



FACULTY OF MECHANICAL  
ENGINEERING  
UNIVERSITY  
OF WEST BOHEMIA

DEPARTMENT OF  
POWER SYSTEM ENGINEERING

# KKE/ESV - Solar and Wind Energy

2018/2019  
1st lecture



# About the course



Lessons take place every 14 days:

- 5 March - General information, conditions, evaluation, introduction to renewable sources (UX 236)
- 19 March - Solar energy (UX 236)
- 2 April - Solar systems - computer modelling (UX 227)
- 16 April - Wind Energy (UX 236)
- 30 April - Wind systems - computer modelling (UX 227)
- 14 May - Student presentations - energy storage systems (UX 236)
- 28 May - Test and evaluation (also possible 21 May if interested) (UX 236)

# Study materials



- Courseware will be used for sharing study materials.
- <https://portal.zcu.cz/portal/studium/courseware>

## EDIT:

- **Given the current situation, the UWB and its staff operate in a limited mode. People managing the schedules and information system do not communicate, and therefore, until Courseware will be available, the study materials will be posted at:**  
<http://home.zcu.cz/~richter/>

# Computer modelling



- Free software tools of the United States government will be used.
- The System Advisor Model (SAM) is a free techno-economic software model that facilitates decision-making for people in the renewable energy industry:
  - Project managers and engineers
  - Policy analysts
  - Technology developers
  - Researchers
- <https://sam.nrel.gov/>

# Students presentations



- Pumped Storage Hydropower (PSH)
- Pit storage
- Cold water storage
- Underground thermal energy storage (UTES)
- Residential hot water heaters with storage
- Compressed air energy storage (CAES)
- Sodium-sulphur (NaS) batteries
- Ice storage
- Flywheel (low speed)
- Molten salt
- Lithium-based batteries
- Flow batteries
- Flywheel (high speed)
- Supercapacitor
- Superconducting magnetic energy storage (SMES)
- Adiabatic CAES
- Hydrogen
- Synthetic natural gas
- Thermochemical

# Content

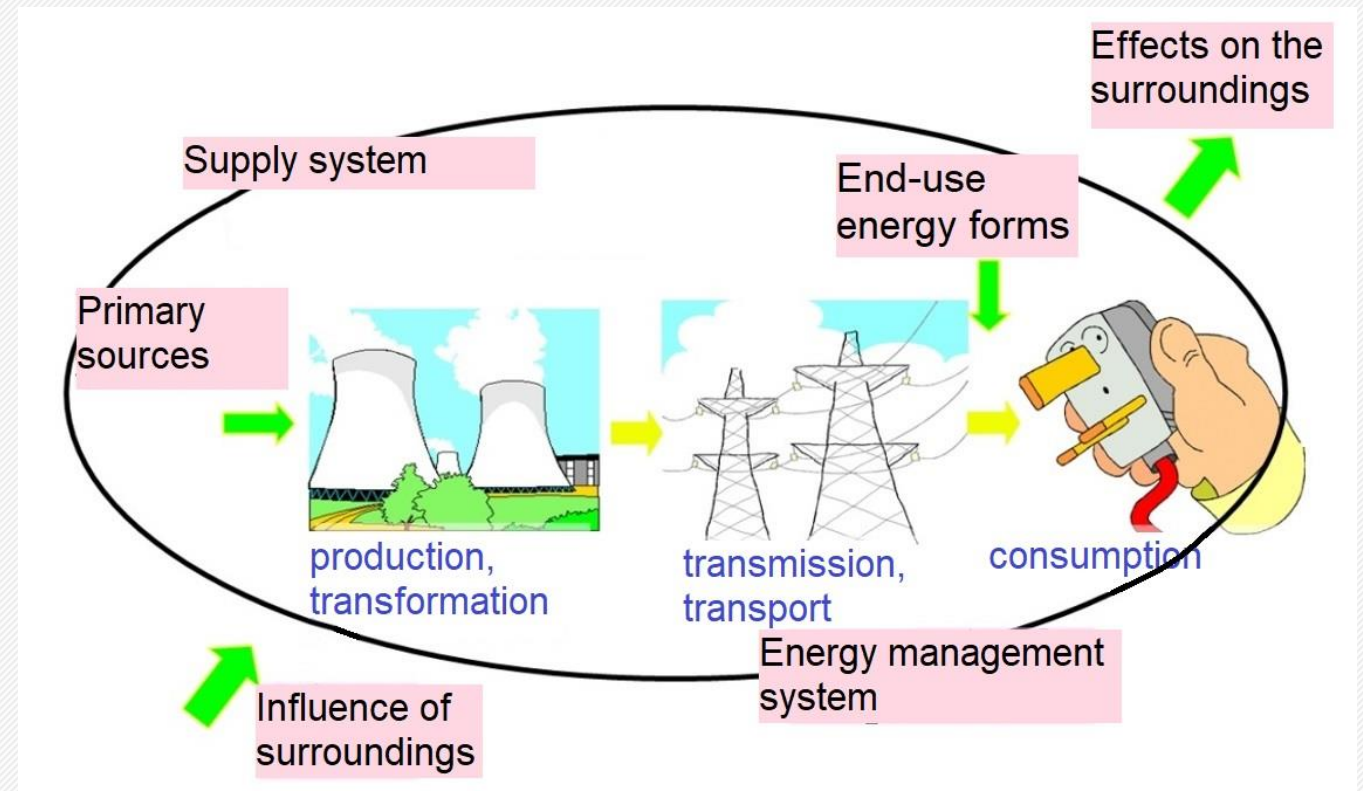


- Energy transformation system
- Types of sources
- Renewable sources in general
- Load diagram
- A bit of statistics
- Climate change
- Smart grids
- Sun and wind usage maps

# Energy transformation system



- It serves to provide the delivery of end-use energy forms:
  - Electrical energy
  - Heat
  - Fuel
- The end-use form is obtained by transforming the energy contained in the primary sources
- Interconnection of individual subsystems (fuel modification, heat release / evacuation system, heat transformation system for mechanical work, environmental impact, etc.)





# Sources of energy



## Forms of energy existing in nature:

- kinetic and potential energy
- radiation and thermal energy
- energy chemically bound in element molecules

## Types of resources

- Primary - fossil and nuclear fuels, water, biomass, other natural resources
- Secondary - waste heat, waste pressures, garbage
- Conventional - commonly used resources (fossil and nuclear fuels, water, ...)
- Unconventional - less used sources (geothermal, tidal energy, ...)
- Renewable - energy from the Sun, from the Earth's rotation, or from the Earth's core (heat)
- Non-renewable - energy is chemically bound in fuel, released by combustion or possibly by nuclear reaction



# Renewable sources



All renewable energies come from:

Sun

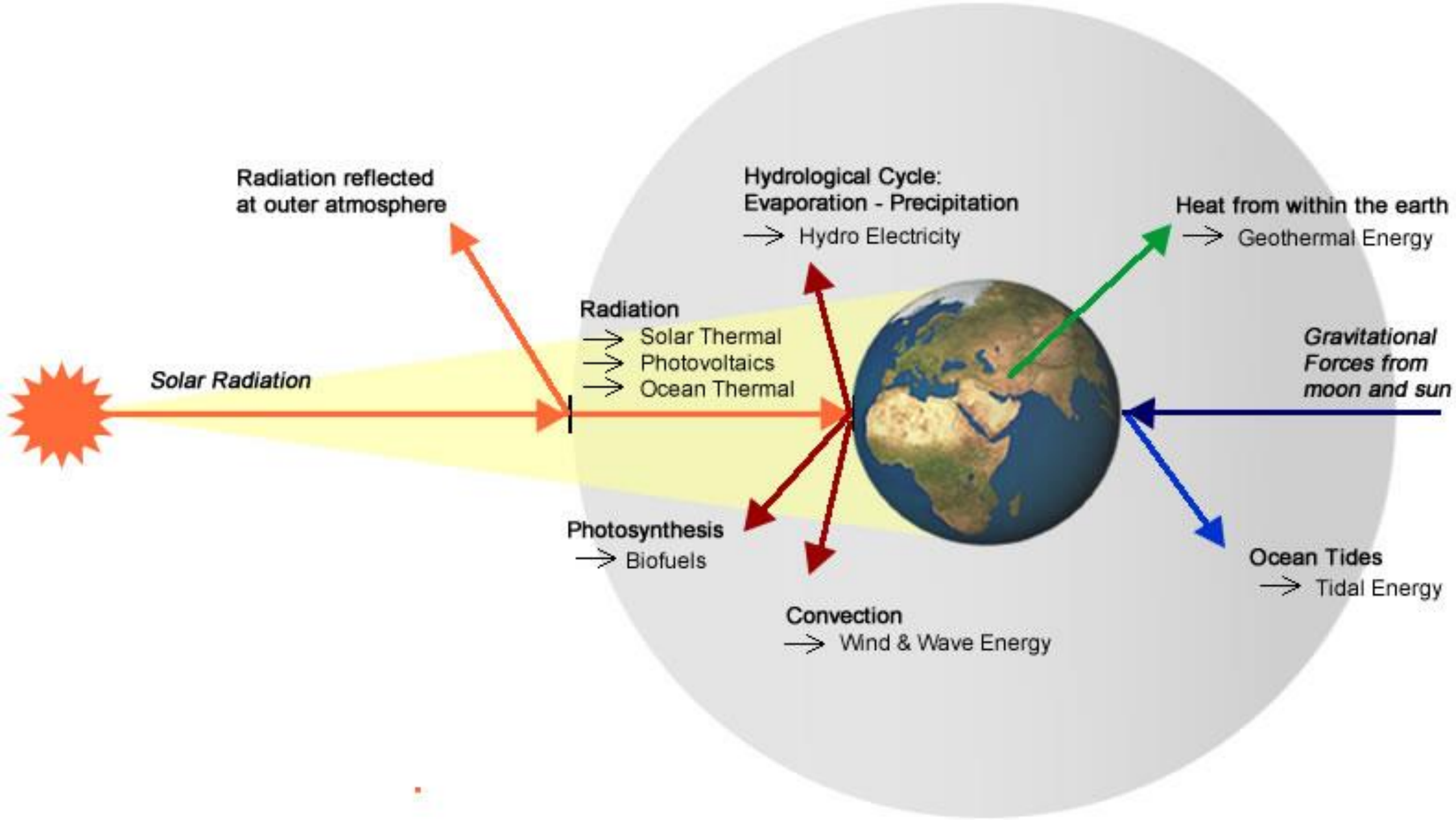
- solar energy - The Sun transmits its energy in the form of radiation to Earth.
- wind energy - The sun warms the Earth unevenly, causing pressure differences in the atmosphere that are balanced by the air flowing
- water energy - The Sun along with the gravitational force of the Earth allows the water cycle.
- energy of biomass - solar radiation allows photosynthesis and is essential for organic life

From the Earth's core

- geothermal energy - residual heat of the Earth's core + heat from the fission of radioactive elements inside the earth body

From Earth rotation

- tidal power - Earth rotation along with the mutual gravitational effects of the Sun and Moon will allow the periodic lifting and lowering of the sea level (tide and outflow)



# Renewable resources - properties

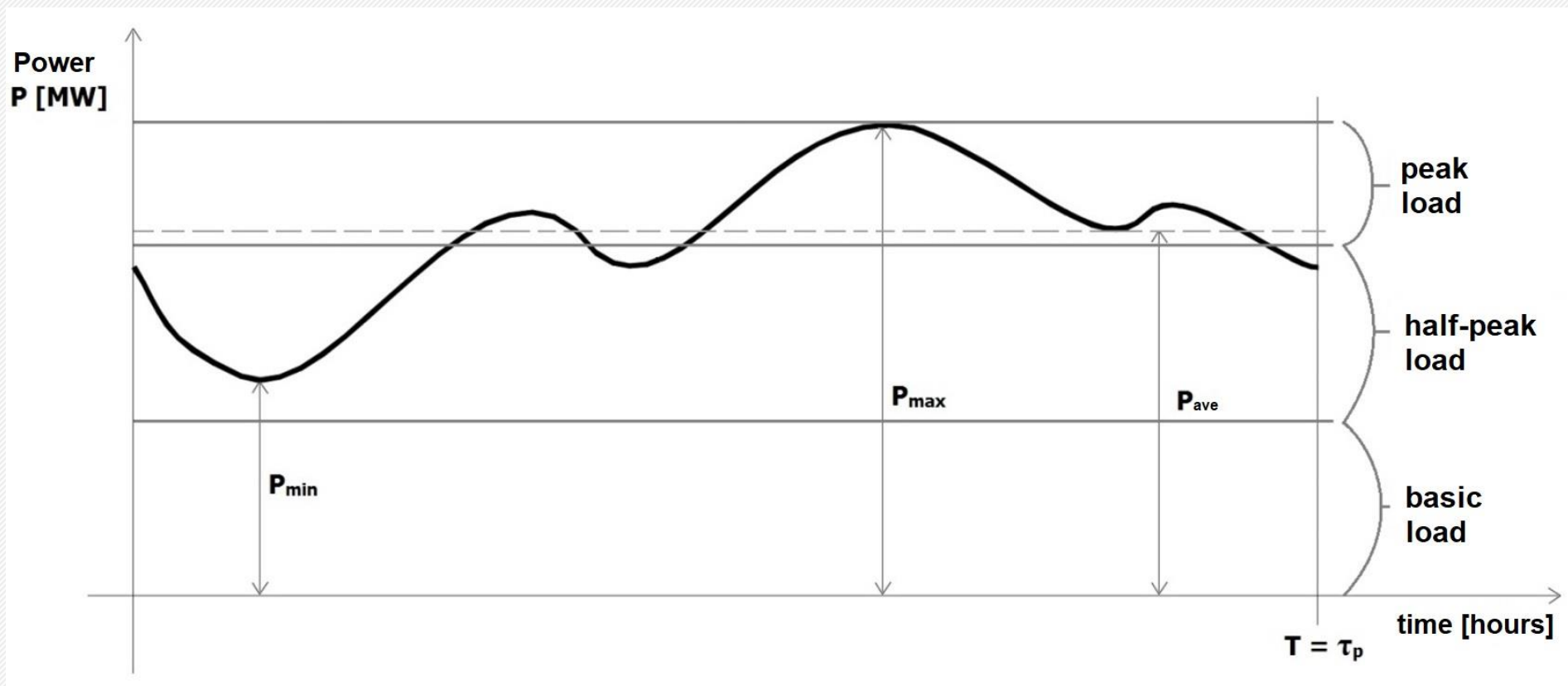


- Advantages:
  - The amount of energy in the order of magnitude exceeds today's and future energy consumption
  - The ability to use it anywhere in the world (the possibility of decentralizing resources)
  - Less negative impact on the environment
  - Renewable sources do not produce greenhouse gases
- Disadvantages:
  - Material and space-intensive collection devices, often high acquisition costs
  - Significant and unpredictable fluctuations in some types of RES - there is a risk of power overflows and overloading in the power grid (in the extreme case the need to regulate the power of other power plants) - the solution: energy storage (to a large extent it is not yet possible)

# Load diagram



- The load diagram shows the ratios in the power grid. The most common is the daily load diagram, i.e. the dependence of electricity generation (consumption) on time, i.e. within 24 hours.

