



# Joint EPS-SIF International School on Energy 2017

## Advances in Basic Energy Issues

G.Alimonti INFN & Università degli Studi, Milano



- Energy & Development
- Energy indicators (few)
- Current production and its limits
- Possible solutions...



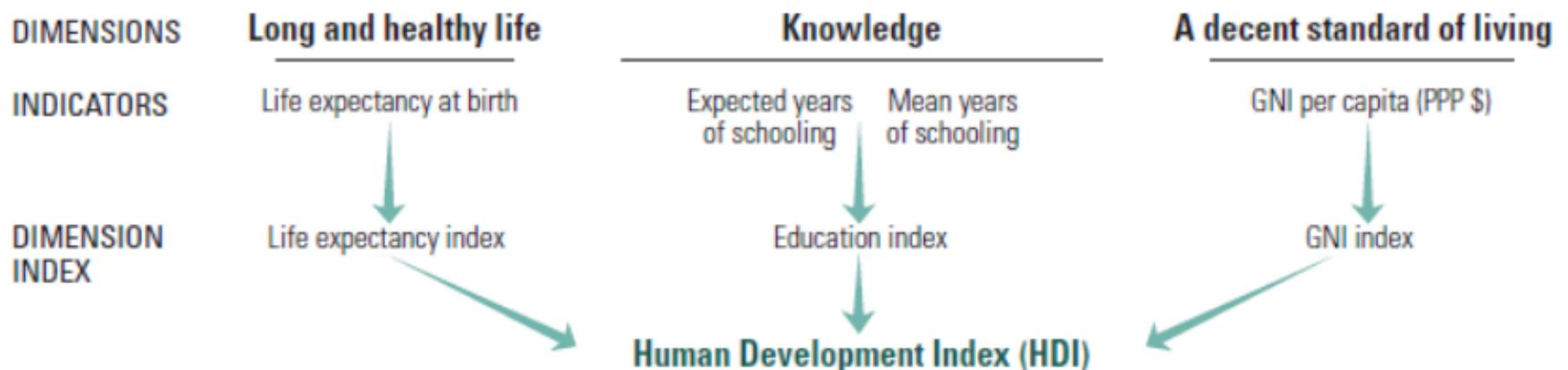
The history of energy, evolution and discoveries in transforming energy,  
is the history of mankind (from Prometheus to Newcomen&Cawley...)

# Human Development Index

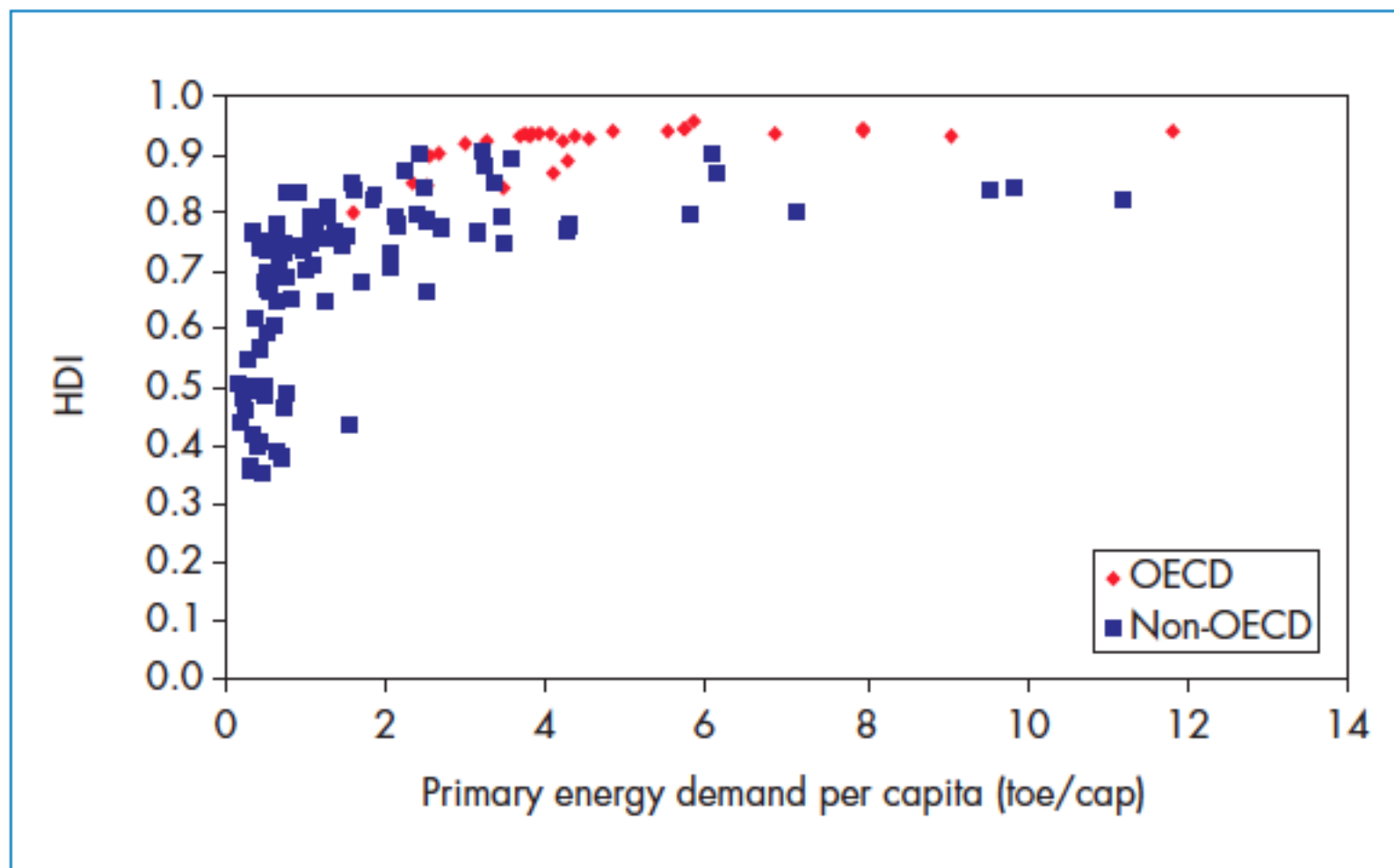
The Human Development Index (HDI) was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone.



HDI is a summary measure of average achievement in key dimensions of human development: **a long and healthy life, being knowledgeable and have a decent standard of living**. The HDI is the geometric mean of normalized indices for each of the three dimensions.



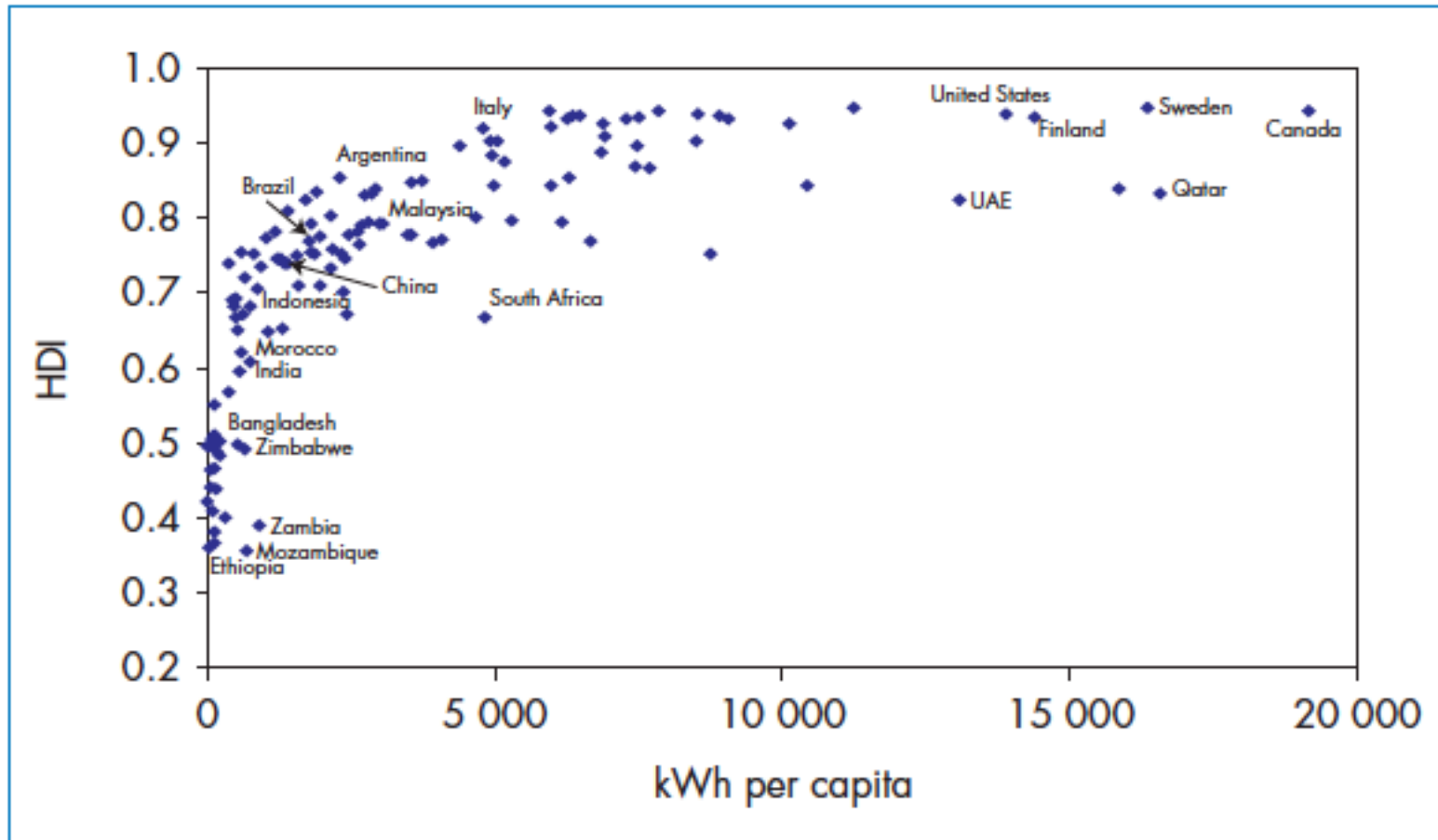
*Figure 10.1: HDI and Primary Energy Demand per Capita, 2002*



Sources: IEA analysis; UNDP (2004).

