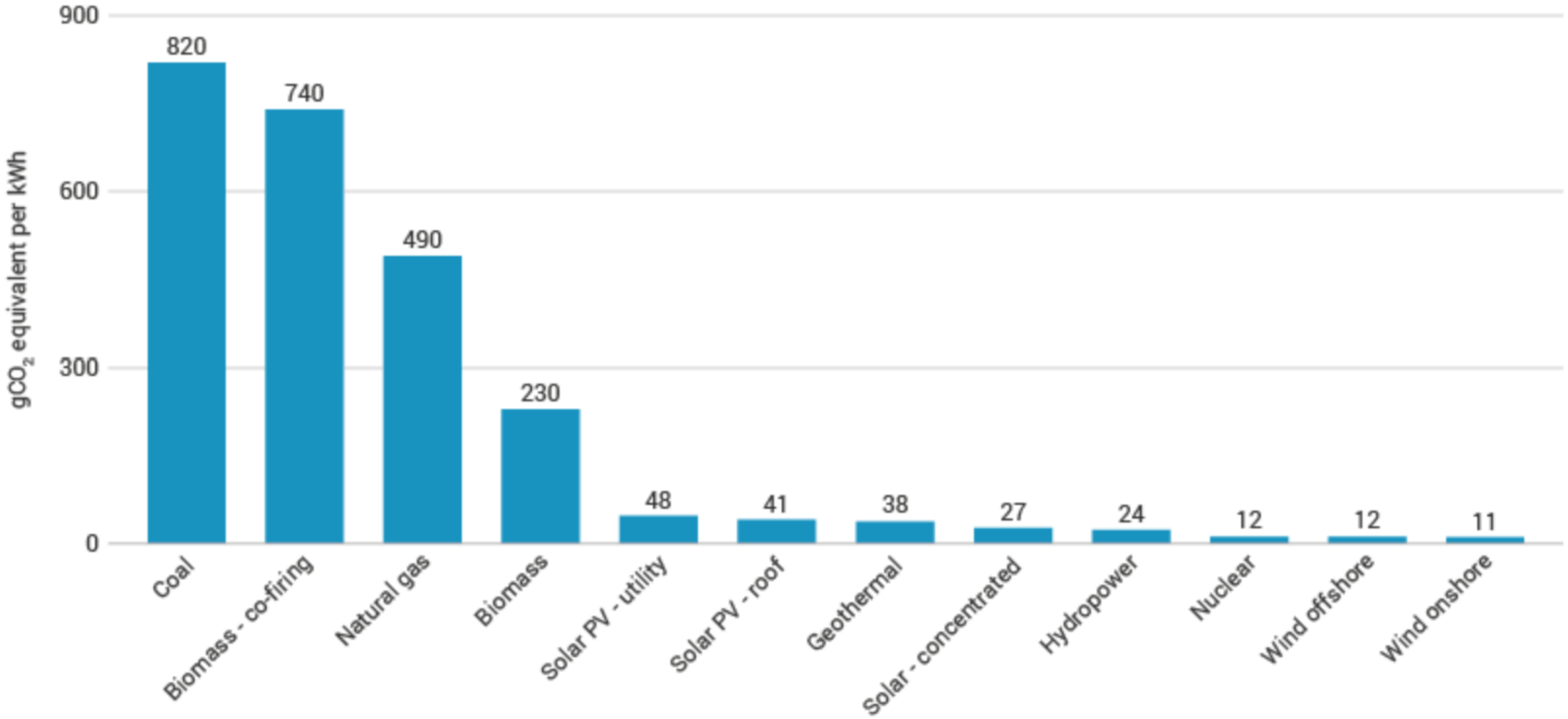






Greenhouse impact

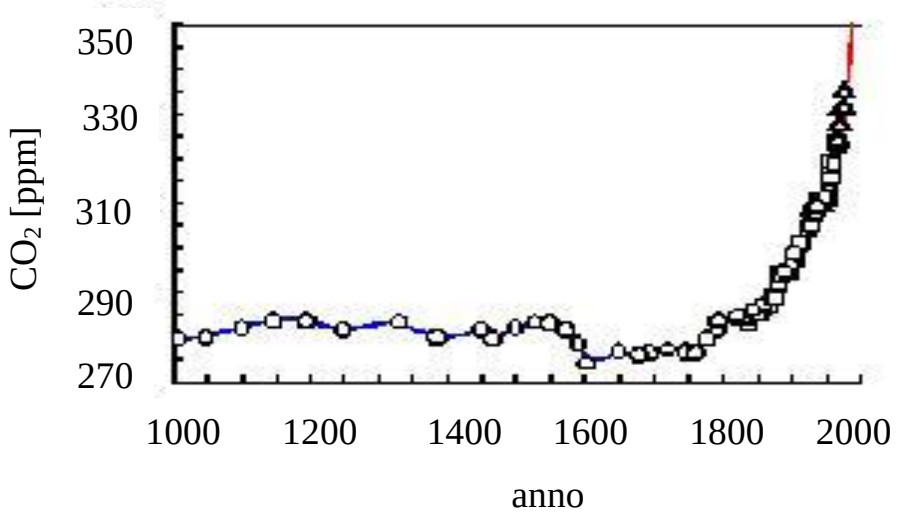
The generation of electricity is responsible for over 40% of all energy-related emissions