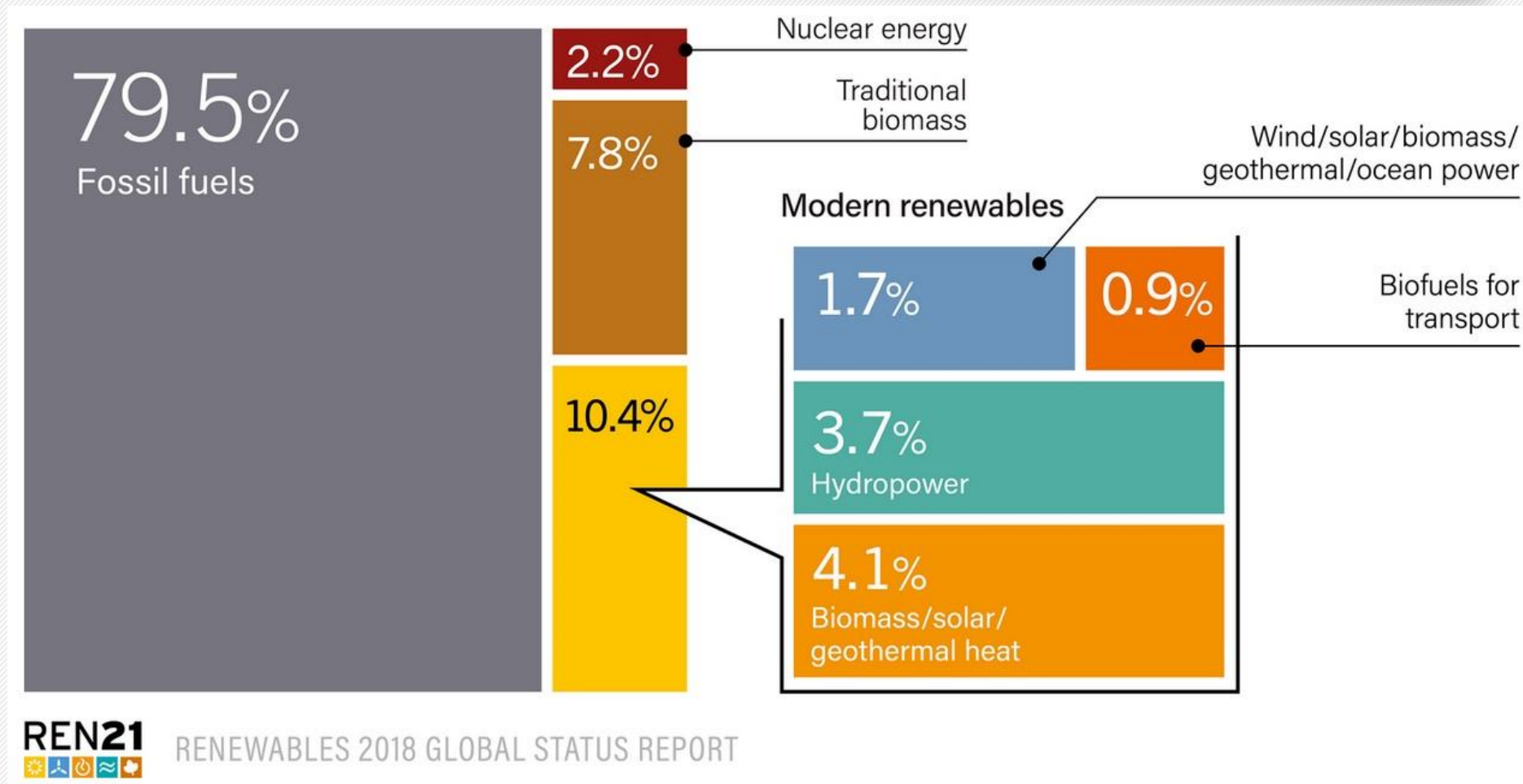


# Load diagram - coverage



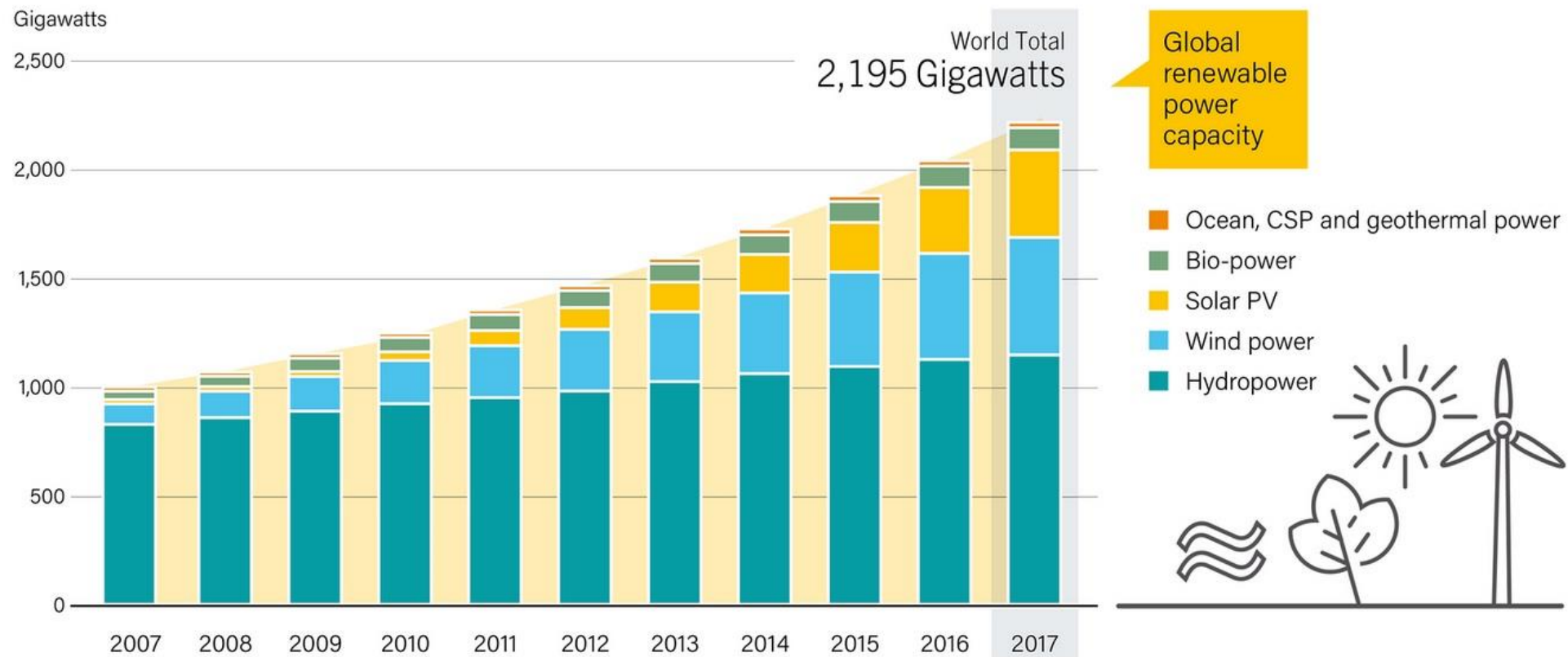
- **The load diagram coverage strategy** corresponds to the ability and economic difficulty of regulation from poorly regulated blocks to well regulated plants.
- **Basic load** - poorly regulated power plants: conventional thermal power plants with high efficiency and high power, nuclear power plants, wind, solar and water-jet (weir) power plants
- **Half-peak load** - older conventional thermal power plants with less efficiency, steam-gas and water (dam) power plants
- **Peak load** - water pumping power plants, sometimes also water dams, gas power plants, fast-start steam turbines, exceptionally diesel and jet engines

# Estimated share of individual sources in total energy consumption in the world (2016)



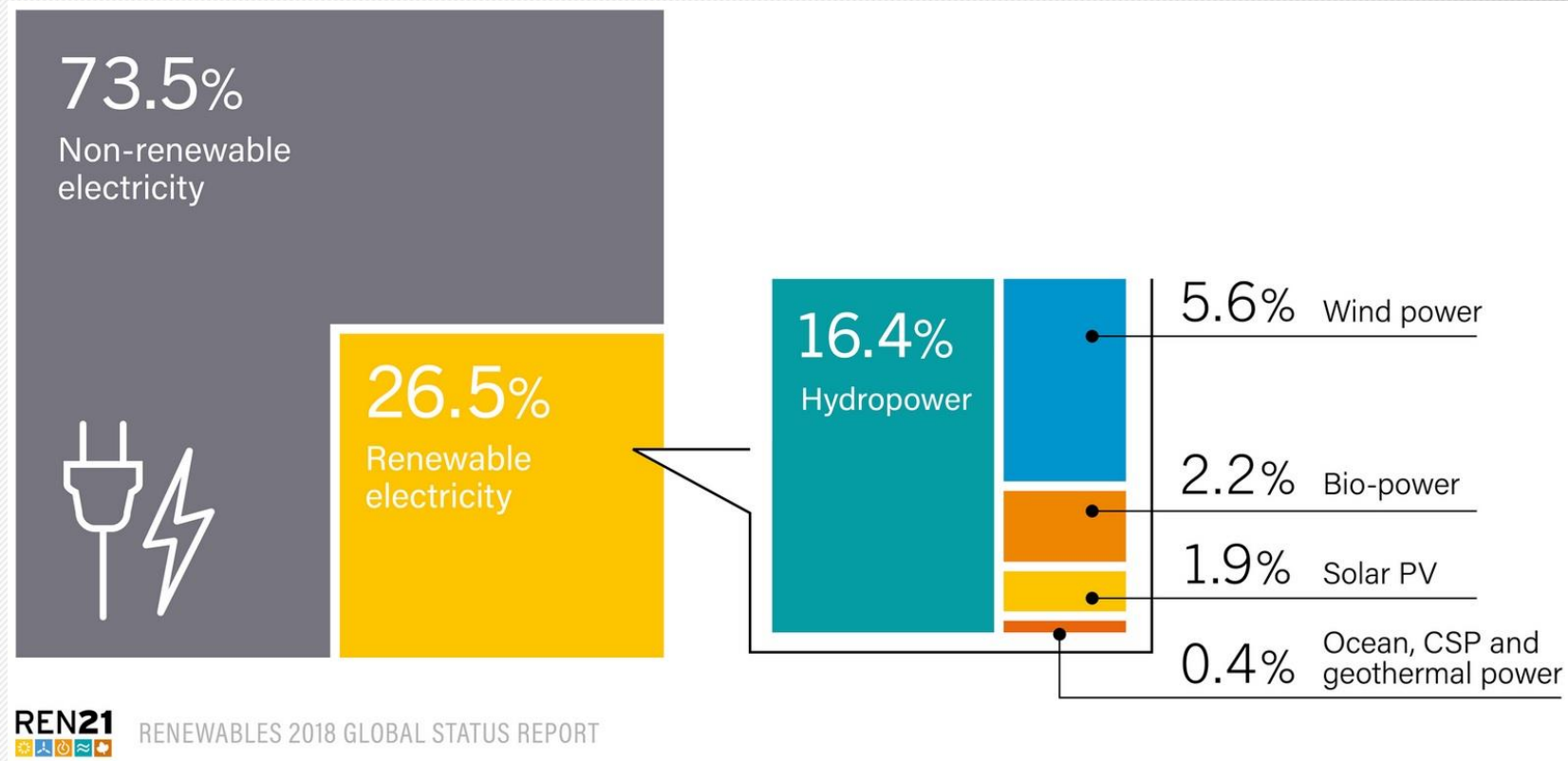


# The course of installed RES in the world





# Share of renewable energy in electricity generation (end of 2017)



- Question to Consider: Is an electric vehicle really so green when it is powered by conventional non-renewable sources?

# How to measure energy on a large scale

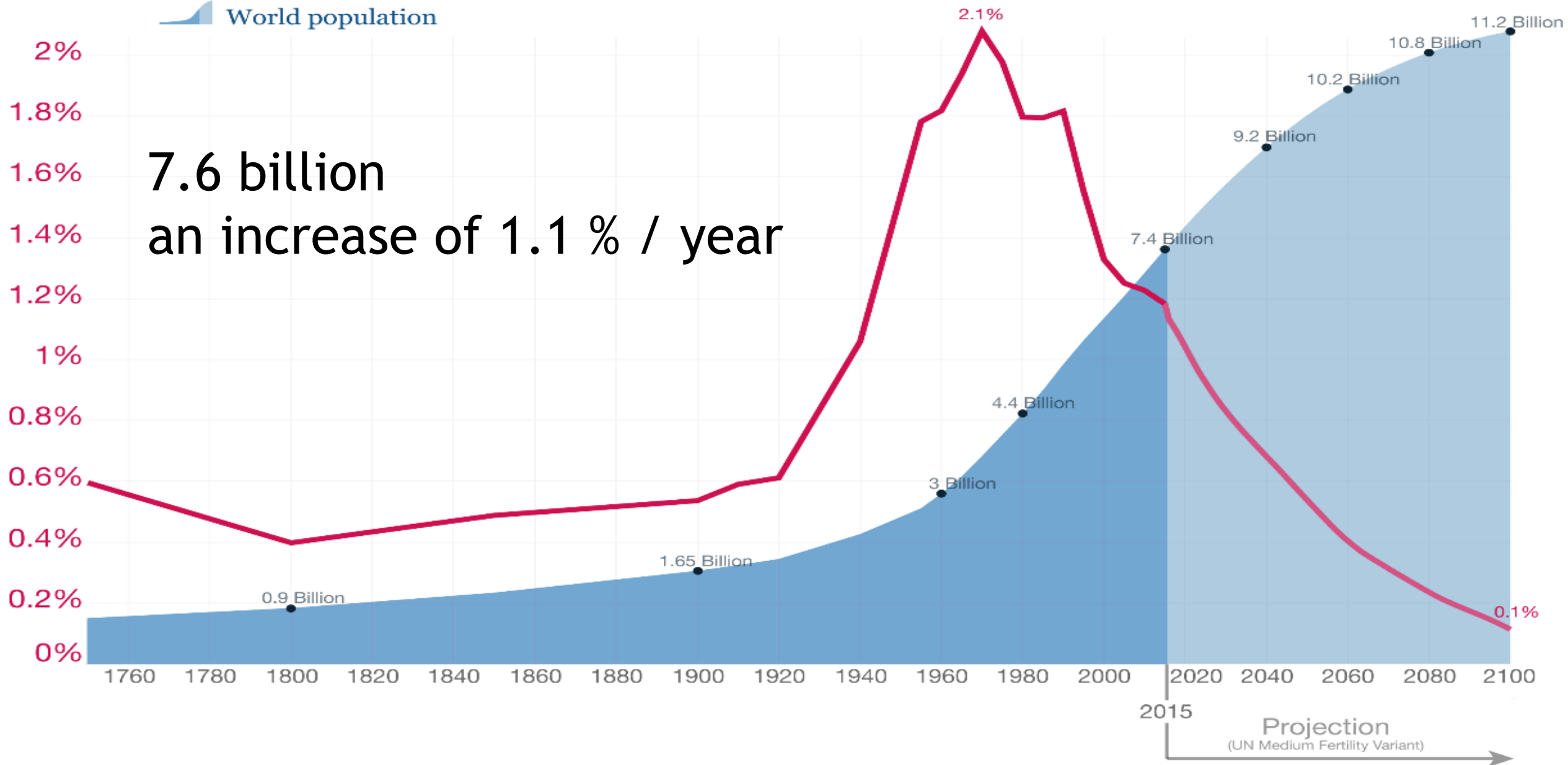


Units on a global scale:

- 1 BTU = British thermal unit = 1.055 kJ
- 1 toe = tonne oil equivalent
  - = 7.4 barrels of oil
  - = 1270 m<sup>3</sup> of natural gas
  - = 2.3 tonnes of coal
  - = 41.9 GJ

# World population growth, 1750-2100

 Annual growth rate of the world population  
 World population

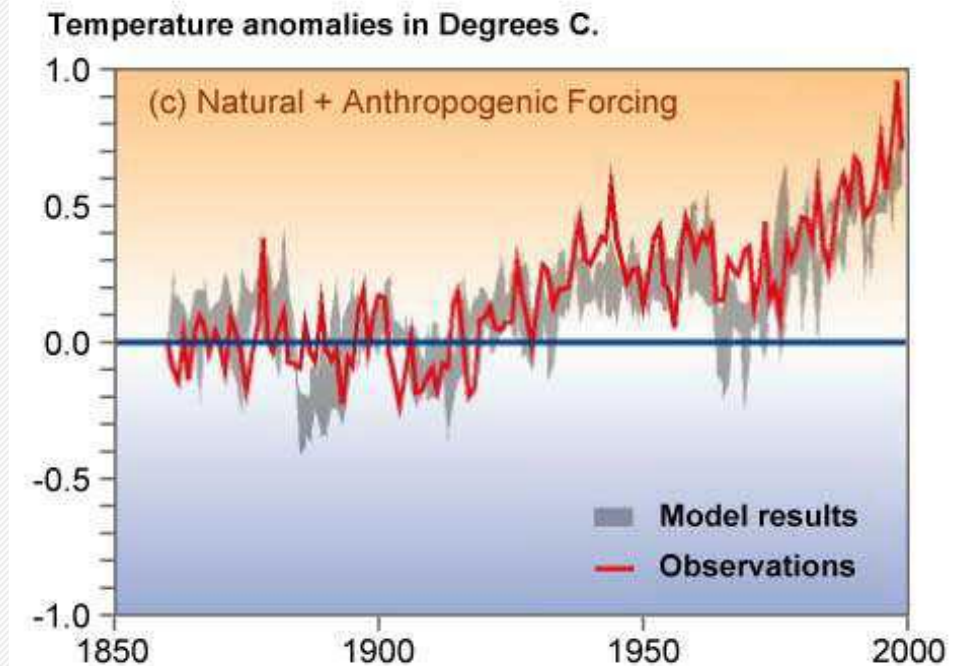
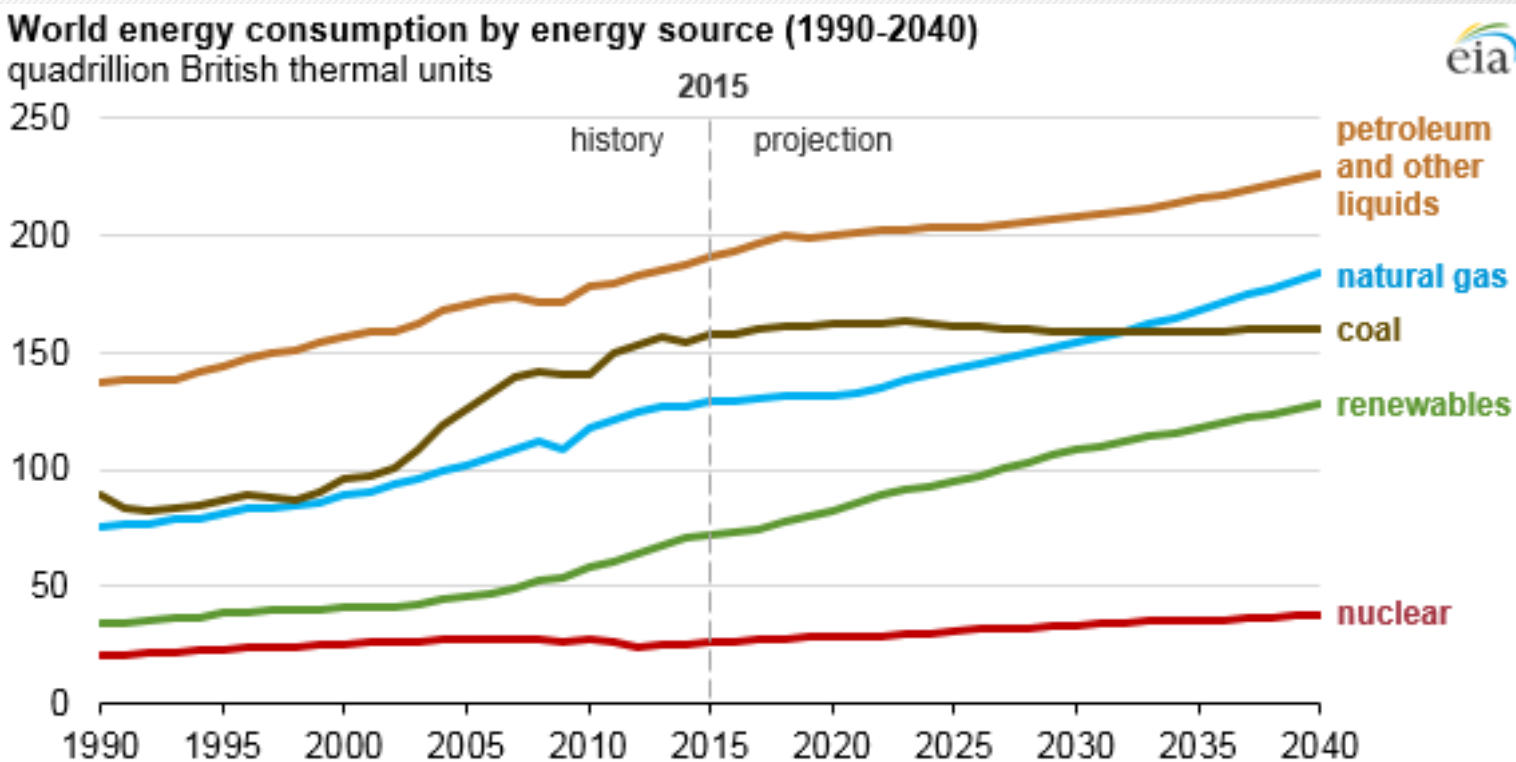


2015

Projection

(UN Medium Fertility Variant)

# Energy demand and climate change

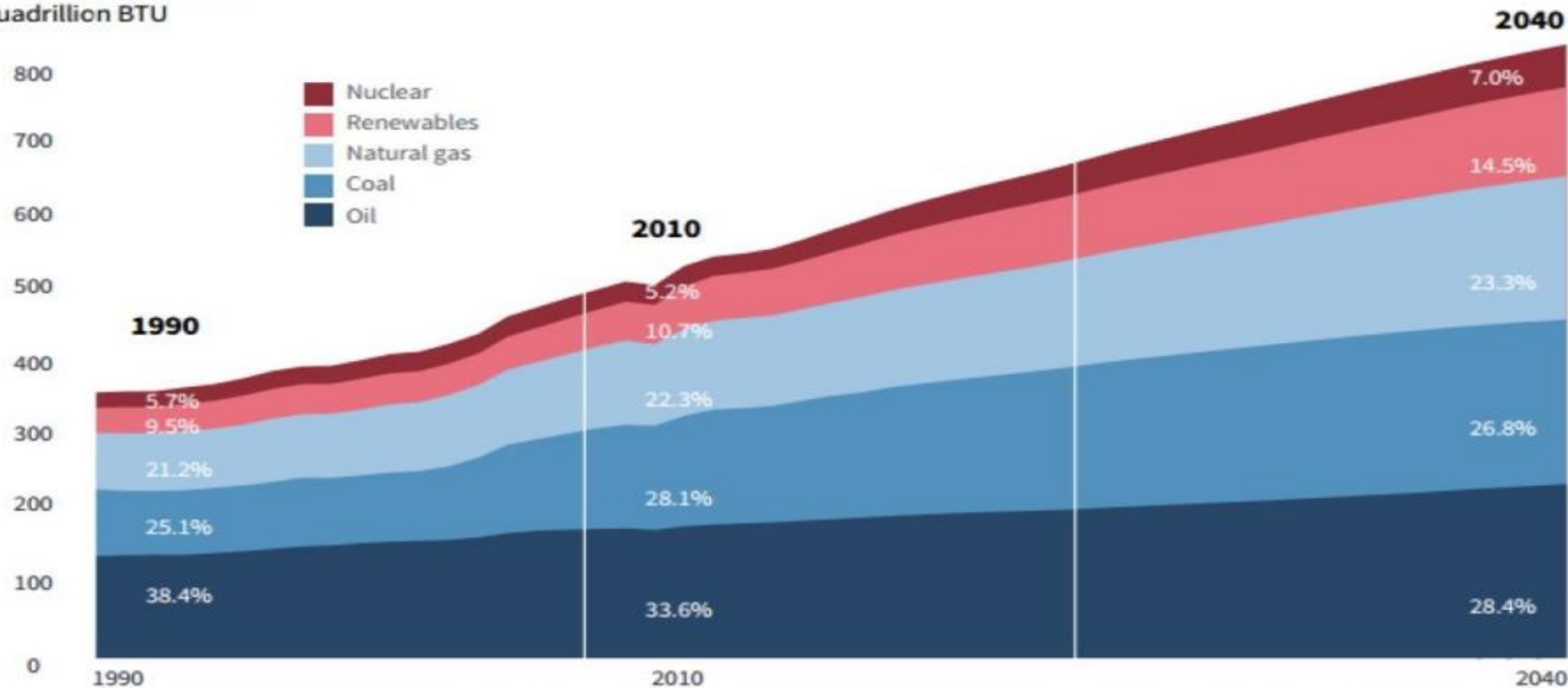


Consumption 11.8 Gtoe = 490 EJ ( $10^{18}$ ) with an increase of 1.6 % / year  
- natural gas 2.3 t CO<sub>2</sub>/toe      oil 2.8 t CO<sub>2</sub>/toe      coal 3.8 t CO<sub>2</sub>/toe