OECD (Organisation for Economic Co-operation and Development): Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

*Figure 10.4: HDI and Electricity Consumption per Capita, 2002*

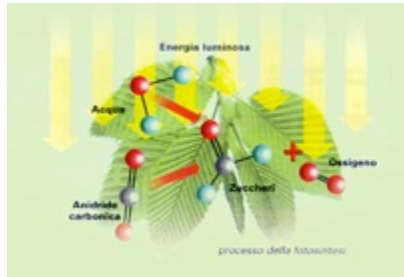
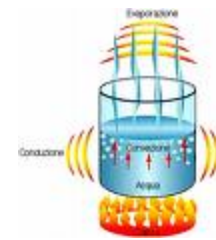


Sources: IEA analysis; UNDP (2004).

HDI does not appear to increase much once you hit European levels of per-capita electricity consumption. But lower electricity consumption has an impact.



Energy can neither be created nor destroyed, but only transformed into different forms

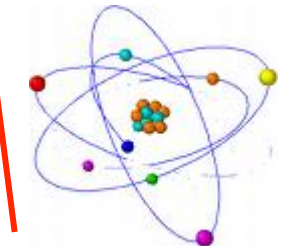


**Chemical**

**Thermal**



**Electricity**



**Nuclear**

**Mechanical**

**Light**



# General conversion factors for energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	$2.388 \times 10^2$	$2.388 \times 10^{-5}$	$9.478 \times 10^2$	$2.778 \times 10^{-1}$
Gcal	$4.187 \times 10^{-3}$	1	$1.000 \times 10^{-7}$	3.968	$1.163 \times 10^{-3}$
Mtoe	$4.187 \times 10^4$	$1.000 \times 10^7$	1	$3.968 \times 10^7$	$1.163 \times 10^4$
MBtu	$1.055 \times 10^{-3}$	$2.520 \times 10^{-1}$	$2.520 \times 10^{-8}$	1	$2.931 \times 10^{-4}$
GWh	3.600	$8.598 \times 10^2$	$8.598 \times 10^{-5}$	$3.412 \times 10^3$	1

1KWh= $10^3$ Wh= $10^3 \times 3600$ Ws= $3.6 \times 10^6$ Joule

1 eV= $1.6 \times 10^{-19}$ Joule: (important for PV and nuclear energy)

1 Toe =  $10^{10}$  Calories (by definition) “heat content of 1 Ton of oil”

about 1/3 of the italian per capita energy use; allows a car to run for about 15000 Km.

<http://www.iea.org/statistics/resources/unitconverter/>

# Energy/Power

Never mix energy with power!

(a FIAT 500 with the same weight of a Ferrari has the same energy when travelling at the same speed... even if, given the different power they have, they may need different time to reach the same velocity)

$$\text{Power} = \text{Energy/Time}$$

Energy is related to Power the same way Length is related to Velocity

or

the amount of water in a dam with the incoming/outgoing water flux

or

money in a bank account is related with salary and expenses!

**The Watt is the SI unit for Power: 1Watt=1Joule/1Second**

(4,1868 Joule=1 Calory, energy to increase 1g of distilled water from 14,5°C to 15,5°C)

Some examples: light bulb, oven, car, train...

# Let's practice...

Evaluate “the mean power” of a human body:

We eat 2000 Kcal per day:  $2 \times 10^6 \text{ Cal} \sim 8 \times 10^6 \text{ Joule}$   
and we assume we use them all (we would rather doing this!...)  
 $8 \times 10^6 \text{ Joule} / 10^5 \text{ sec} = 80 \text{ Watt}$

Evaluate how much water has to drop from what height to produce 1 KWh  
( let's assume an hydro plant transforms potential energy to EE with  $\epsilon=1$  )

The potential energy is  $mgh$ :  
 $1 \text{ KWh} = 3.6 \times 10^6 \text{ Joule} = mgh \text{ [Kg][Meter/Sec}^2\text{][Meter]} = m \times 9.8 \times h \sim 10mh$   
1KWh is about 1ton of water falling from 360 meters...

Burning 10g of wood may lift a man by  $>100$  meters  
Energy content of 100g chocolate would lift a man by  $\approx 2000$  meters



# Primary Energy

Primary energy is the energy directly available in nature



**Renewables** (directly or indirectly coming from the Sun)

- Hydro (and ocean)
- Wind
- Solar
- Biomass
  - Waste



**Not Renewables**

- Fossil fuels
  - Coal
  - Oil
  - Natural gas
- Nuclear fission (not breeder)