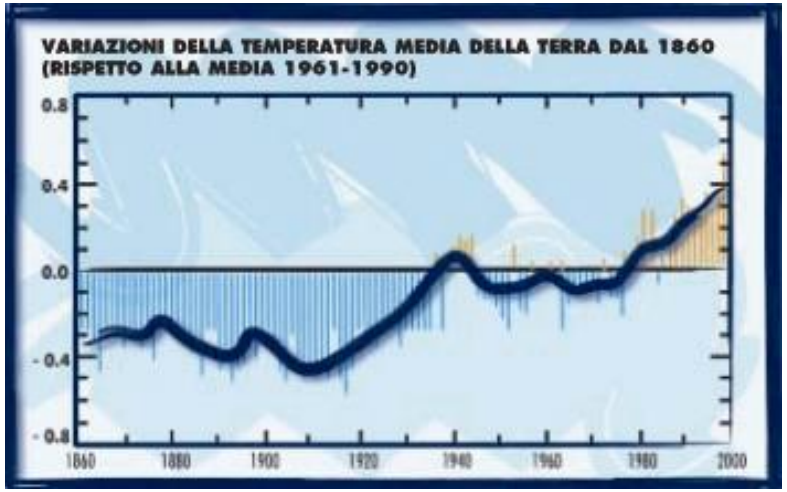


Greenhouse impact

Greenhouse gases:

- Carbon dioxide (CO_2)
- Natural gas (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)