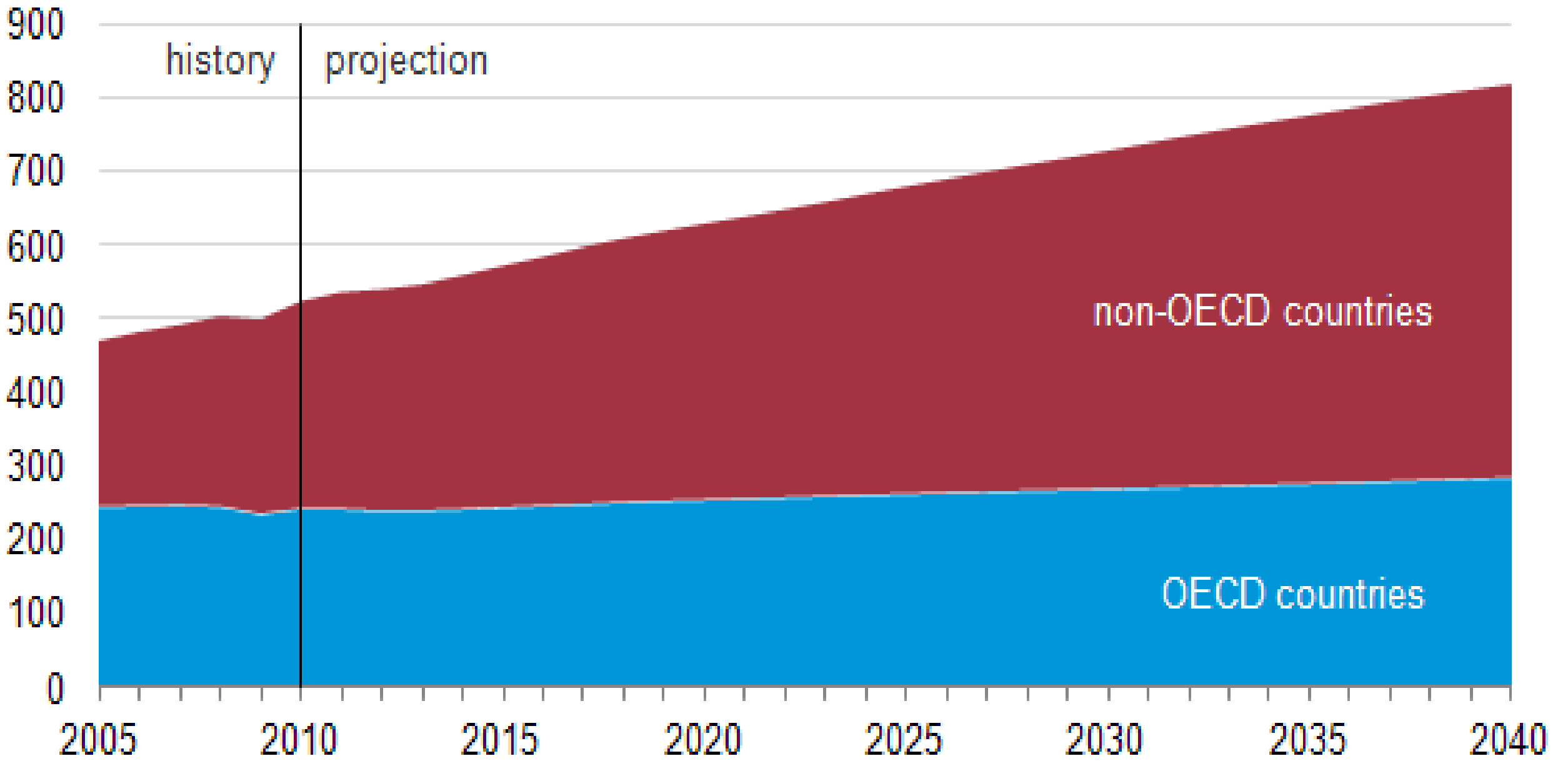
# Future Global Energy Demand

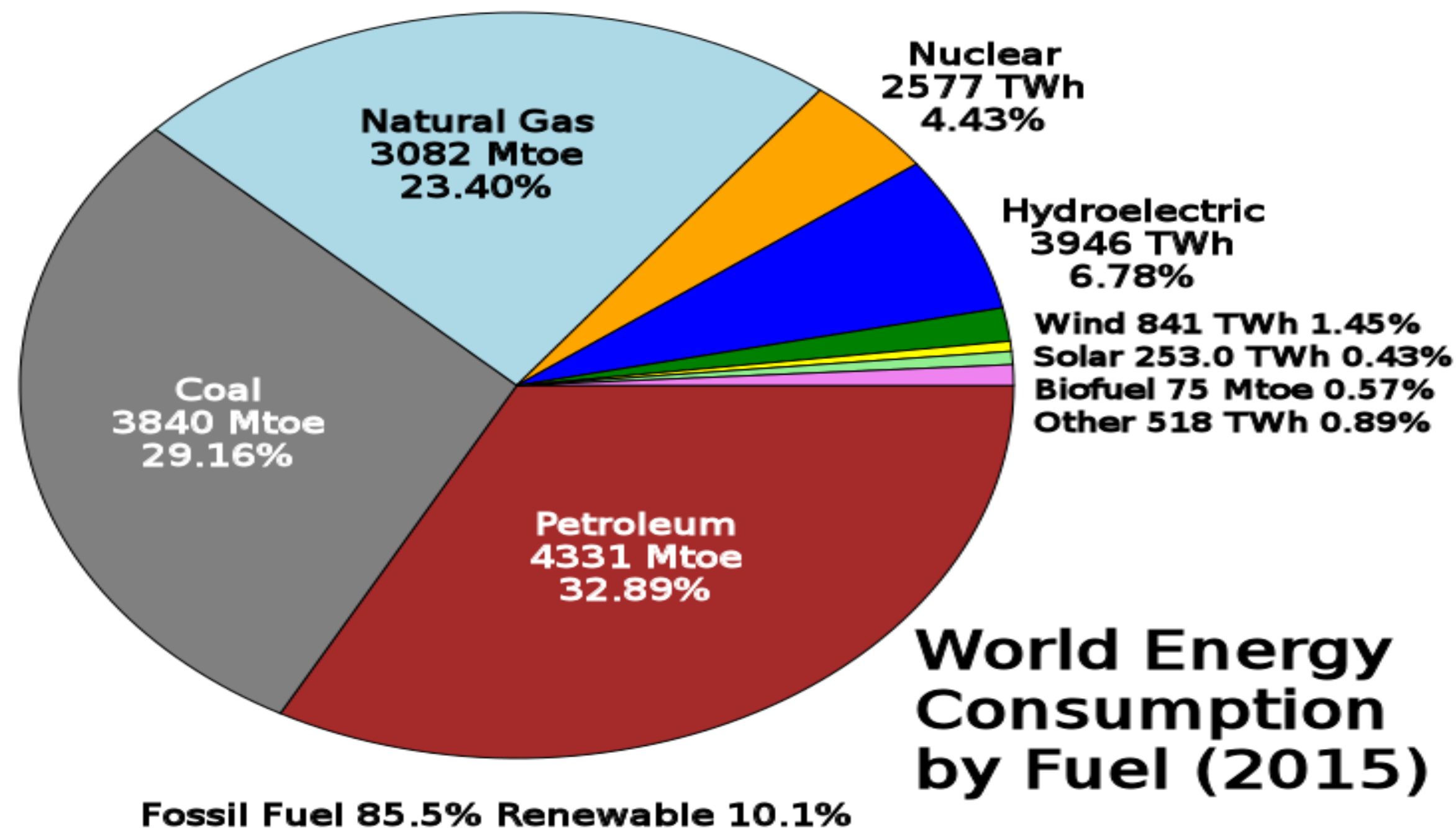
## FUTURE GLOBAL ENERGY DEMAND

Quadrillion BTU



# Projected world primary energy consumption quadrillion Btu

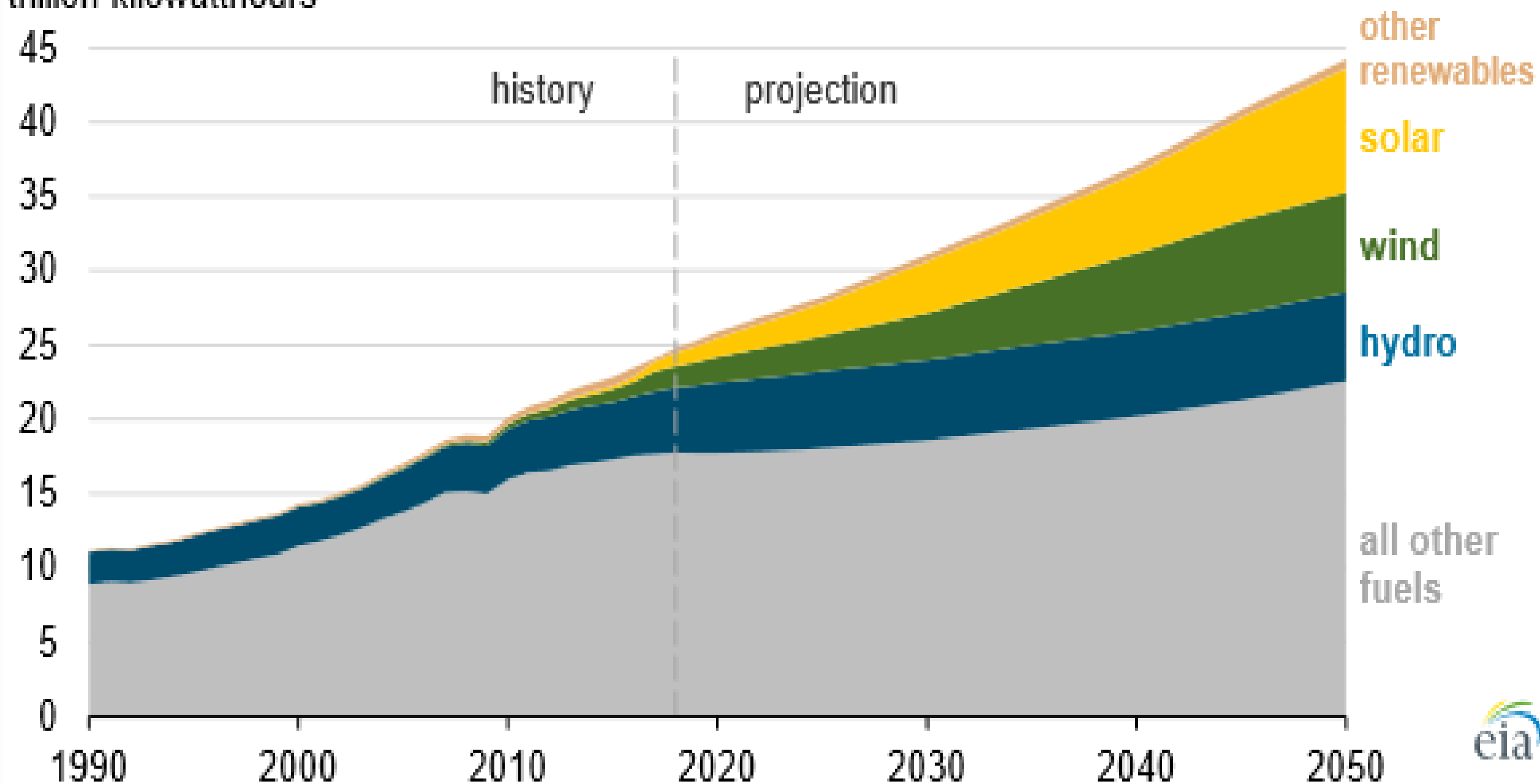






# World net electricity generation, IEO2019 Reference case (1990-2050)

trillion kilowatthours

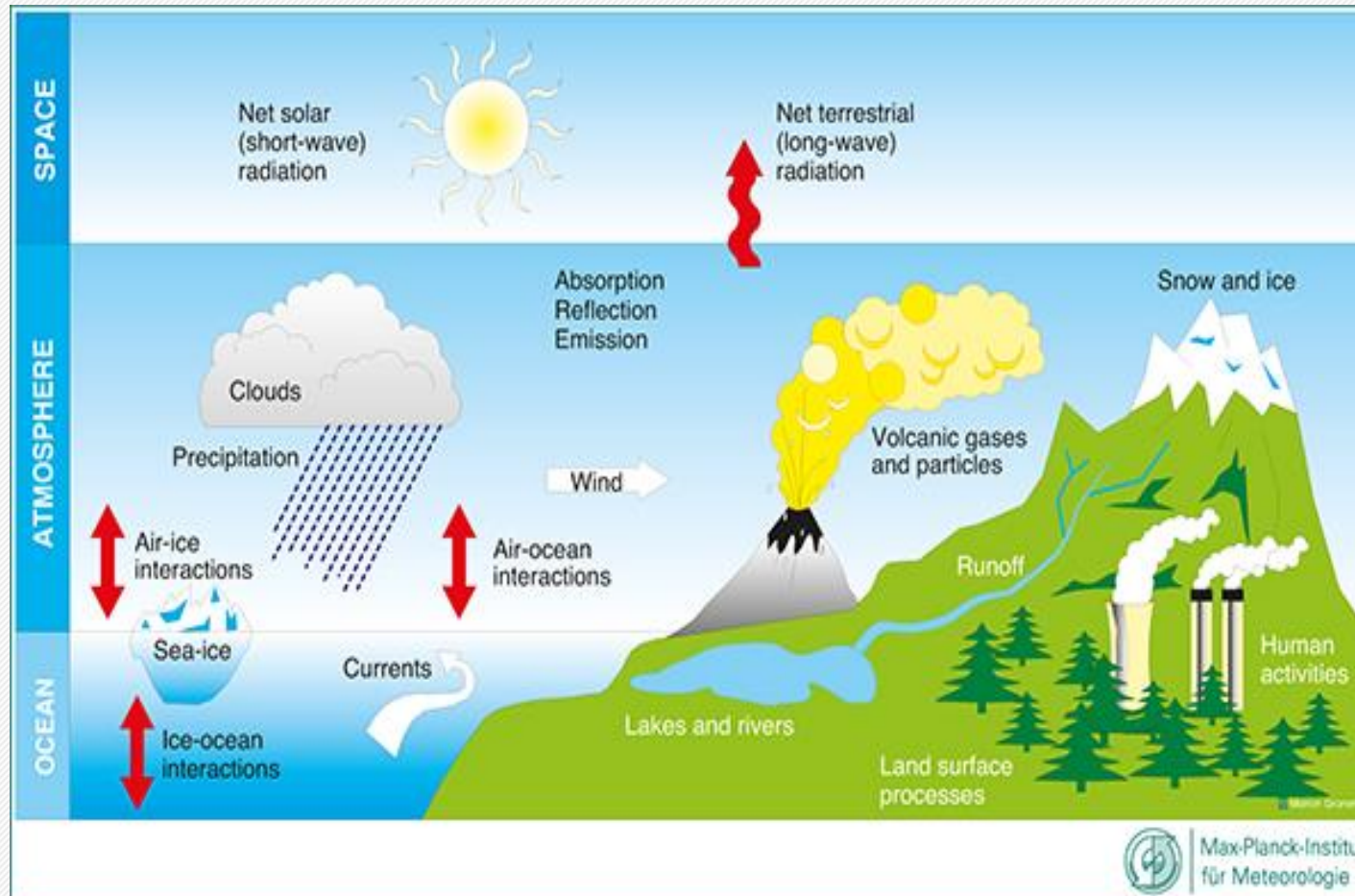


# Fuel supplies

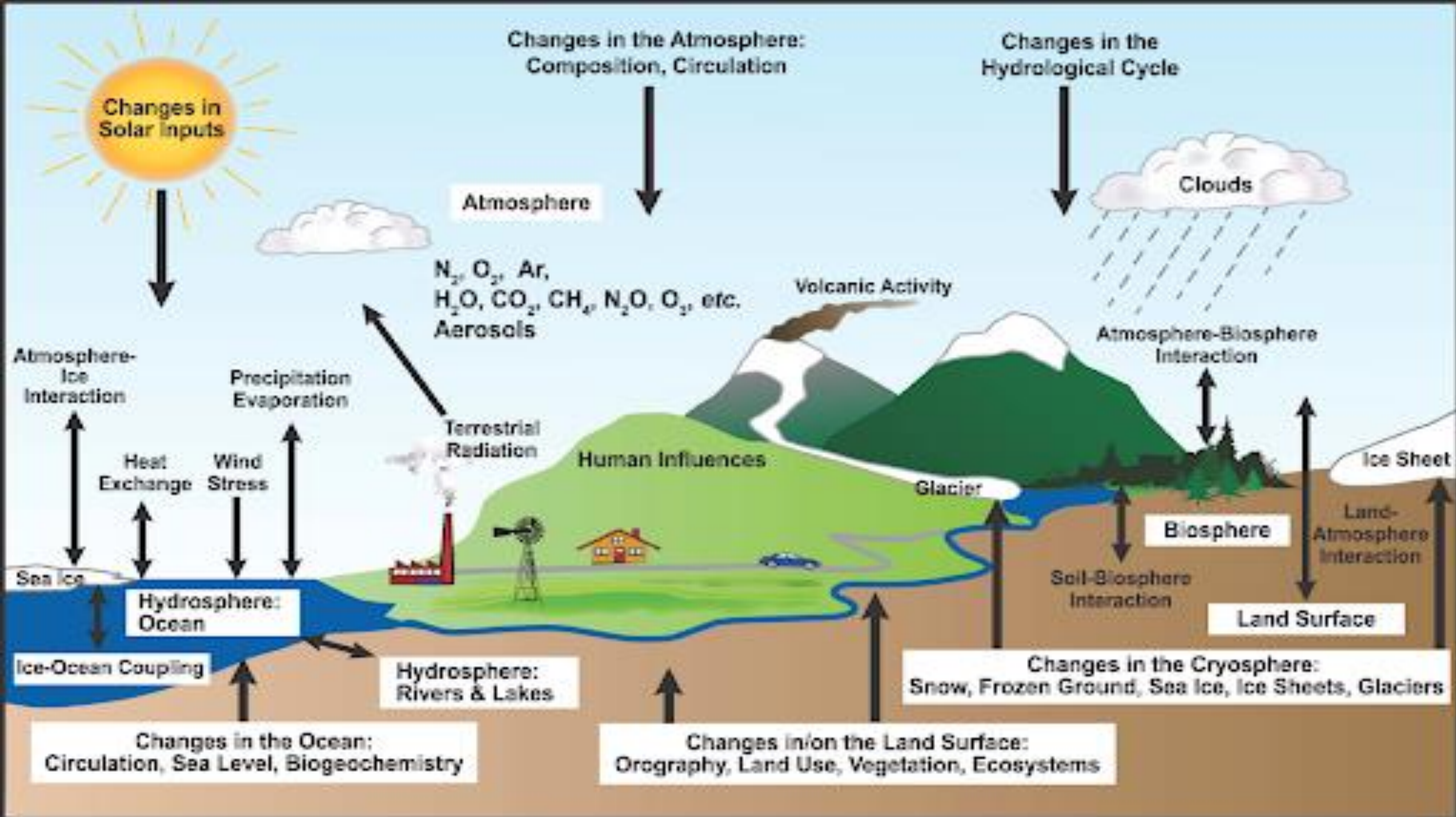


Fuel	Supplies	Current consumption	Enough for
oil	190 Gt	4 Gt/year	46 years
natural gas	190 Tm <sup>3</sup>	3 Tm <sup>3</sup> /year	59 years
coal	860 Gt	4 Gt/year	118 years
uranium	5.5 Mt	51 kT/year	108 years

# Climate system



The climate system consists of 5 interconnected components of the geophysical system - atmosphere, hydrosphere, lithosphere, cryosphere and biosphere (mutual interactions must always be taken into account)

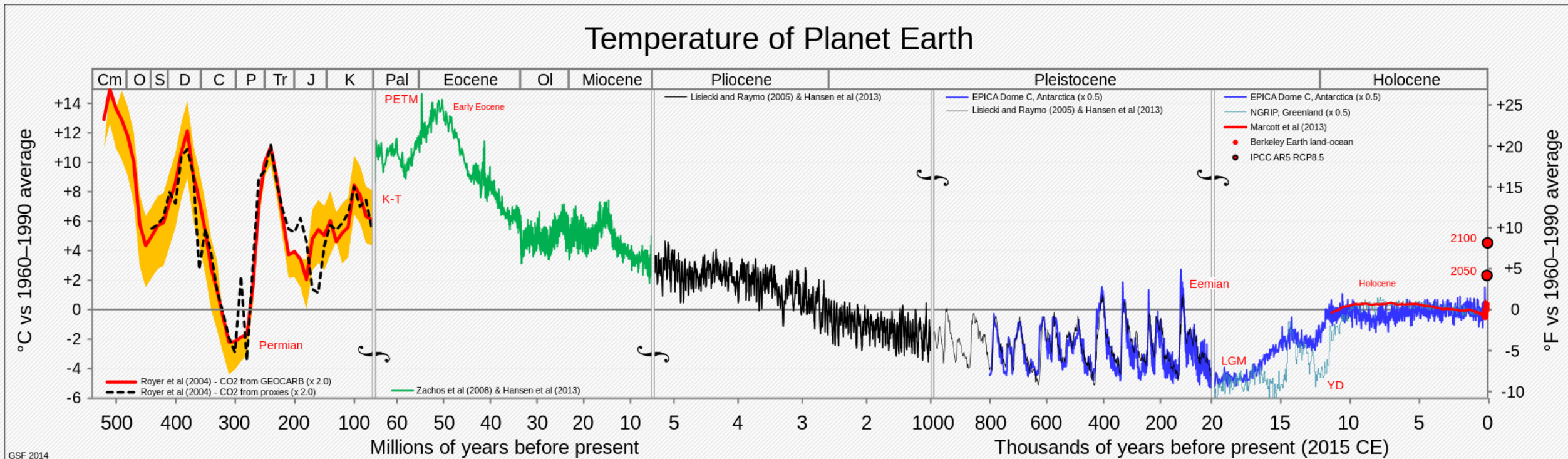




# Climate Change



- The climate has always changed in the past, natural climate change is ongoing and will continue.