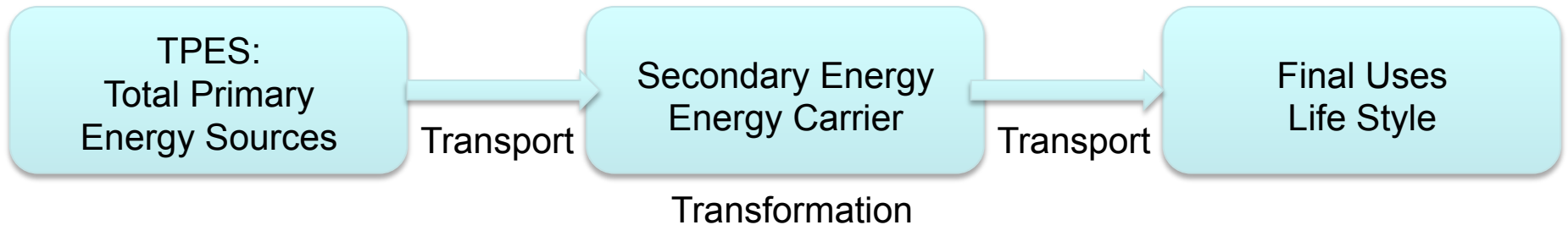


**Almost unlimited**

- Geothermal
- Nuclear fission (breeder)
- Nuclear fusion

# Secondary Energy/Energy Carriers

**Secondary Energy:** Primary Energy Sources transformed in a different form more suited to transport and/or final use

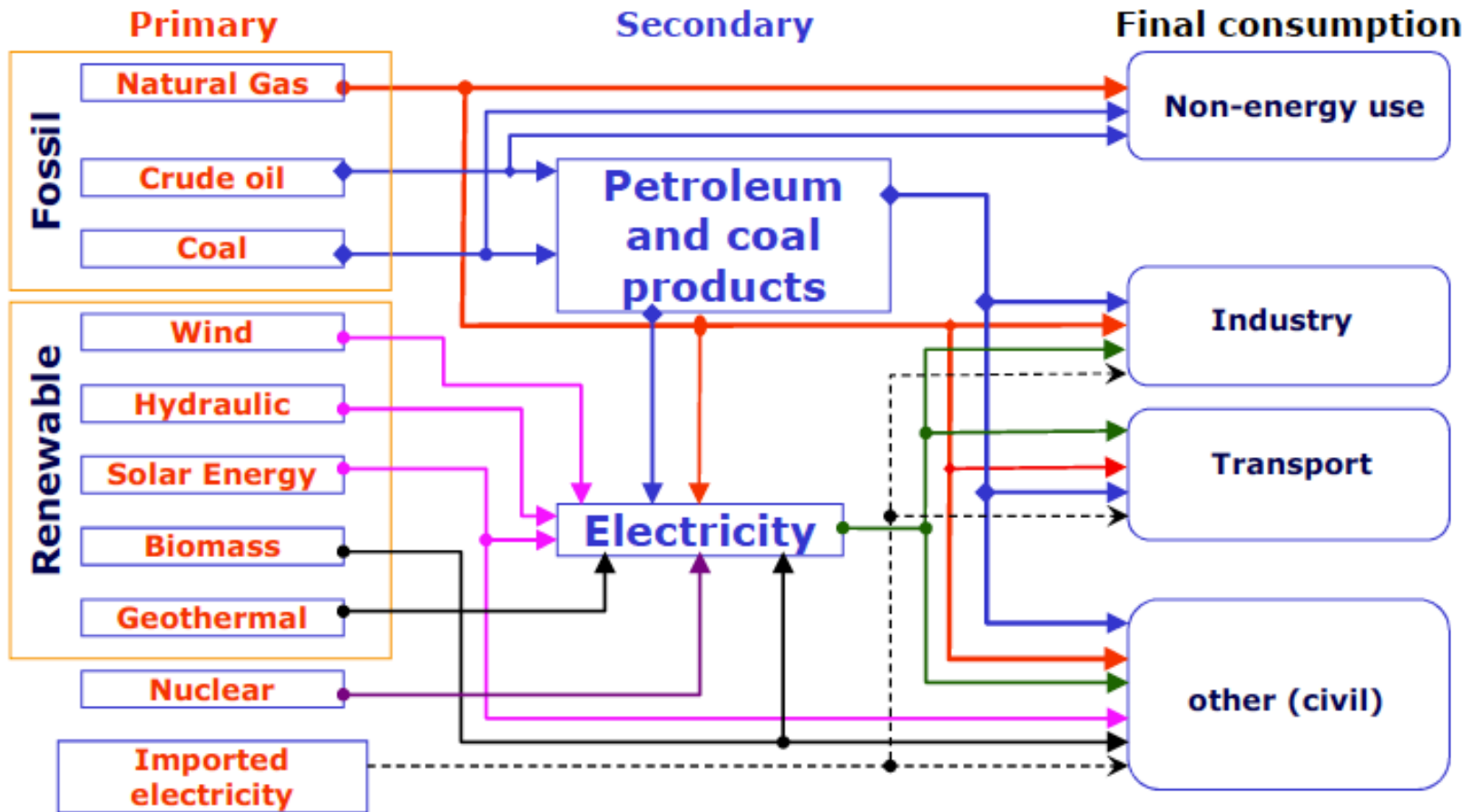


A fundamental step for the energy use is the transformation (**losses**) from an available form to an easily usable/transportable form

**An example of secondary energy is the electricity: it can not be stored and therefore must be produced at the same time of the request,** but has the advantage of being easily transportable over great distance to the final user, who can very easily convert it with very high efficiency into mechanical energy, heat, or use it as light source.

How would you consider the food?...

# From Primary Energy Sources to final consumption



**Non-energy use:** fuels not used as raw materials or consumed as fuels. Ex: petrochemical feedstocks.

**Other (civil):** residential, commercial or public services, agriculture, forestry and not specified consumption.

# From Primary Energy Sources to final consumption

**Primary energy**  
1 kg wood = 4 kWh

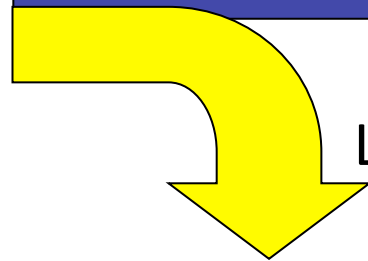
**Final consumption energy**



Thermal En.



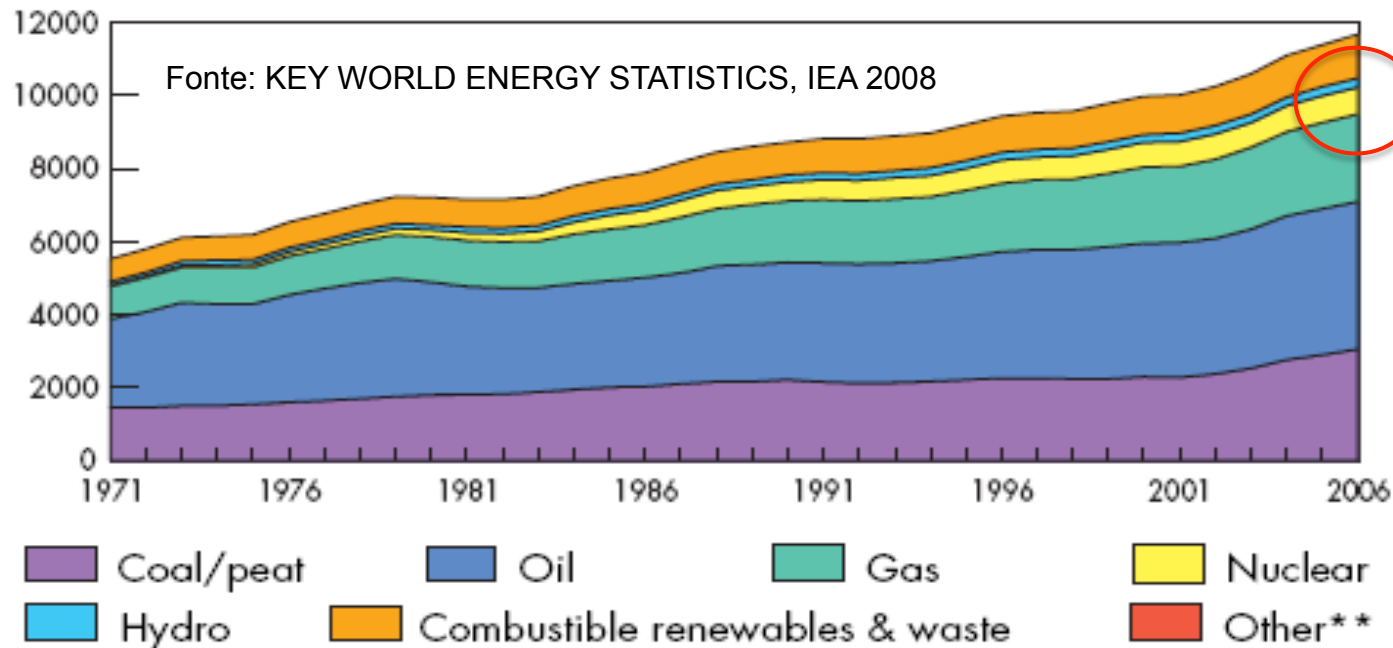
Electric En.



Losses 3 kWh<sub>t</sub>

What amount of primary energy can be associated to 1 Kwh<sub>e</sub> hydroelectric?

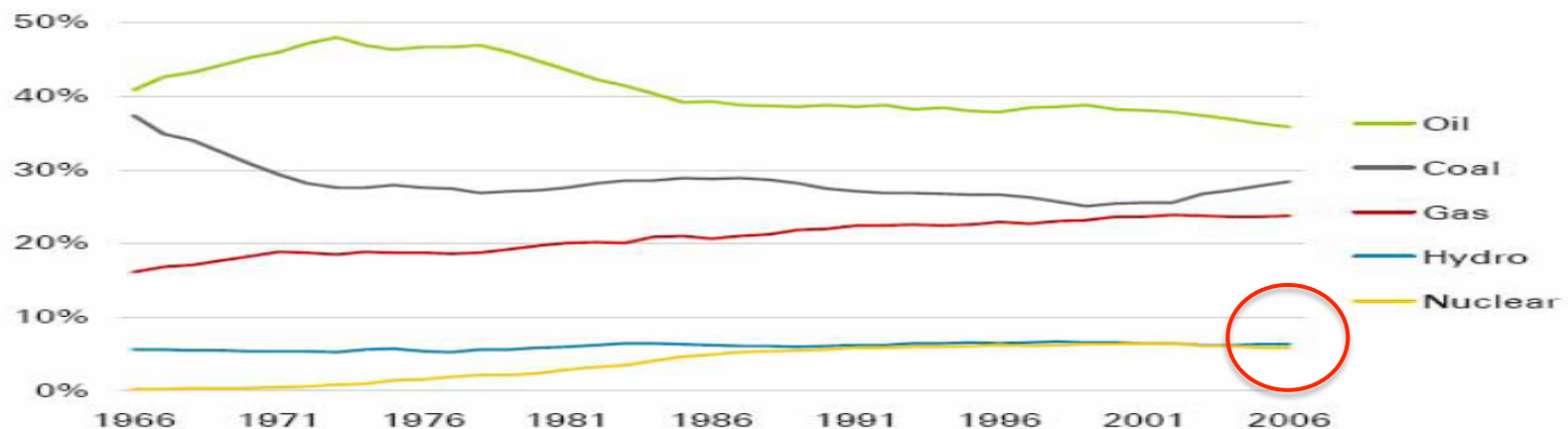
# Evolution from 1971 to 2006 of world total primary energy supply\* by fuel (Mtoe)



## World Fuel Shares



### Share of global primary energy consumption



# Conventions for electricity

Figures for electricity production, trade, and final consumption are calculated using the energy content of the electricity (i.e. at a rate of 1 TWh = 0.086 Mtoe). Hydro-electricity production (excluding pumped storage) and electricity produced by other non-thermal means (wind, tide/wave/ocean, photovoltaic, etc.) are accounted for similarly using 1 TWh = 0.086 Mtoe. However, the primary energy equivalent of nuclear electricity is calculated from the gross generation by assuming a 33% conversion efficiency, i.e. 1 TWh =  $(0.086 \div 0.33)$  Mtoe. For geothermal and solar thermal, if no country-specific information is reported, the primary energy equivalent is calculated as follows:

- 10% for geothermal electricity;
- 50% for geothermal heat;
- 33% for solar thermal electricity;
- 100% for solar thermal heat.