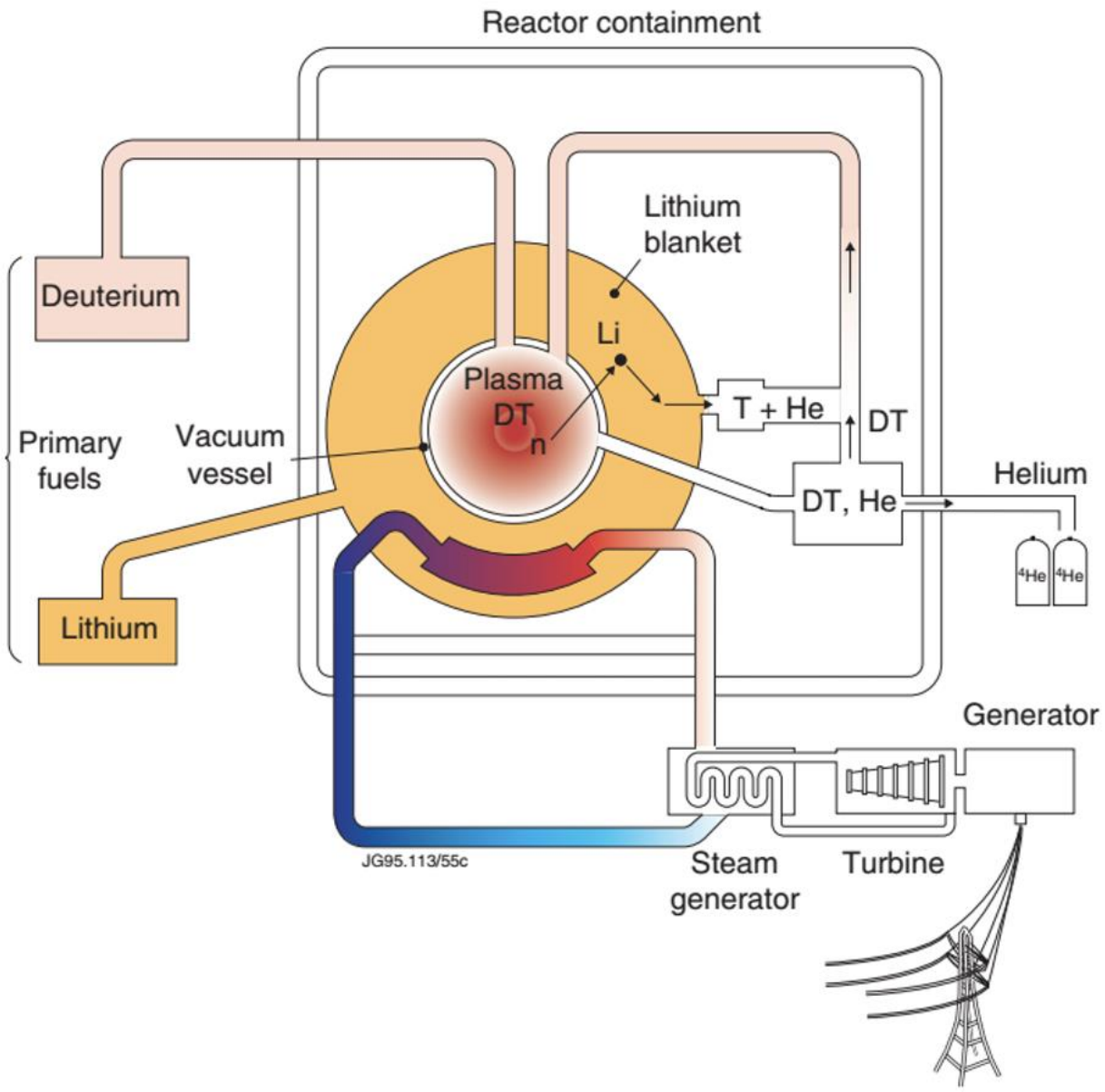


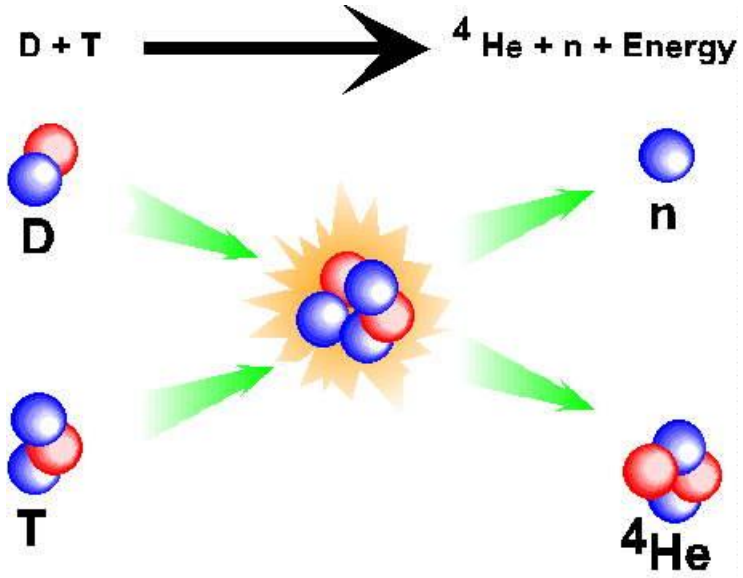


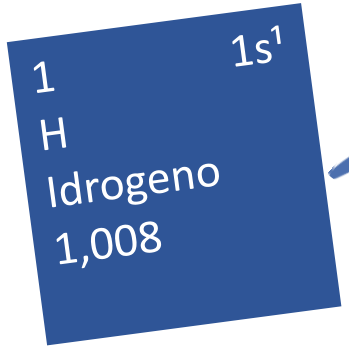
Greenhouse effects:

- Temperature increasing
- Rainfall increasing
- Glaciers decreasing
- Sea level rising

Fusion Power Plants – a promise for the future







1 g

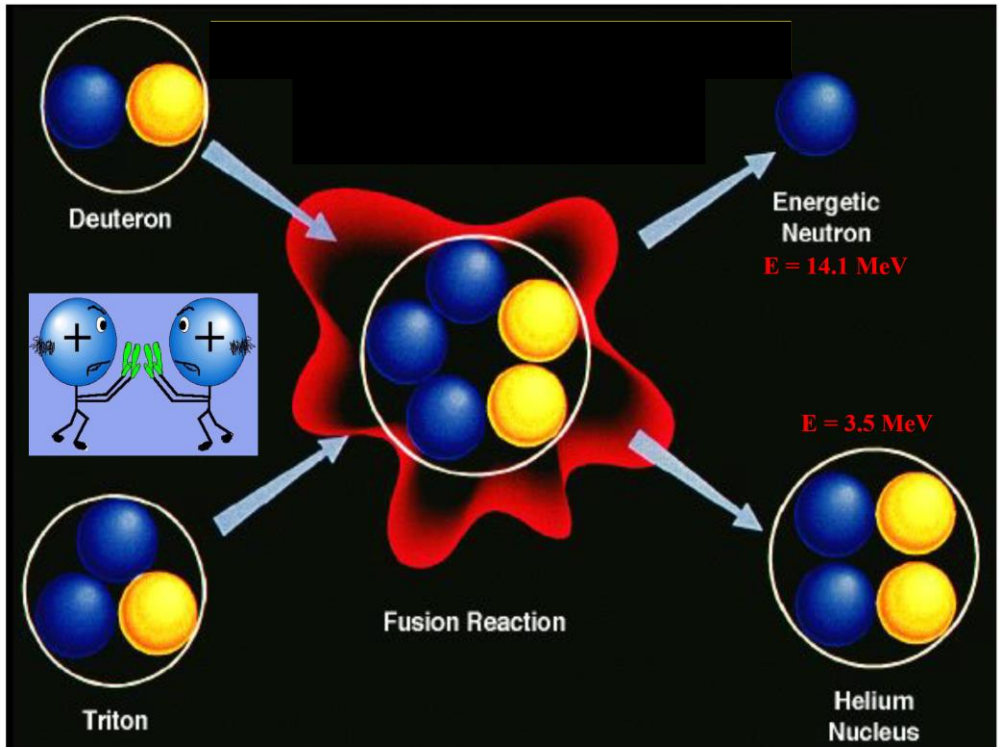
30 tonnes of coal

Fuel availability about 1.000.000 years

Fusion vs Fission

Fusion occurs when two atoms slam together to form a heavier atom

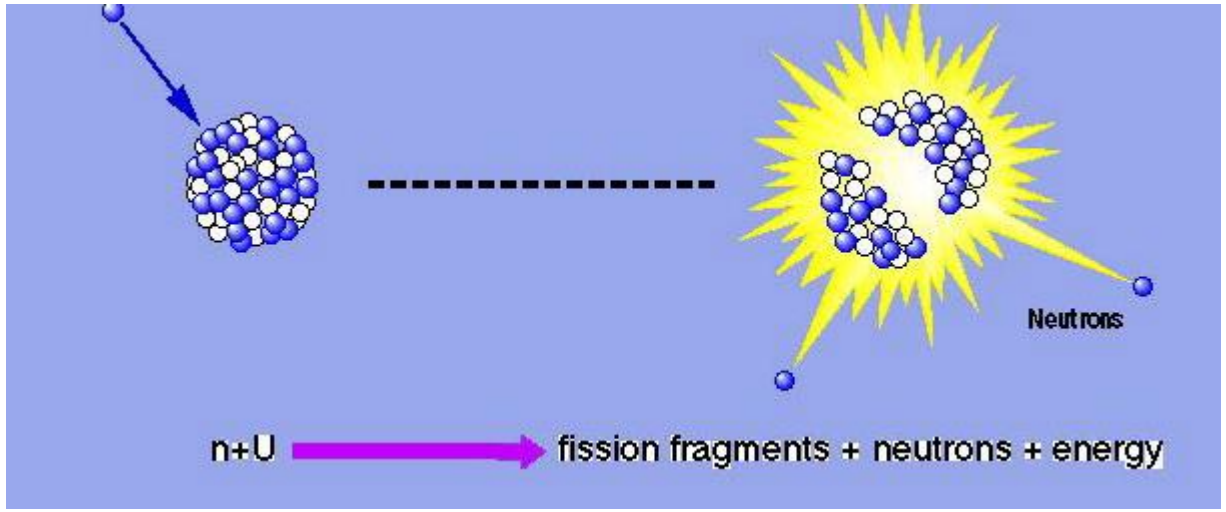
The Fusion reaction is difficult to be triggered because of the large amount of energy needed to join the nuclei together