# Climate change - causes



## Long-term changes (millions of years or more)

- Changes in continent configuration, continental collisions, formation of mountains, cooling of the Earth, decreasing the frequency of radioactive decay of elements, changes in the amount of radiated solar energy given by the life cycle of the Sun.

## Medium-term changes (tens of thousands to hundreds of thousands of years)

- Changes in the rate of expansion of the mid-ocean ridges, changes in the intake of solar energy - Milankovitch cycles (the main cause of recent ice ages - due to fluctuations in the Earth's orbit around the Sun combined with inhomogeneity of Earth's intake).

## Short-term changes (hundreds to thousands of years)

- Greater volcanism (warming by releasing carbon dioxide), human activity - warming by releasing carbon dioxide (emissions of fossil fuels, aerosols)

## Very short-term changes (years to decades)

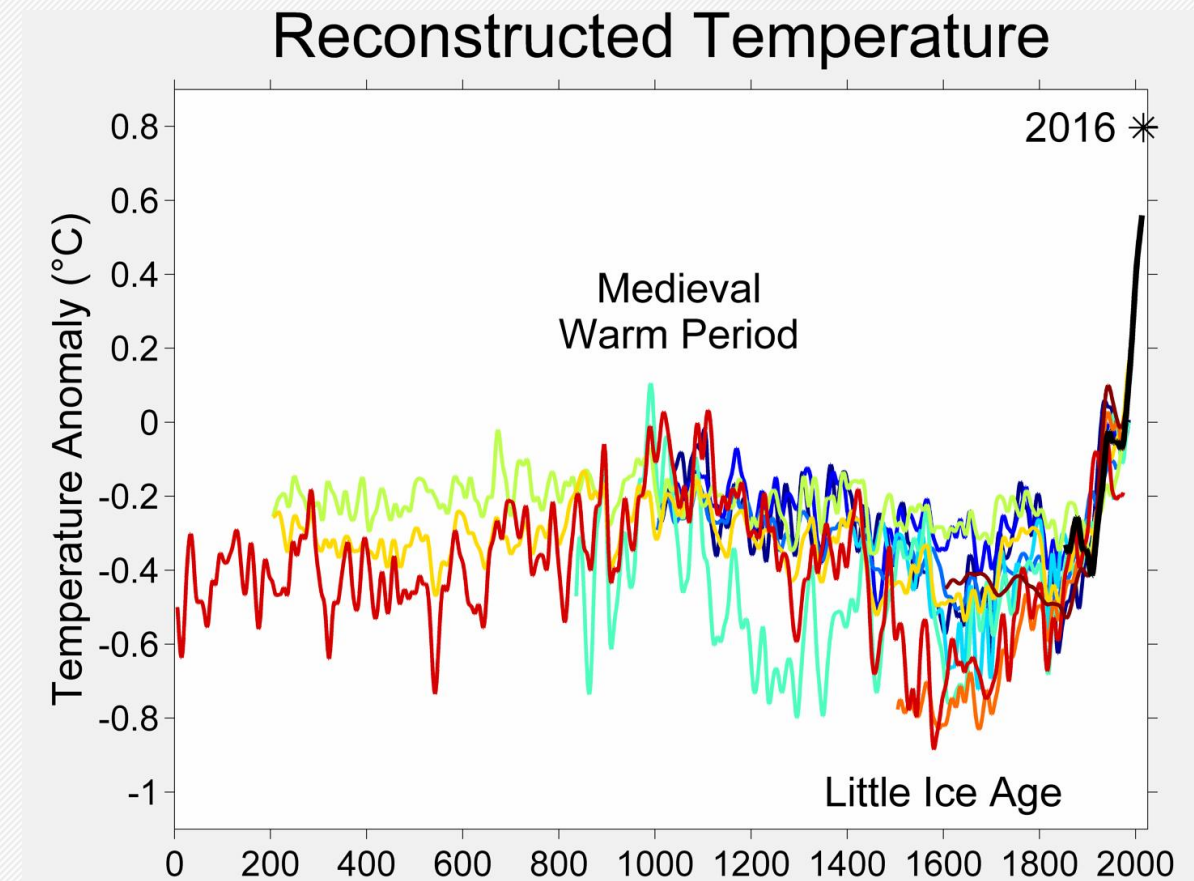
- Volcanic winter (for superculcans), but also minor changes from eruptions, large fires, solar cycles, impact winter (for large asteroids / comets).

# Climate of the last millennium



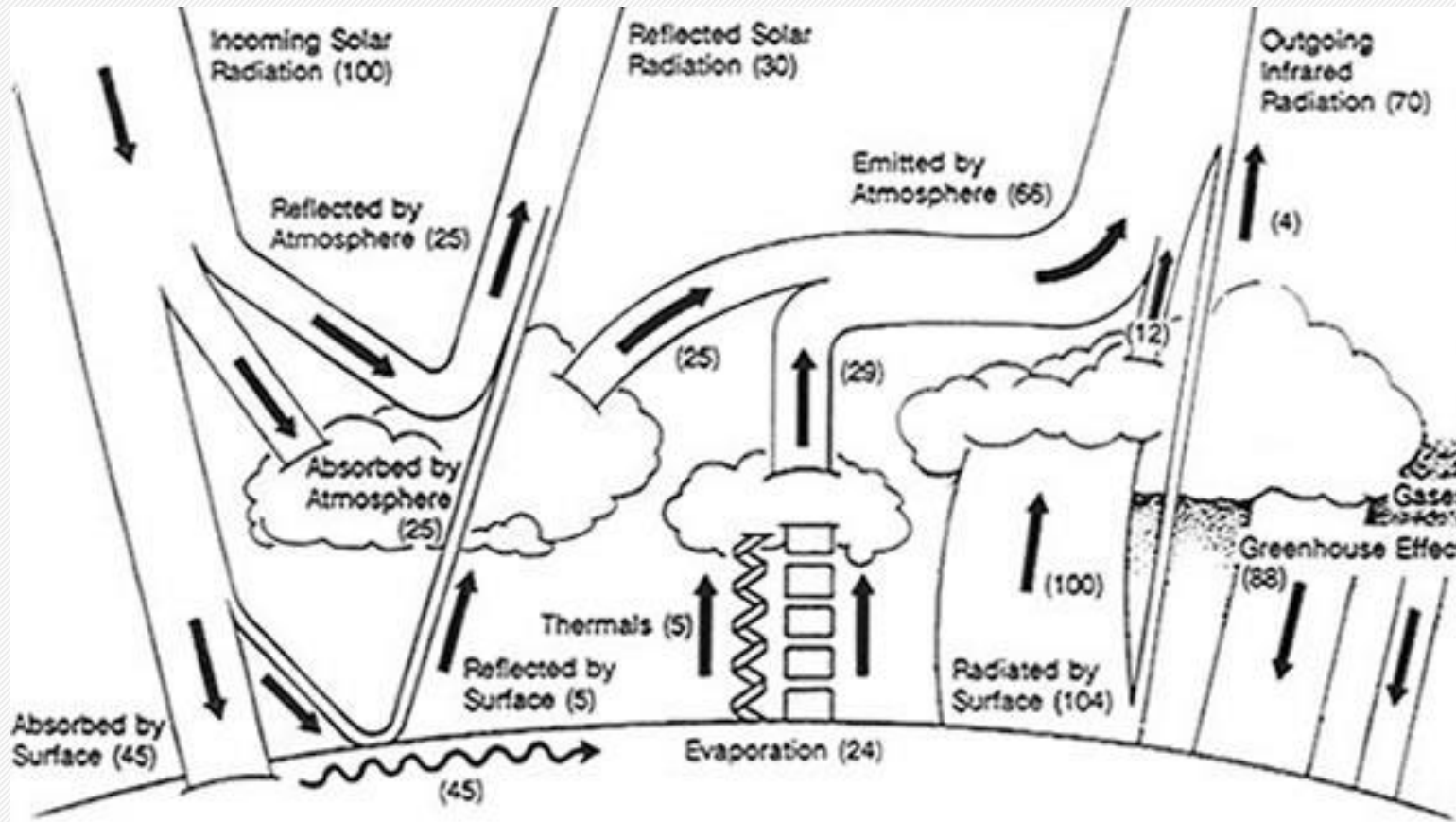
In the climate of the last millennium three periods can be discerned: the medieval warm period, the so-called small ice age in the 16th to 19th centuries, and the subsequent period of global warming - the industrial revolution, the greenhouse effect of anthropogenic origin.

During the last 800 000 years, when we are able to say it with certainty, there has been no such rapid rise in global temperatures as we have seen in the last 200 years since the Industrial Revolution !!!





# Greenhouse effect scheme



Short wave radiation is absorbed in the Earth's surface and radiated in long-wave form. Long-wave radiation emitted by the Earth's surface is captured by water vapor and greenhouse gas molecules -> part of long-wave radiation is reflected back to earth. This phenomenon is called a greenhouse effect and without it, the Earth's surface temperature would be about 33 °C lower than today.

# Greenhouse gases



- The most important greenhouse gases (GHG) include water vapor, carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). There is a dependence between GHG and atmospheric temperature, with their increasing concentration, the global temperature also increases.
- In the past millennia, the concentration (CO<sub>2</sub>) ranged from 180-280 ppmv, while its concentration is now close to 380 ppmv. Additional GHG such as halogenated hydrocarbons and sulfur hexafluoride are released into the atmosphere. Ground ozone concentrations also increase.
- Increasing GHG is closely tied to the development of an industrial society. CO<sub>2</sub> is generated as a result of burning fossil fuels, CH<sub>4</sub> gets into the air from industrial plants and agriculture. Halogenated hydrocarbons are released from air conditioners, refrigerators and sprays.
- Forests and phytoplankton in the oceans can absorb huge amounts of CO<sub>2</sub>, forest degradation and marine pollution further reduces the ability to slow down temperature rise.

# Carbon cycle



- The most important greenhouse gases  $\text{CO}_2$   $\text{CH}_4$  are part of the so-called global carbon cycle. Carbon flows continuously between reservoirs in the ocean (dissolved in water such as  $\text{CO}_2$  and plankton), on earth (living organisms) and in the atmosphere (gaseous forms of  $\text{CO}_2$  and  $\text{CH}_4$ ). The cyclic exchange of carbon between the reservoirs and the photosynthesis of plants make it possible to very well balance the carbon emissions into the atmosphere by natural removal.
- The industrial revolution and human have damaged this natural balance. In ancient times, much of the carbon leaked out of the cycle and formed in the Earth's crust as coal, or a gaseous and liquid hydrocarbon that human extracts and burns and thus still gets of the carbon cycle from equilibrium by bringing emissions to the atmosphere through anthropogenic activities. The cycle is no longer able to naturally eliminate these emissions.