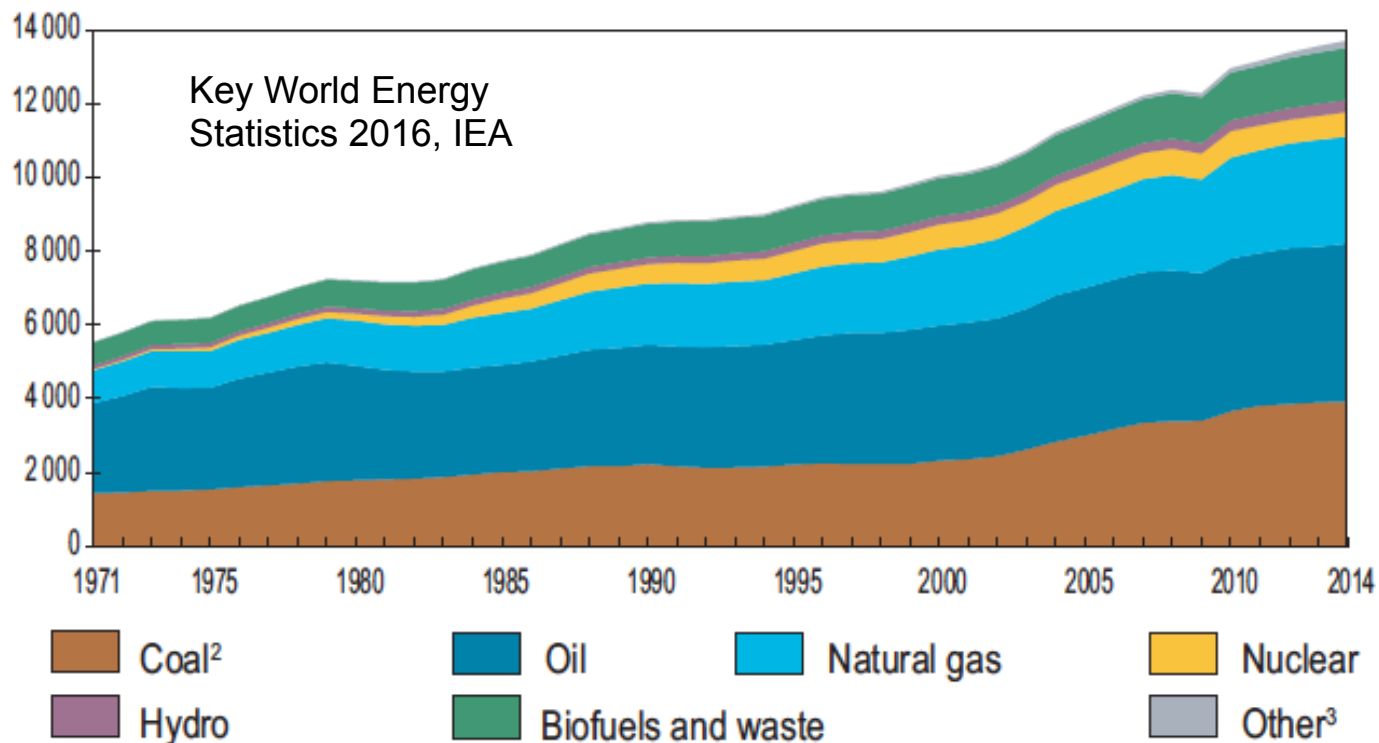
Key World  
Energy Statistics  
2016, IEA

RES EU targets (20% in 2020) based on final energy consumption  
Efficiency EU targets (-20% in 2020) based on primary energy consumption

# TOTAL PRIMARY ENERGY SUPPLY

## World

World<sup>1</sup> total primary energy supply (TPES) from 1971 to 2014 by fuel (Mtoe)



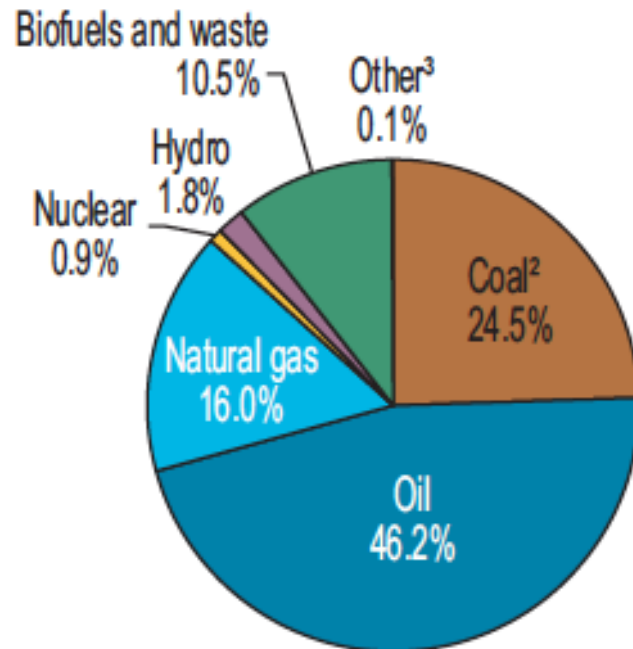
1. World includes international aviation and international marine bunkers.

2. In these graphs, peat and oil shale are aggregated with coal.

3. Includes geothermal, solar, wind, heat, etc.

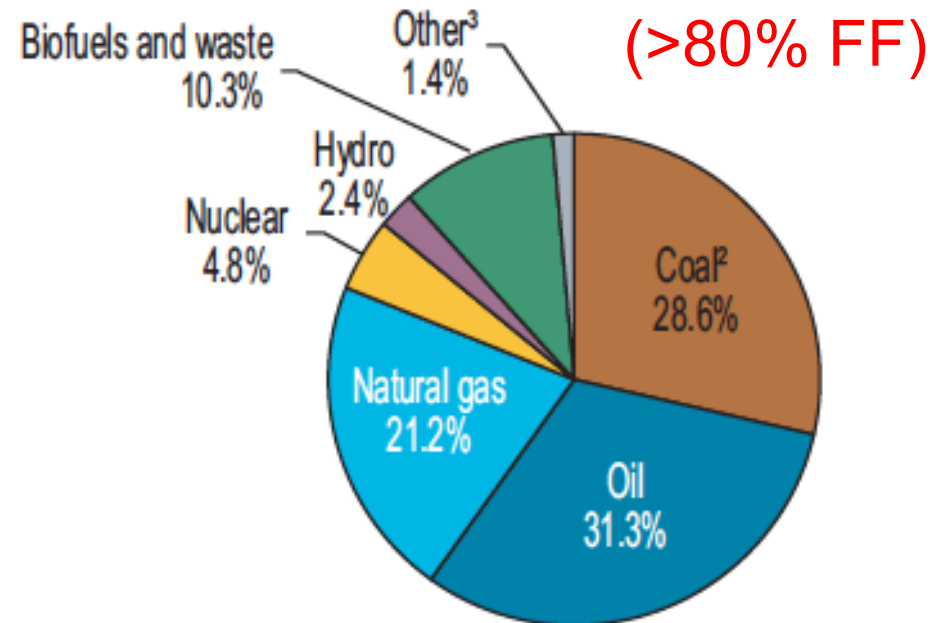
## 1973 and 2014 fuel shares of TPES

1973



6 101 Mtoe

2014



13 699 Mtoe

1. World includes international aviation and international marine bunkers.

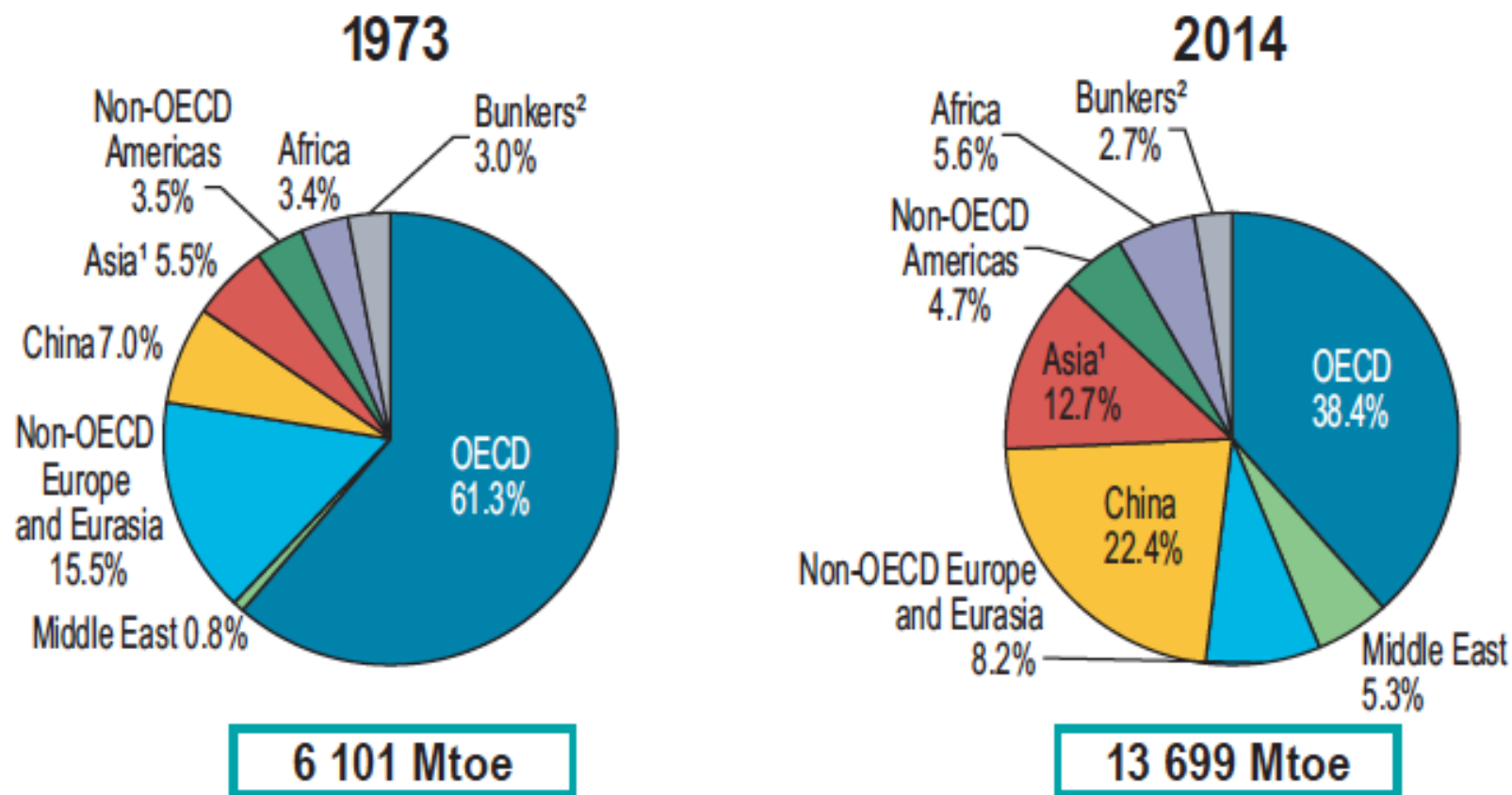
2. In these graphs, peat and oil shale are aggregated with coal.