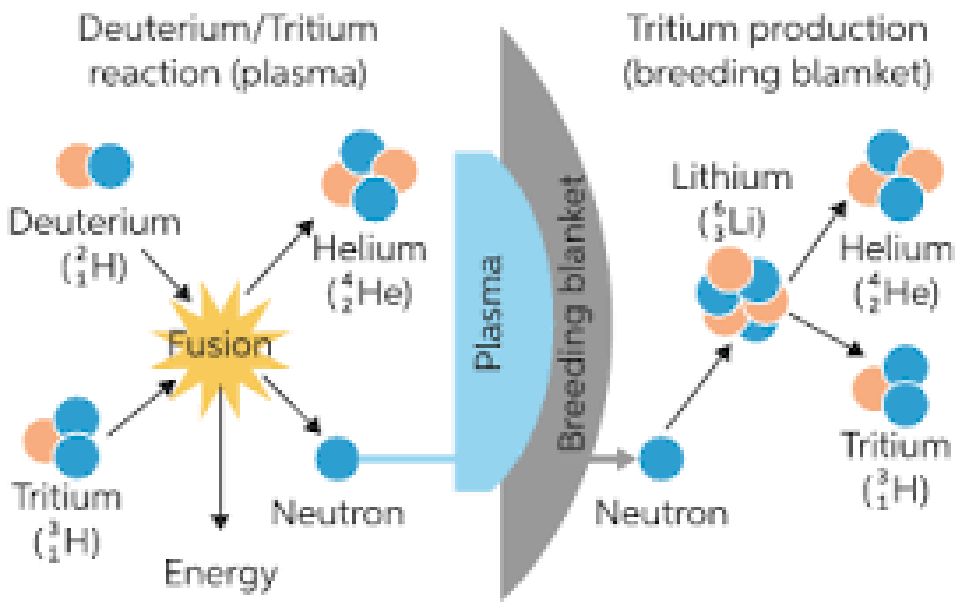
Fission occurs when a neutron slams on a larger atom, forcing it to excite and split into two smaller atoms.

Fission is a spontaneous process: a neutron, available from radioactive decays, it affects a nucleus of Uranium by fragmenting it. Additional neutrons are also released that can initiate a chain reaction.

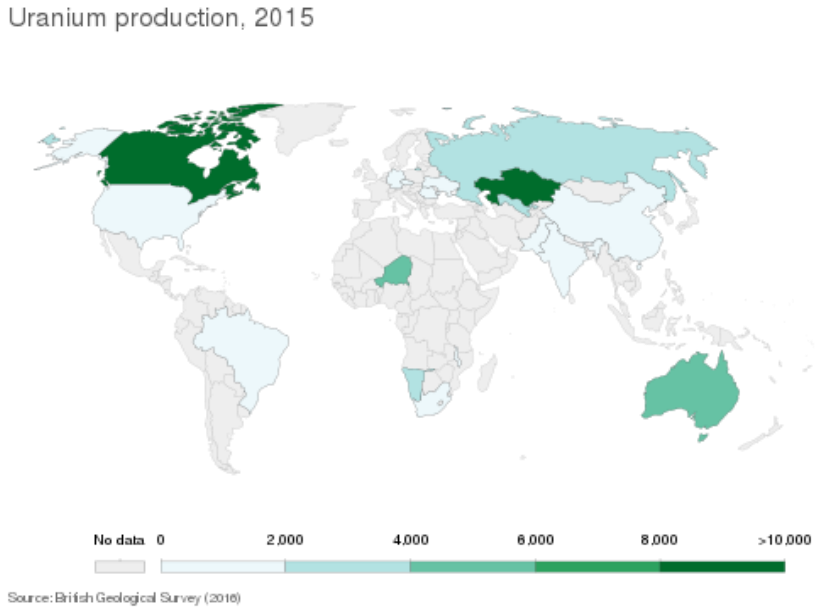
Producing Energy Only Requires Control the Chain reaction