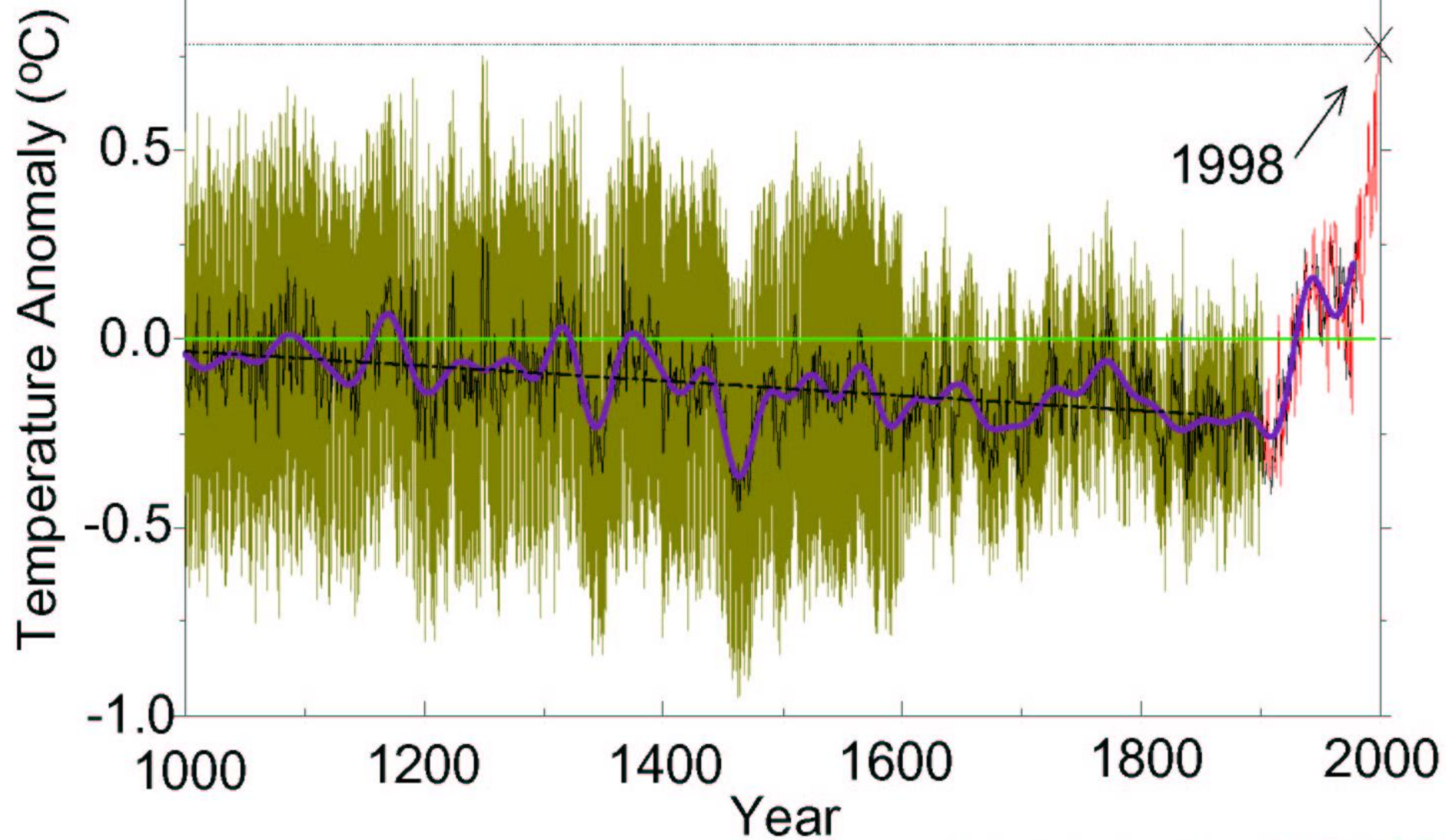
# Greenhouse gases



Pollutant	Emission [ 10 <sup>6</sup> tons ]	Sources of pollution	
		natural [%]	anthropogenic [%]
carbon dioxide CO <sub>2</sub>	500 000	volcanic activity 96	combustion processes 4
carbon monoxide CO	5 300	oceans, wildfires 94	transport 75 production 15 waste disposal 10 TOTAL 6
hydrocarbons C <sub>x</sub> H <sub>y</sub>	2 700	methane - wetlands, activity of natural organisms, terpenes from forests 97	oil transport and processing 65 production 25 energetics 10 TOTAL 3
aerosols + fine dust	4 400	sea salt, wind, volcanoes 94	energetics 60 production 40 TOTAL 6
nitrogen oxides NO <sub>x</sub>	830	oxidation by lightning 94	energetics 55 transport 40 production 5 TOTAL 6
ammonia NH <sub>3</sub>	1 160	decomposition of organic residues 99	production 0.5 manuring 0.5 TOTAL 1
sulfur compounds SO <sub>2</sub> , SO <sub>3</sub> , H <sub>2</sub> S	750	volcanoes, organic decomposition 82	energetics 70 production 28 transport 2 TOTAL 18

Greenhouse gases of anthropogenic origin are carbon oxides, methane, oxides of nitrogen, partially and completely fluorinated hydrocarbons, sulphur hexafluoride and sulphur compounds (their emissions controlled by the Kyoto Protocol and the Framework Convention) hard (CFC) and soft (HCFC) freons, halons (their emissions controlled by the Montreal Protocol and its amendments)





1998

- reconstruction (AD 1000-1980)
- raw data (AD 1902-1998)
- calibration period (AD 1902-1980) mean
- reconstruction (40 year smoothed)
- linear trend (AD 1000-1850)

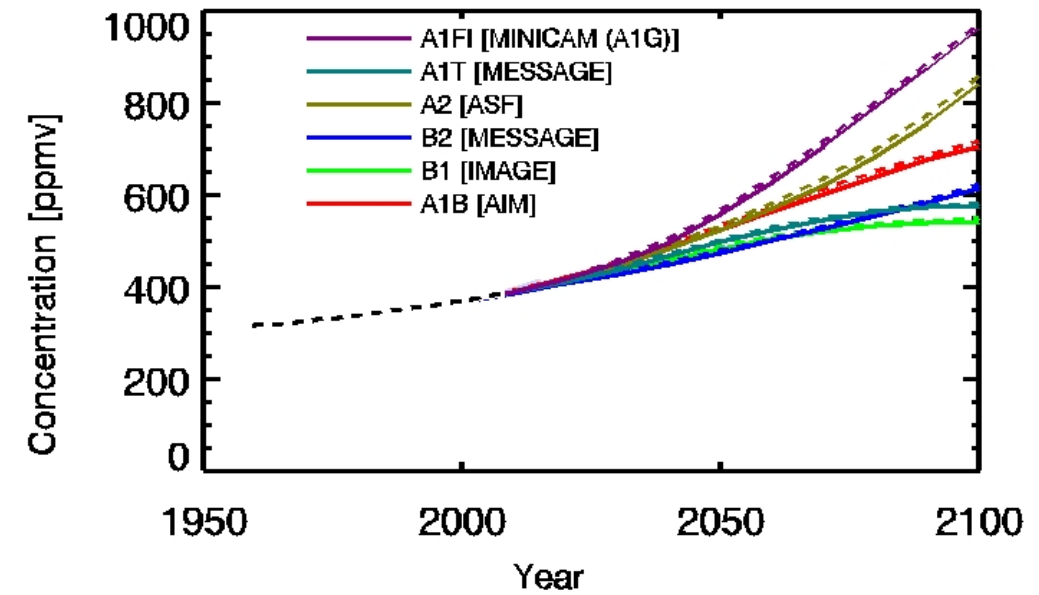
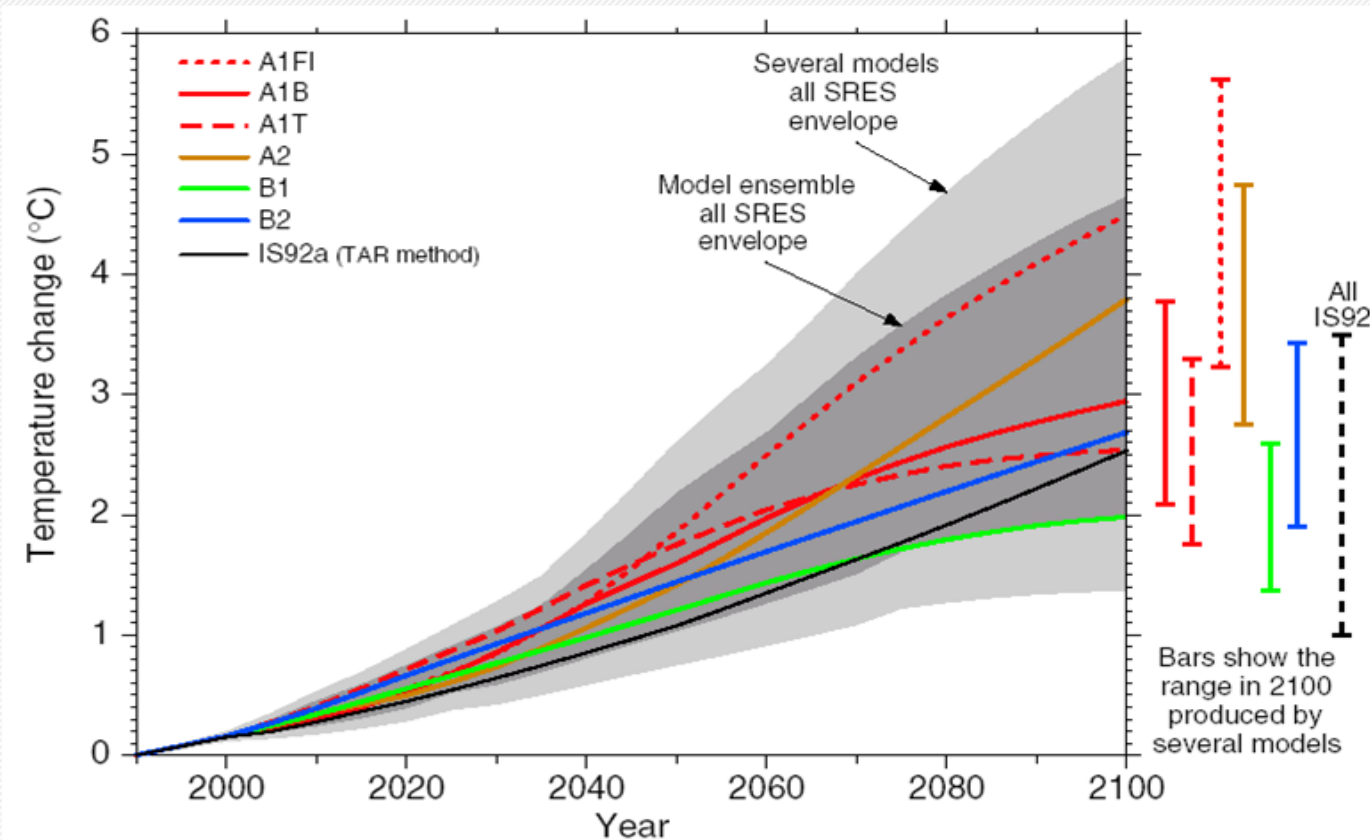
# Climate modeling



For climate modeling, it is necessary to take into account the development of human society over the next 100 years, and therefore four core groups of internationally recognized SRES scenarios have been created.

- Scenario A1: Very fast growth of the economy, development of new technologies, culmination of population growth around 2050, then decline. Scenario A1 is divided into:
  - A1FI = intensive use of fossil fuels
  - A1T = no fossil fuels
  - A1B = balanced use of all energy sources
- Scenario A2 corresponds to a steady population increase (19 billion at the end of the 21st century)
- Scenario B1 is based on globalization, the introduction of new technologies
- Scenario B2 puts emphasis on sustainable development, support for regional economies, diversity of technologies.

# Climate scenarios





# Climate change - how to defend ?



In principle, there are 3 solutions for the human population:

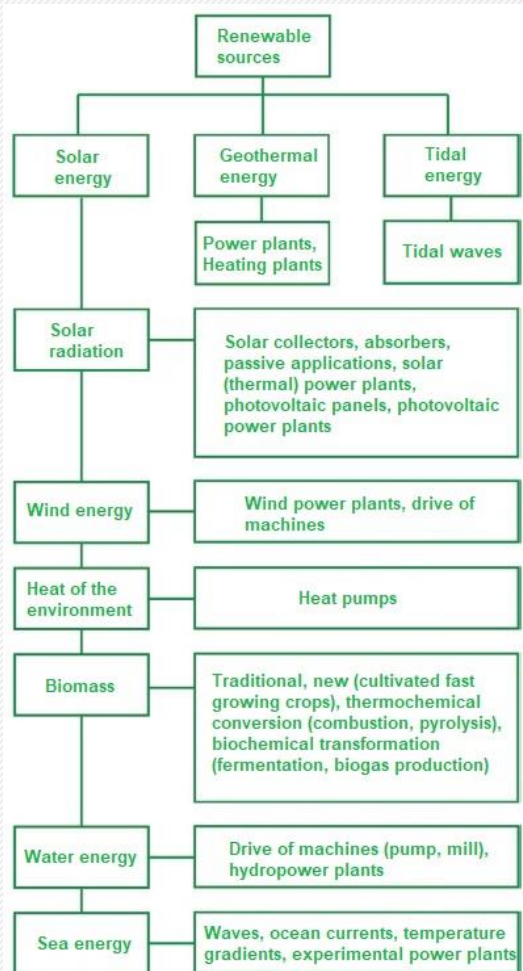
- If we are suspected of climate change as a result of GHG, it is essential to reduce the production of these gases, it is very difficult to do it worldwide.
- The second option is to adapt to these changes, i.e. to look for effective and cheap ways to reduce the negative consequences.
- There is, of course, a combination of both ways. At least regionally reduce GHG production in advanced countries and at the same time begin to implement adaptation solutions.

# Variants of GHG reduction (both classic and "revolutionary" methods)



- Projects for enrichment of seas and oceans with iron due to the growth of phytoplankton.
- Already tested CO<sub>2</sub> storage method in extracted oil and gas deposits, CO<sub>2</sub> will be stored safely thanks to the high water pressure in the deposits.
- Reducing the radiation that falls on the ground - methods that increase the reflection of the atmosphere seem curious, but they can be technically managed (for example a fleet of micro balloons in the stratosphere). An increase in reflection of 1 % would compensate for a double increase in CO<sub>2</sub>.
- The "classic" method is the reduction of CO<sub>2</sub> concentrations under the 1997 Kyoto Protocol and the subsequent "softened" Bonn 2001 limits for individual states. The original GHG emissions reduction of 5.6 % was softened to 2 % in 2008-2012.

# Climate change - how to defend? With renewable sources



Renewables have the potential to mitigate global warming.

- An unquestionable advantage is their practical inexhaustibility, i.e. their recoverability. In operation, they do not pollute the environment, unlike fossil fuels, and do not permanently increase the amount of greenhouse gases.
- Renewable sources also have disadvantages, mostly due to their nature. The energy they capture has a smaller area or spatial density. Therefore, facilities with a capacity comparable to conventional ones (thermal power plant) are much larger and technologically more demanding and more expensive in terms of initial investment. Furthermore, the energy supplied by renewable sources is fully dependent on natural conditions such as sunshine, wind and rain (power fluctuations).

# Smart grids

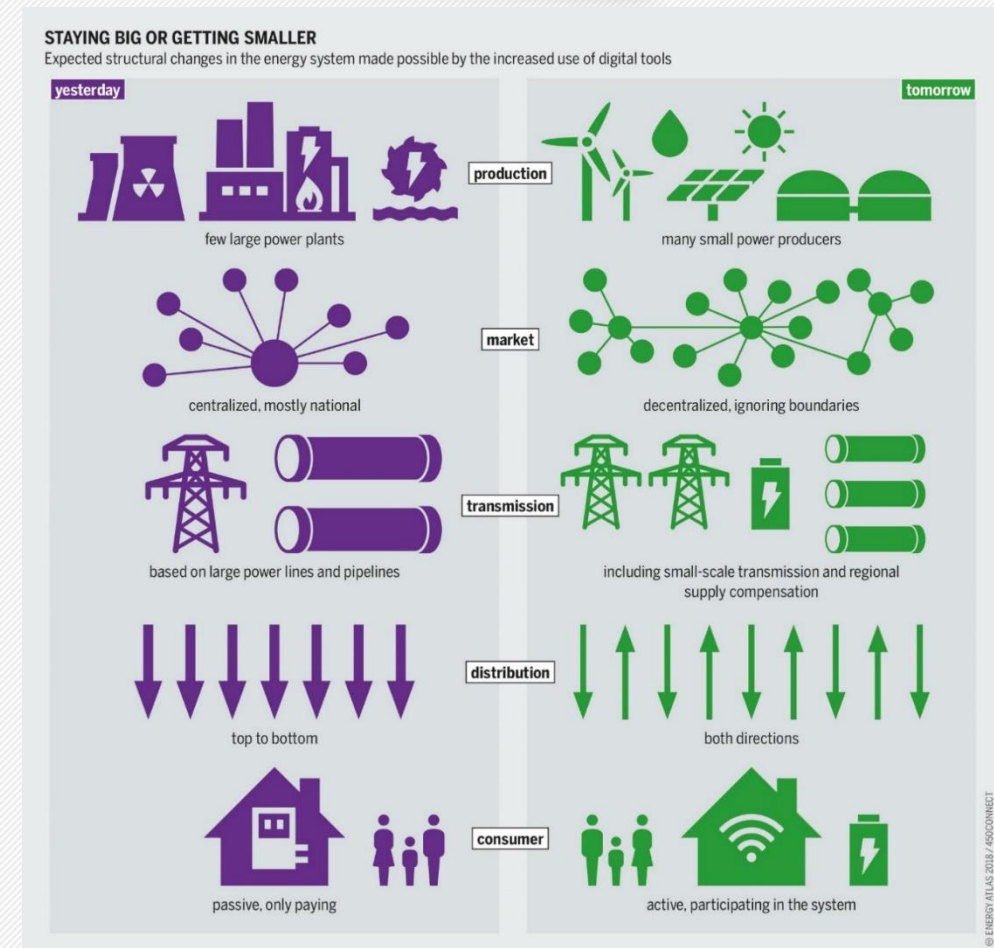


- Smart Grids and energy storage will enable large-scale integration of renewables into the electricity grid. Smart grids are part of the 4th Industrial Revolution (Industry 4.0, Energy 4.0). The basis for this conceptual change in the energy sector is a decentralized distribution system based on:
  - a) Smart Grids - each part of the district creates a partially self-sustaining “ecosystem” that behaves externally, sometimes as a consumer, sometimes as a producer (changing consumption profile). Smart grids will therefore include both sources (alternative power plants, waste heat sources, cogeneration units, batteries) as well as consumers as well as prosumers (who sometimes act as sources, sometimes as consumers) - all of these elements will be optimized locally with the aim of maximum self-sufficiency.
  - b) The backbone grid - made up of centralized, high-performance conventional sources (which should cover only 70% of consumption in 2030, only 60% in 2040 and this share should continue to decline). Hierarchically, the smart grid will eventually seek support in the backbone grid.