3. Includes geothermal, solar, wind, heat, etc.

Key World Energy  
Statistics 2016, IEA



## 1973 and 2014 regional shares of TPES



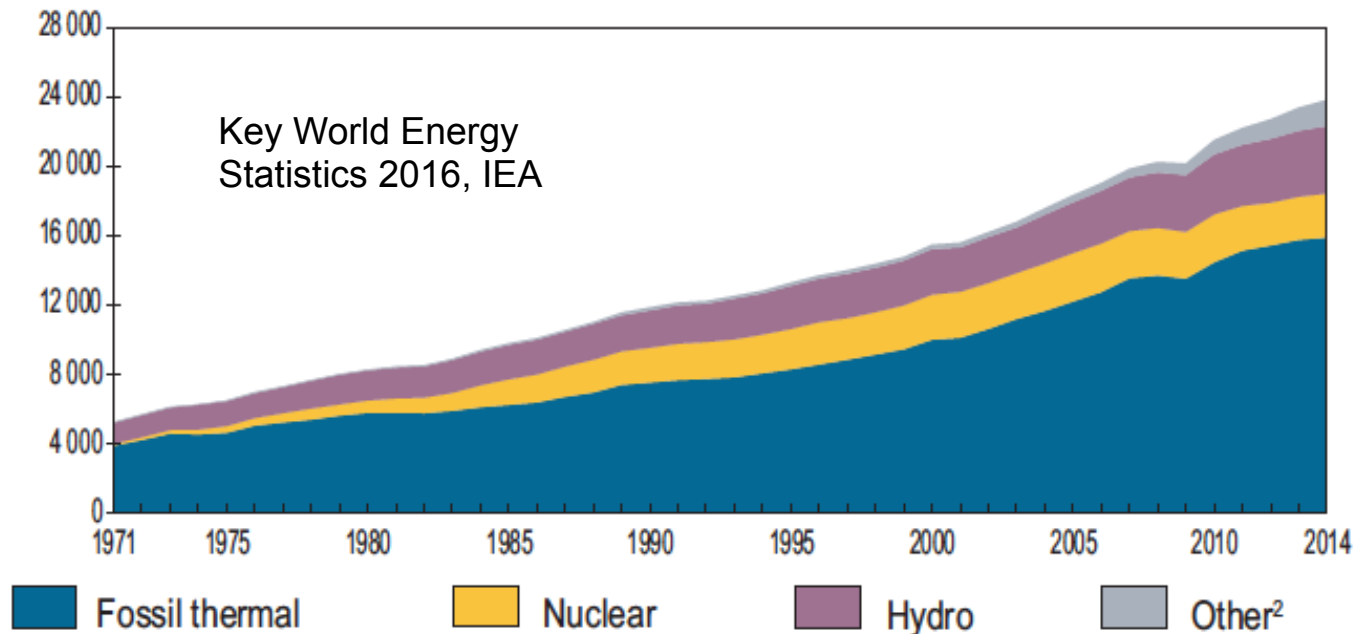
1. Asia excludes China and OECD countries of Asia.
2. Includes international aviation and international marine bunkers.

Key World Energy  
Statistics 2016, IEA

OECD (Organisation for Economic Co-operation and Development): Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

# Electricity generation by fuel

World electricity generation<sup>1</sup> from 1971 to 2014  
by fuel (TWh)