Fusion vs Fission



The most commonly used "fuels" are, mixtures with a high content of uranium 235 or some plutonium isotopes



Deuterium is abundant in any material containing hydrogen. 1 l of water contains about 120 mg of Deuterium, in sea water 30 g / m^3

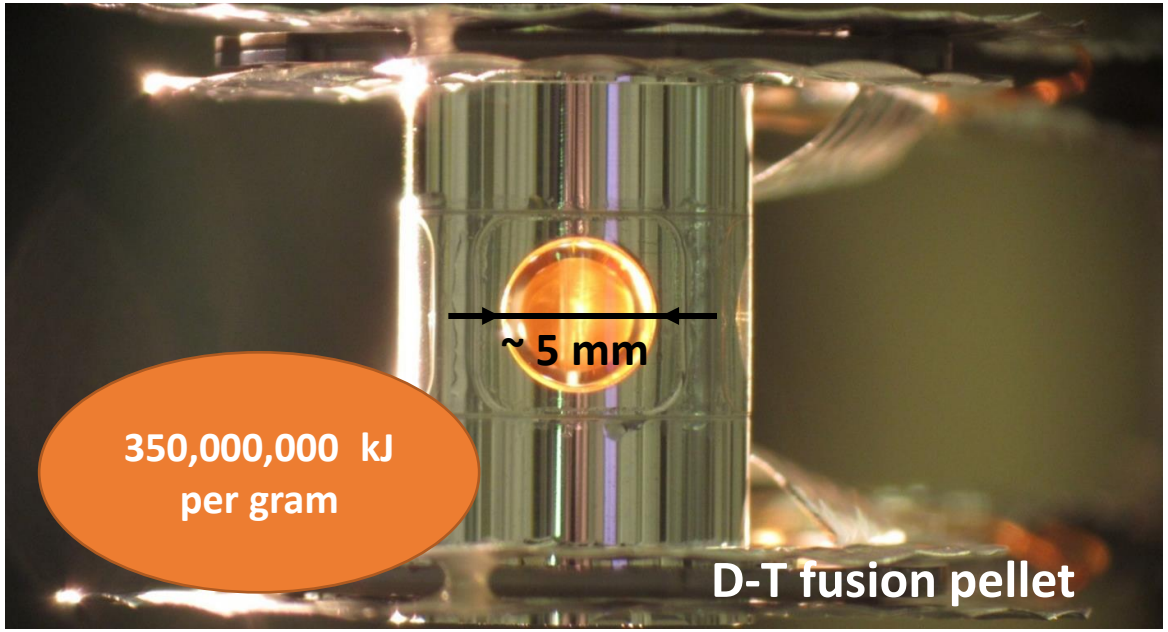
Natural lithium (composition 92.5% Li7, 7.5% Li6) abounds in the rocks of the earth's crust (30 parts per million per unit of weight) and is also present, in a lower concentration, in the oceans.

Uranium is a non-renewable element which, due to the long sequence of nuclear reaction from which it originates, is quite widespread but relatively scarce.
The range of uranium availability is between 46 and 78 years. These calculations assume that consumption remains constant, that is, that no new power plants come into operation except to replace closed plants.

Fusion vs Others

Coal

oil



Fusion vs Others

- Typical energy scales for chemical bonds→ electron-volts
- Typical energy scales for nuclear reactions → millions of electron-volts (MeV)
- This means that a gigawatt-class fusion power plant will use a pickup truck full of fuel (lithium and deuterium) per year.
- Compare to a 1 GW coal plant – nearly 8000 tons of coal per day!

1 year worth of fusion fuel supply for a 1 GW plant

3 days worth of coal supply for a 500 MW plant