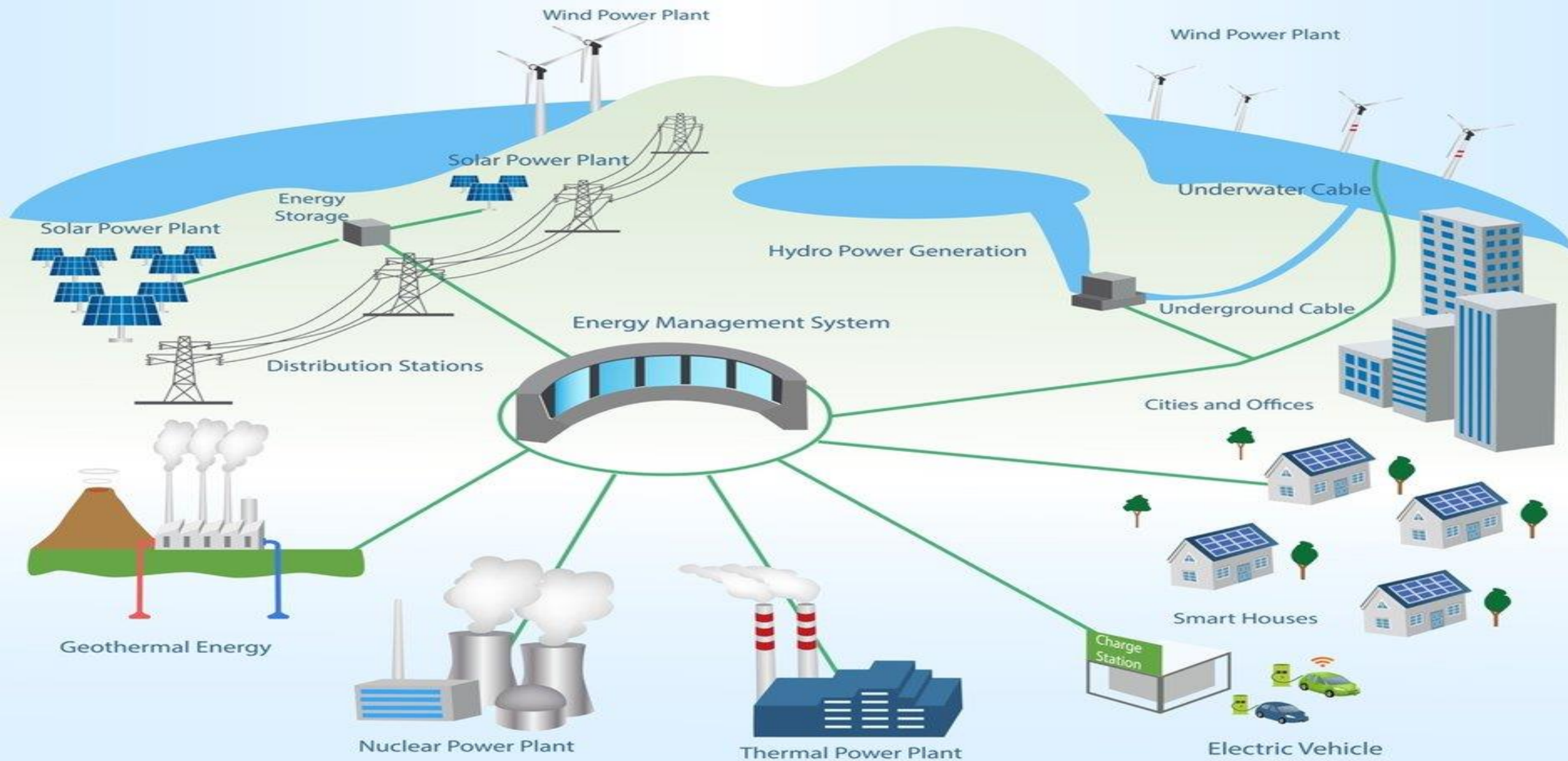


# Smart grids

Each participant in the smart grid must be connected to a sufficiently efficient communication network. The intelligent behavior of the entire system will be based on the Internetisation and virtualization of the physical energy infrastructure. There will be two interconnected networks within the energy sector - energetics and informatics - so the future of energetics is more about computer science than about transmission wires and pipes. It will be crucial to connect the fast computer network to all physically existing elements (transformers, generators, appliances, accumulators, etc.) in all nodes and key equipment.



# SMART GRID

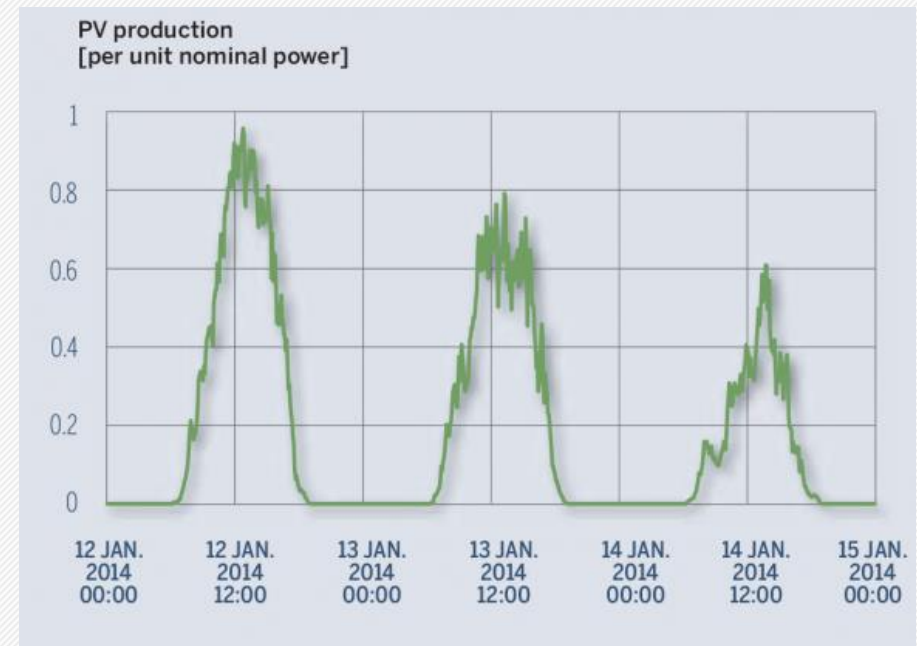
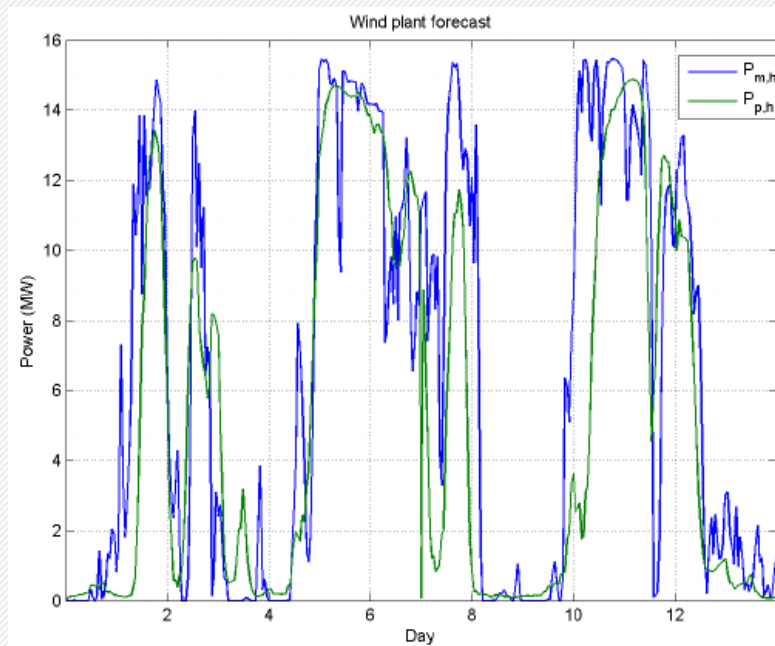




# Smart grids



- The world's most developed renewable sources are solar and wind sources, which are weather dependent and therefore difficult to predict - fluctuations in production profile and balance between production and consumption - difficulty of integration and connection to the electricity grid.



# Smart grids



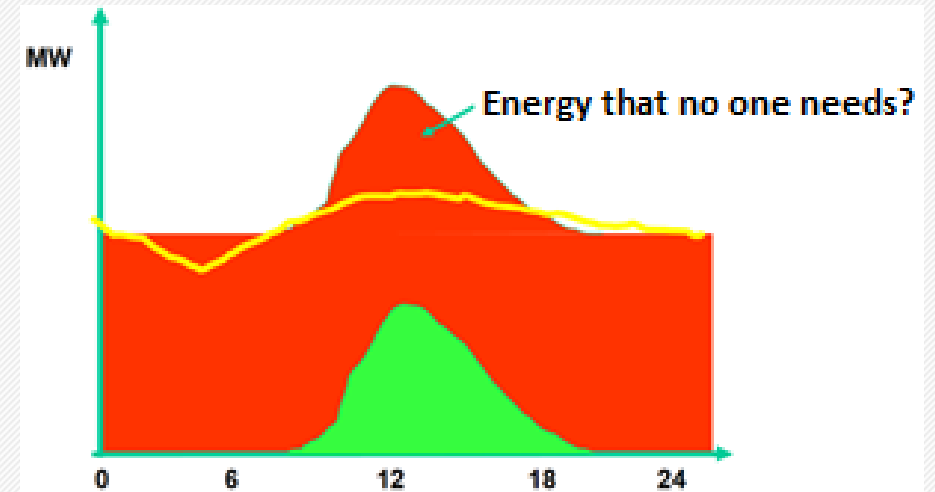
Due to the variable output of solar and wind sources, cooperation with other sources of the electricity system is necessary. These are predominantly conventional thermal power plants and nuclear power plants, which are the sources that operate most efficiently only when operating in a narrow power range close to the nominal power - limited negative power control capability in terms of efficiency, economy and ecology of operation => clean energy production loses meaning when would mean inefficient and unecological operation of conventional thermal and nuclear power plants. The economic unprofitability of the negative power control of conventional large sources is so significant that the operators of these sources are more likely to buy the off-take. I.e. on the short-term wholesale market, to offer electricity at a negative price (now commonplace, for example, at night in Germany or, for example, in California at midday).

# Smart grids



By including resources that are difficult to predict in the power system, an excess of electricity can occur, for example, when it suddenly warms up and consumption decreases. As most of the renewable resources take precedence in some countries in relation to national regulations, they move the basic load of conventional resources above the level of need.

The claim that this surplus is unnecessary is misleading because the need or not need for electricity is only a function of its cost. The problem is that it is currently not technically possible to offer this excess energy to the customer at an attractive price, even though it is in excess.

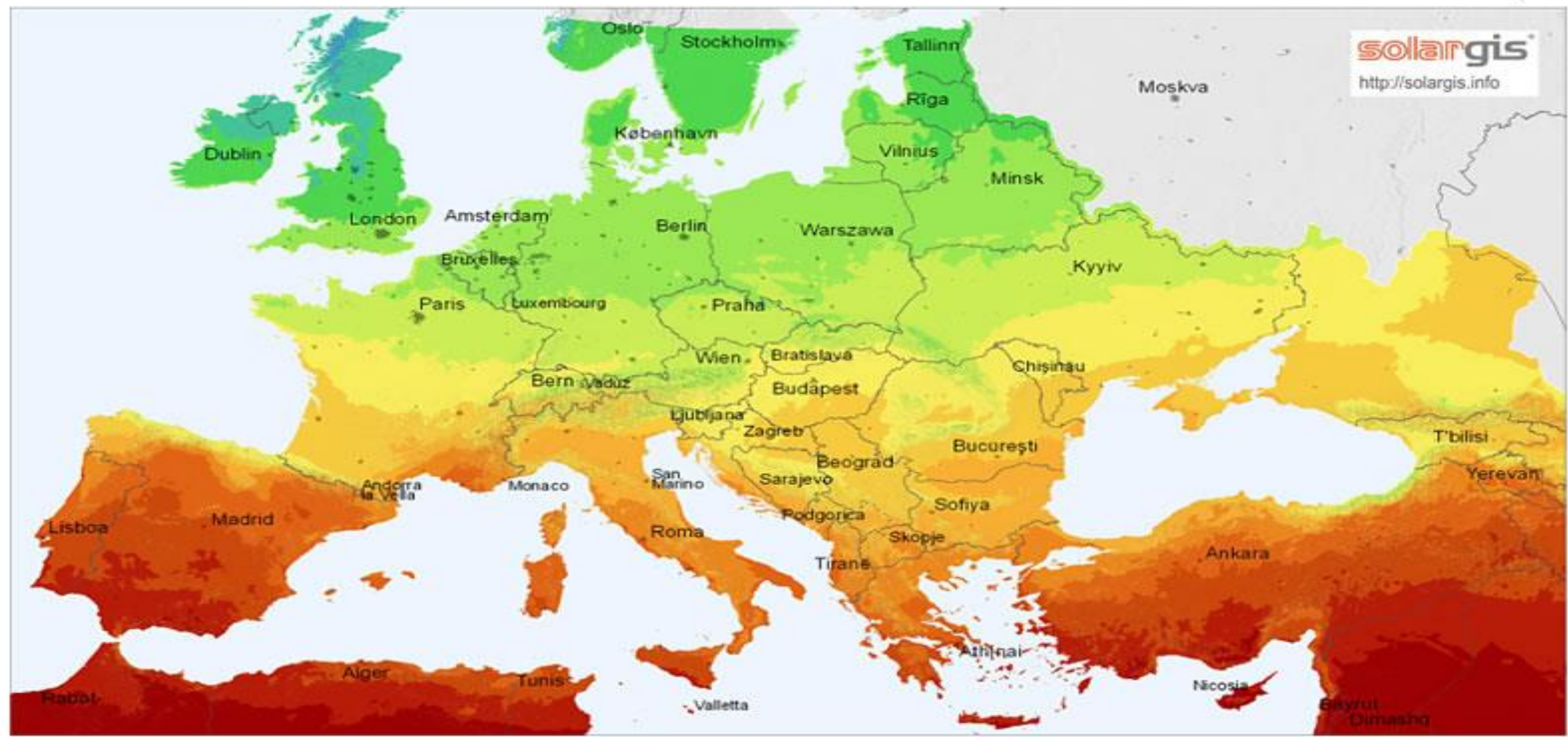


# Smart grids



High volatility and negative electricity prices in short-term markets are important signals for traders and energy companies. Ordinary customers do not benefit from negative electricity prices on the market. The reason is insufficient infrastructure of the electricity grid. This lack of infrastructure is to be changed by smart grids. Using smart grids it is possible to manage consumption on the basis of price mechanism and further it is possible to solve production overhang by export, provided timely prediction and sufficient transmission capacity. Smart grids also includes the principle of accumulation and the principle of integrating renewable sources into “virtual power plants”. Such power plants are, of course, physically tangible, but represent a mix of diverse sources, accumulation, controllable loads, and externally behave as one source with a more favorable production profile and some control capability.