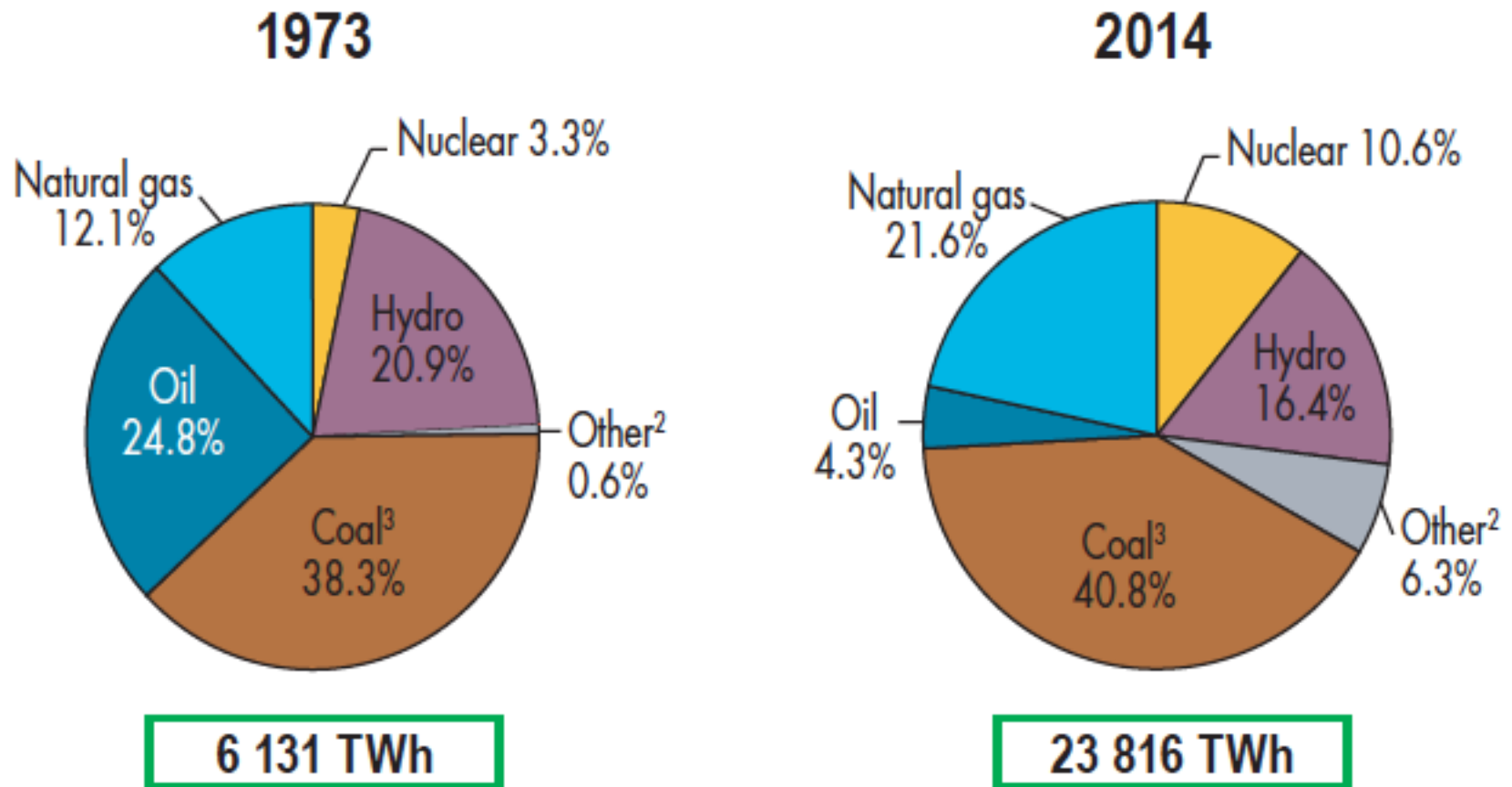


1. Excludes electricity generation from pumped storage.

2. Includes geothermal, solar, wind, heat, etc.

3. In these graphs, peat and oil shale are aggregated with coal.

# 1973 and 2014 fuel shares of electricity generation<sup>1</sup>



1. Excludes electricity generation from pumped storage.

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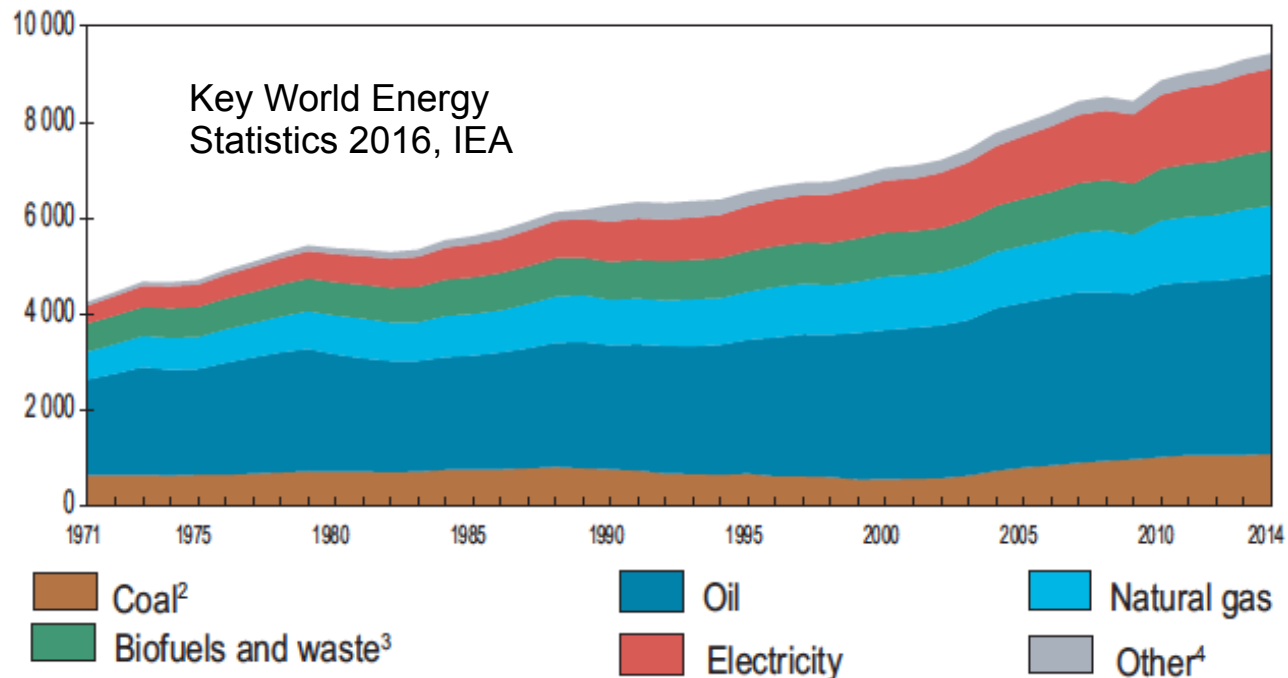
3. In these graphs, peat and oil shale are aggregated with coal.

Key World Energy  
Statistics 2016, IEA

# TOTAL FINAL CONSUMPTION

## World

World<sup>1</sup> total final consumption from 1971 to 2014  
by fuel (Mtoe)



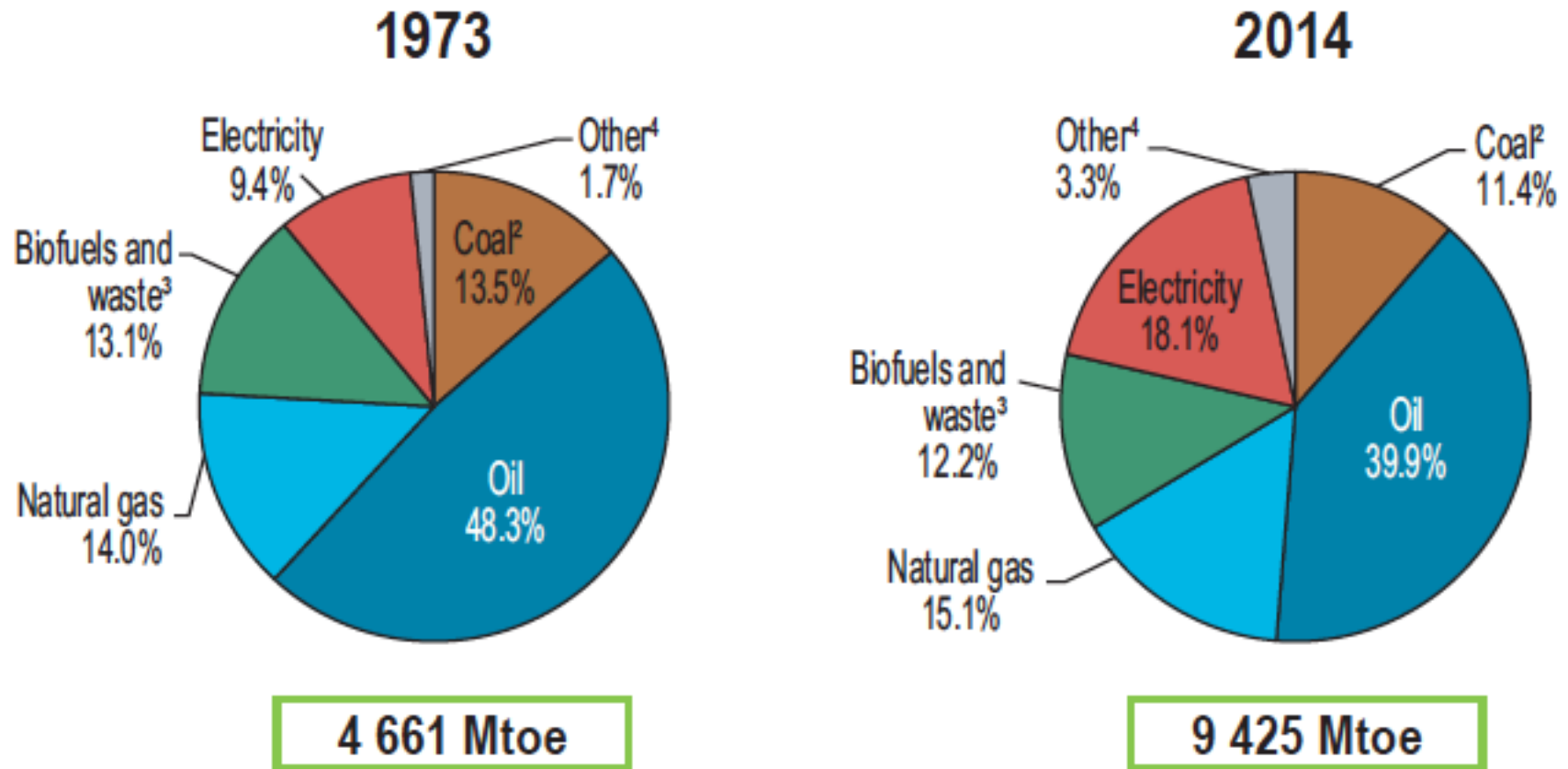
1. World includes international aviation and international marine bunkers.

2. In these graphs, peat and oil shale are aggregated with coal.

3. Data for biofuels and waste final consumption have been estimated for a number of countries.

4. Includes geothermal, solar, wind, heat, etc.

## 1973 and 2014 fuel shares of total final consumption



1. World includes international aviation and international marine bunkers.

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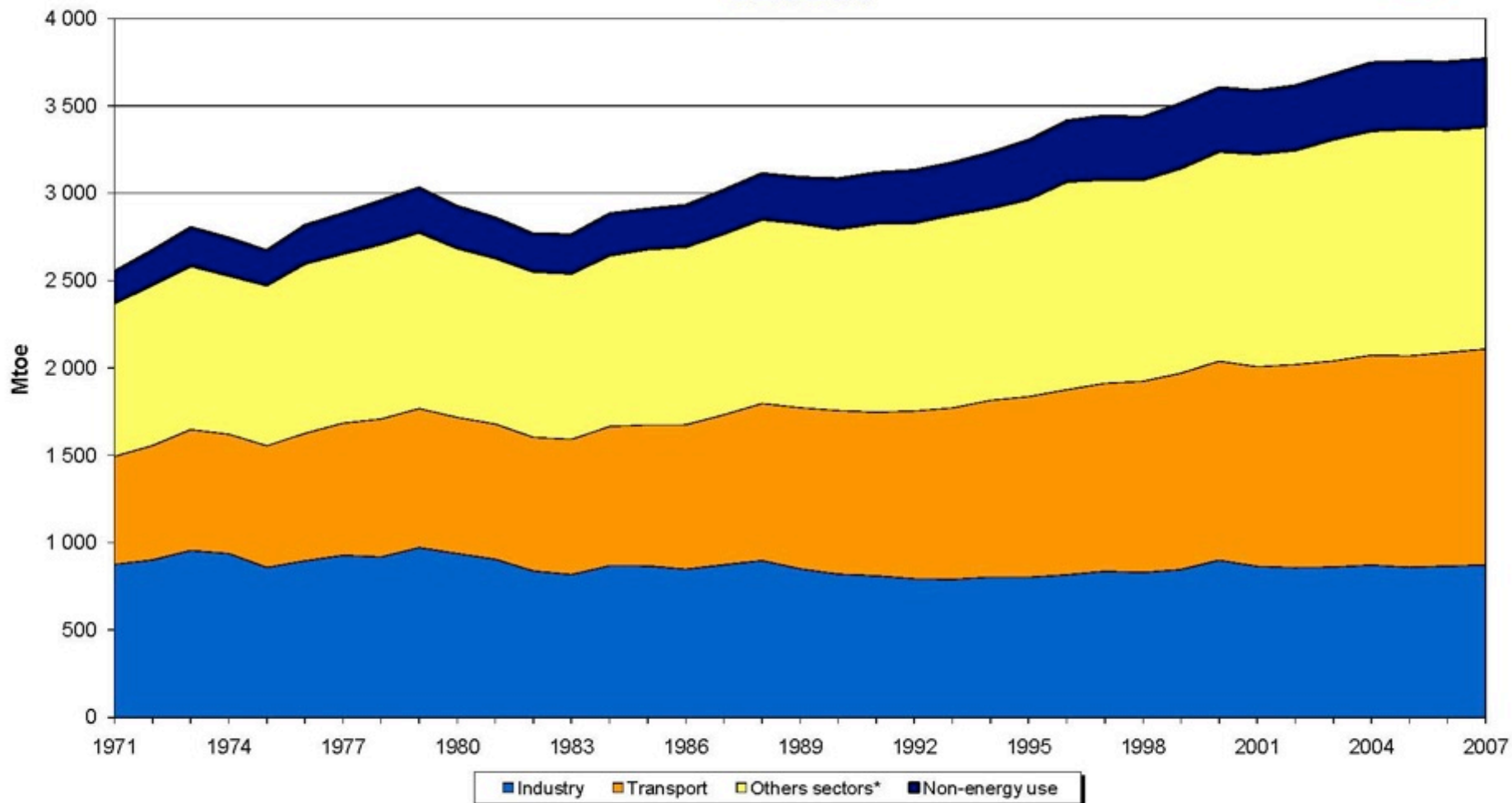
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Key World Energy  
Statistics 2016, IEA



## Final consumption by sector *OECD30*



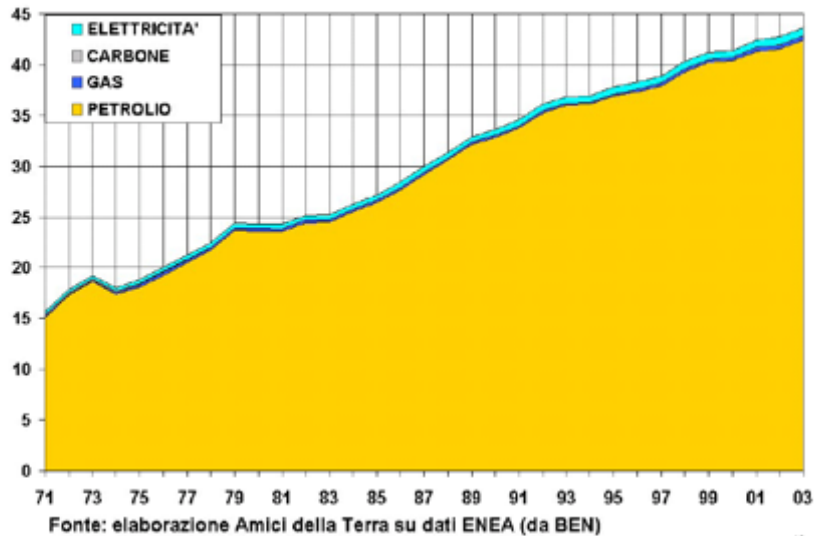
\* Includes residential, commercial and public services, agriculture/forestry, fishing and non-specified.

© OECD/IEA 2009

For more detailed data, please consult our on-line data service at <http://data.iea.org>.

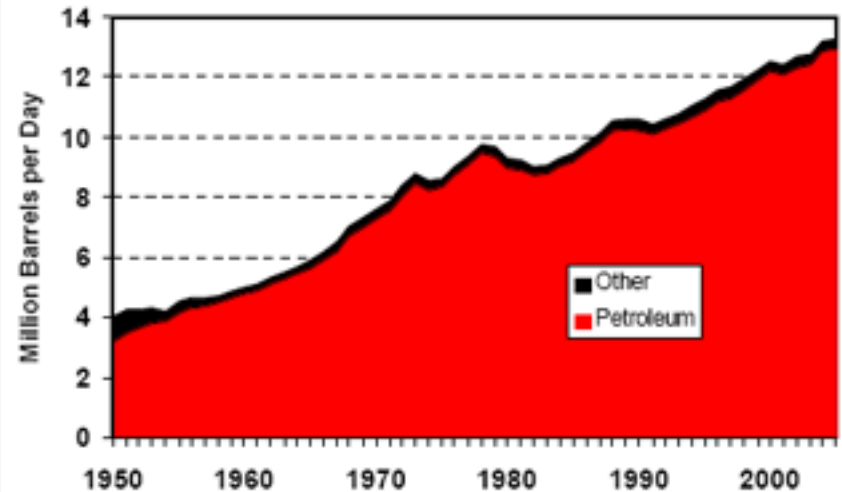
# Transportation depends on oil...

Final energy consumption for transportation in Italy from 1971 to 2003 (Mtoe)



40

U.S. Transportation Energy Use, 1950-2005





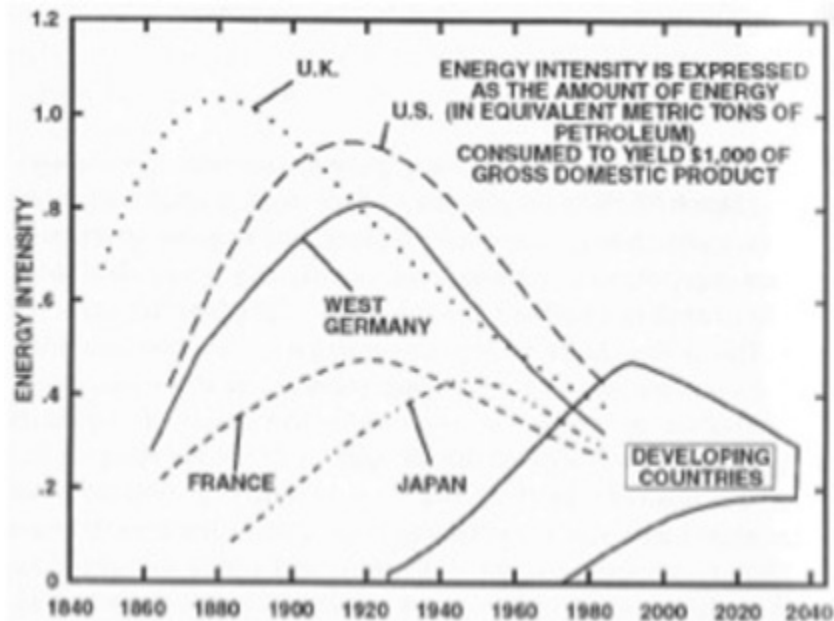
# Energy intensity

$$E_i = \text{Primary Energy}/\text{GDP}$$

It is calculated in units of energy per unit of GDP (the reference year is needed)

$E_i$  is a measure of the energy efficiency of a nation economy.

$E_i$  is a complex index and depends on several parameters:



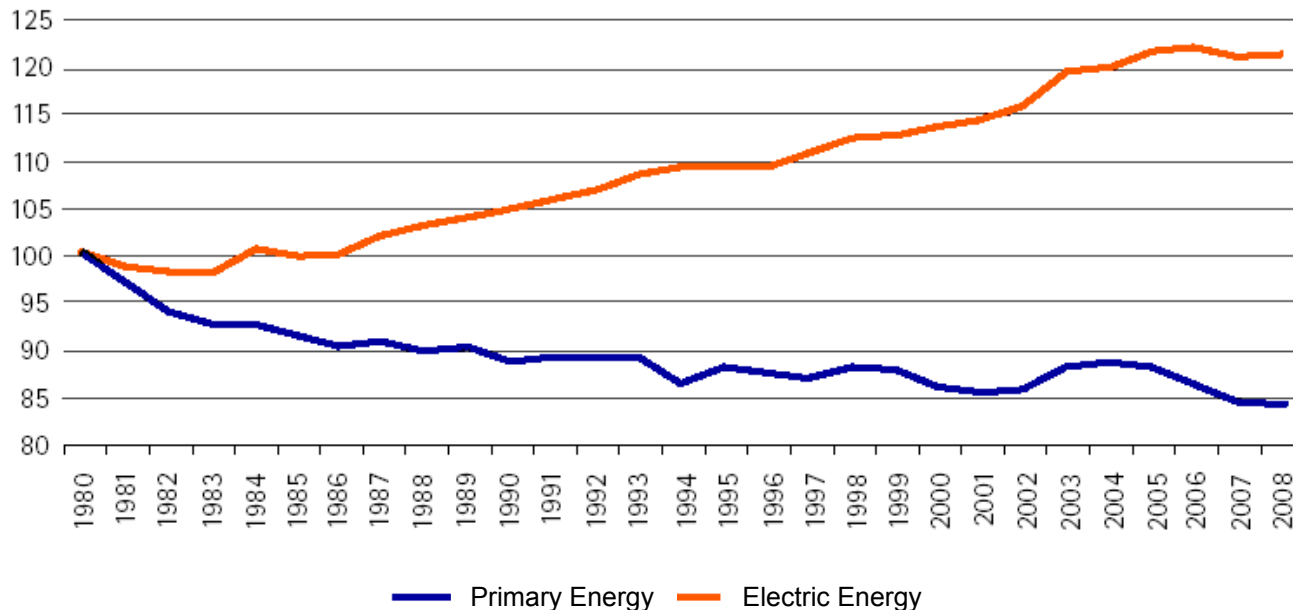
- The higher the technological developments, the better energy use
- Heavy industry requires more energy
- Colder countries require more energy for heating
- Larger countries require more energy for transportation.