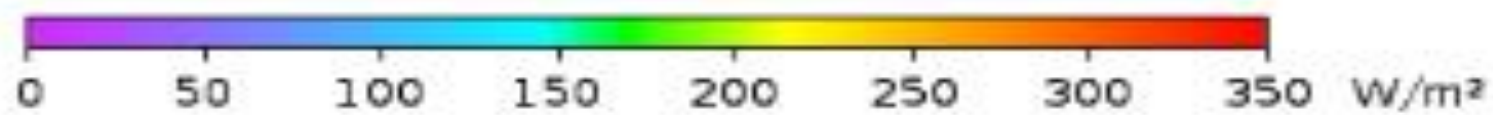
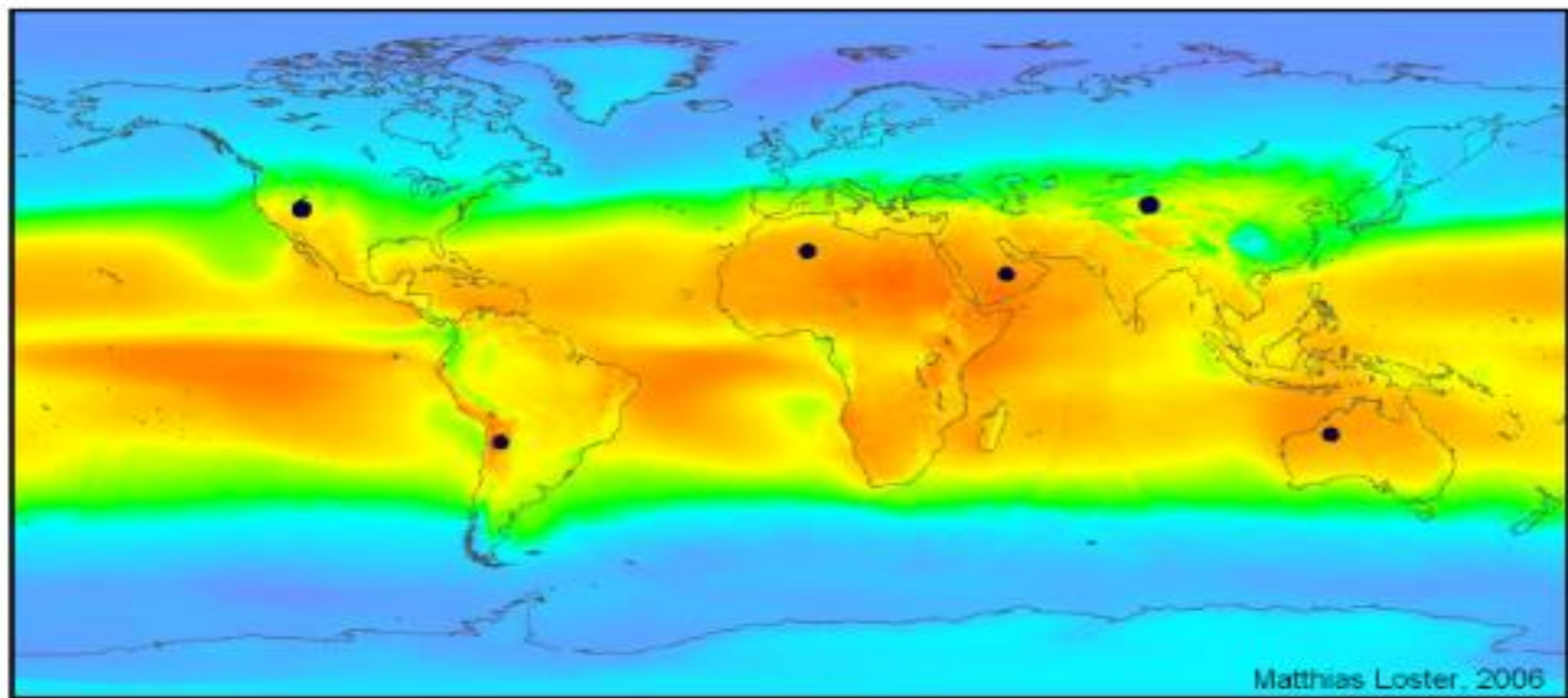


**solarGIS**  
<http://solargis.info>

Average annual sum (4/2004 - 3/2010)

0 250 500 km





$\Sigma \bullet = 18 \text{ TWe}$





Power Density

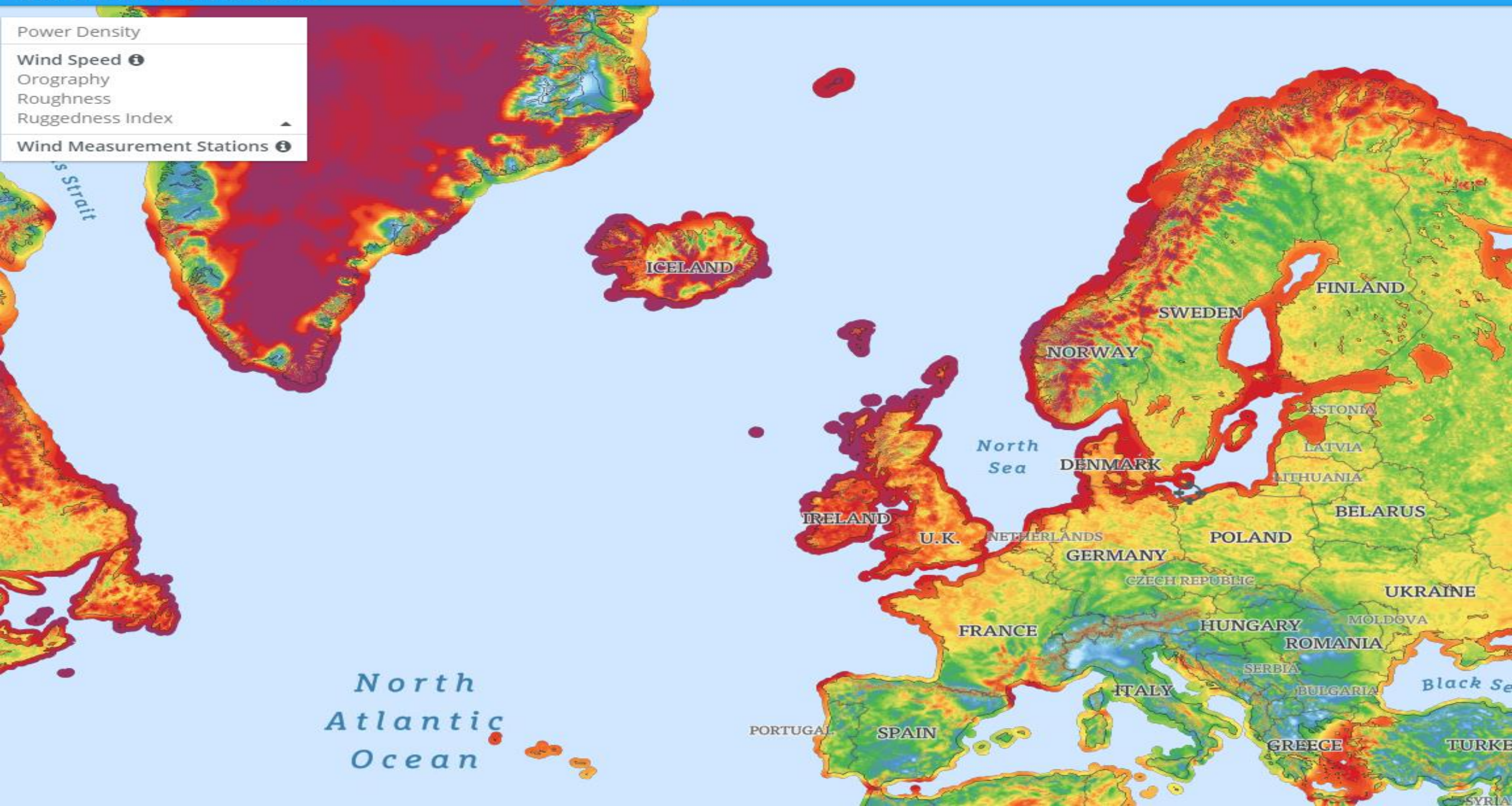
**Wind Speed** ⓘ

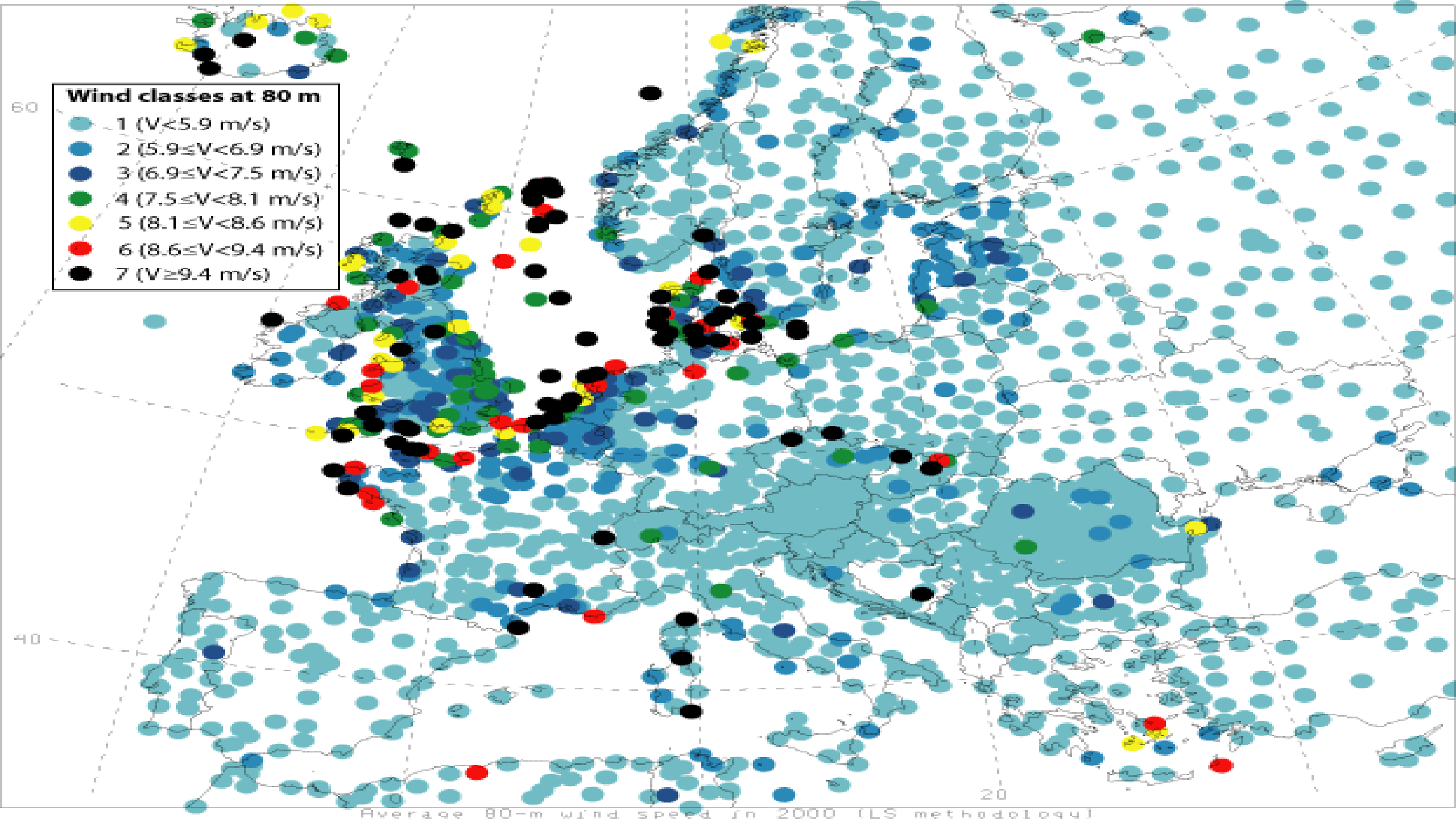
Orography

Roughness

Ruggedness Index

**Wind Measurement Stations** ⓘ





# Links to investigate



- [https://en.wikipedia.org/wiki/World\\_energy\\_resources](https://en.wikipedia.org/wiki/World_energy_resources)
- [https://en.wikipedia.org/wiki/Renewable\\_energy](https://en.wikipedia.org/wiki/Renewable_energy)
- [https://en.wikipedia.org/wiki/Load\\_profile](https://en.wikipedia.org/wiki/Load_profile)
- [https://en.wikipedia.org/wiki/Base\\_load](https://en.wikipedia.org/wiki/Base_load)
- [https://en.wikipedia.org/wiki/Load\\_following\\_power\\_plant](https://en.wikipedia.org/wiki/Load_following_power_plant)
- [https://en.wikipedia.org/wiki/Peaking\\_power\\_plant](https://en.wikipedia.org/wiki/Peaking_power_plant)
- [https://en.wikipedia.org/wiki/Climate\\_change\\_\(general\\_concept\)](https://en.wikipedia.org/wiki/Climate_change_(general_concept))
- [https://en.wikipedia.org/wiki/Greenhouse\\_effect](https://en.wikipedia.org/wiki/Greenhouse_effect)
- [https://en.wikipedia.org/wiki/Smart\\_grid](https://en.wikipedia.org/wiki/Smart_grid)
- [https://en.wikipedia.org/wiki/Wind\\_resource\\_assessment](https://en.wikipedia.org/wiki/Wind_resource_assessment)
- [https://en.wikipedia.org/wiki/Solar\\_irradiance](https://en.wikipedia.org/wiki/Solar_irradiance)
- or google it...

Thank you for your attention