Despite the overmentioned limits, it is observed that  $E_i$  grows in emerging economies and decreases with de-industrialization and growth of service sector (tertiary).



# EE intensity

Electric Energy intensity is defined as the EE over the GDP: similar to Ei but shows an opposite behaviour



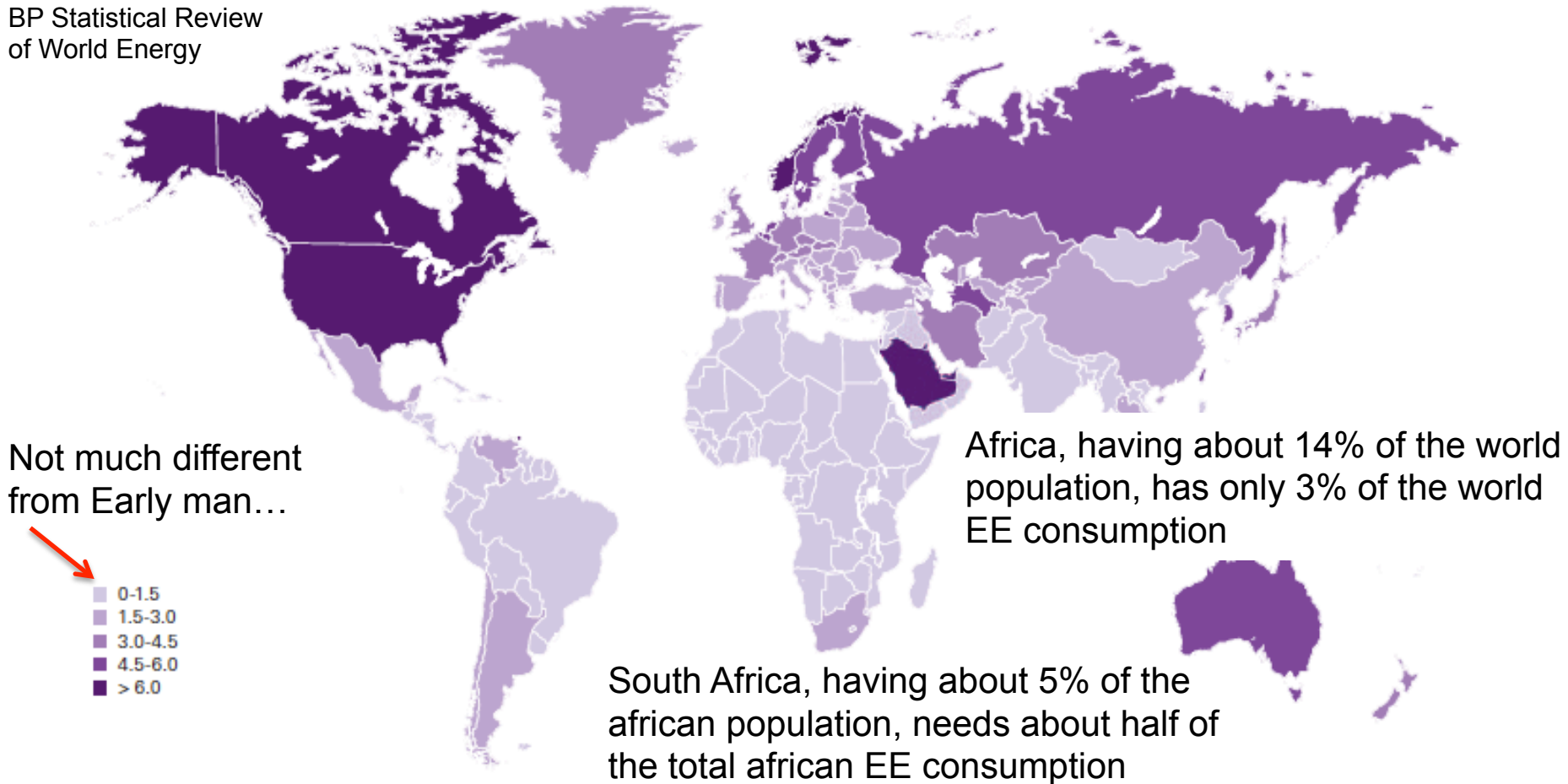
Fonte: Elaborazione AEEG su dati Ministero dello sviluppo economico e Istat.

There is a definite tendency with EE intensity: the optimal use of EE induces an increase in productivity and therefore energy savings in total energy.

# Per capita consumption (Primary Energy)

Consumption per capita 2013  
Tonnes oil equivalent

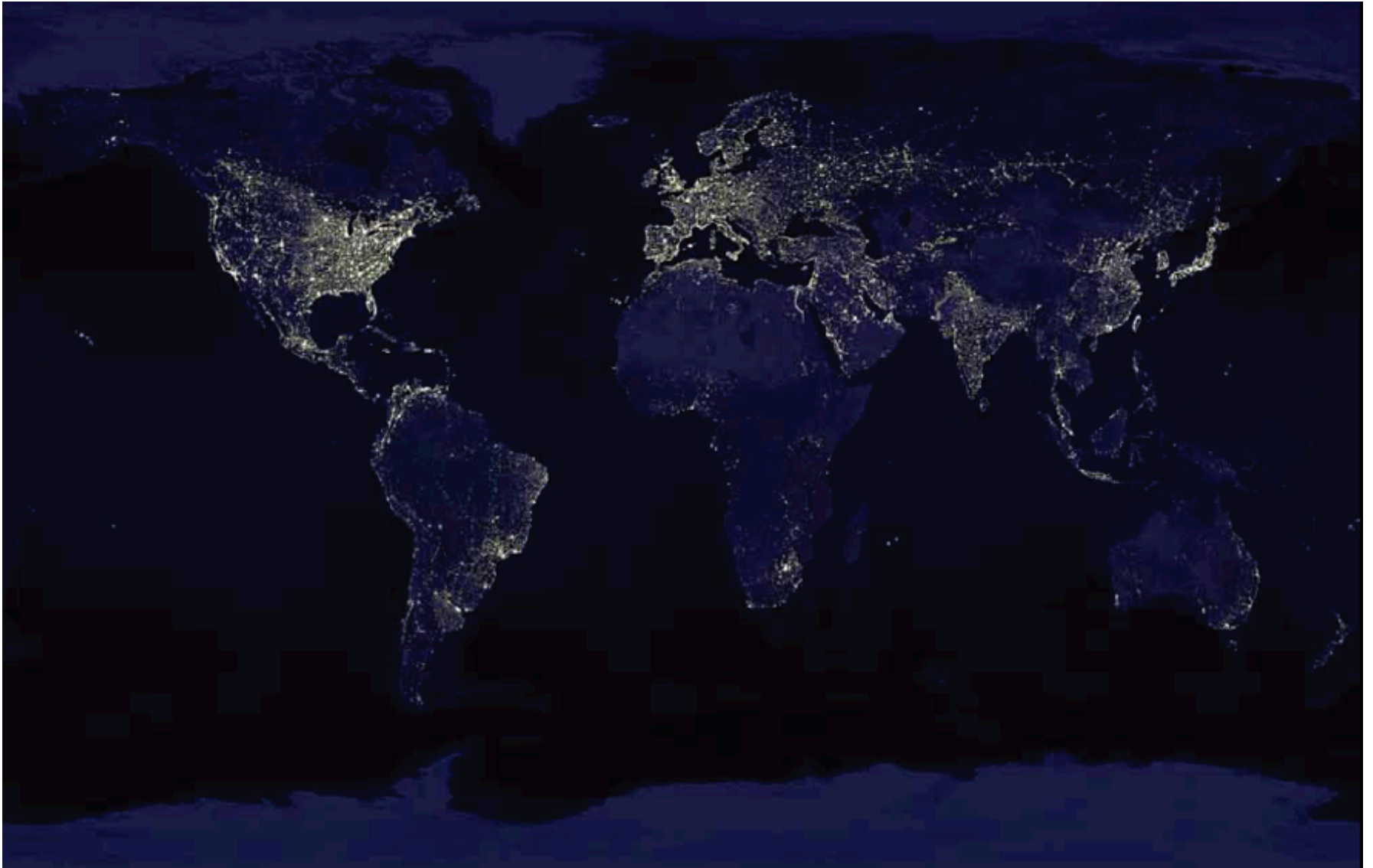
BP Statistical Review  
of World Energy

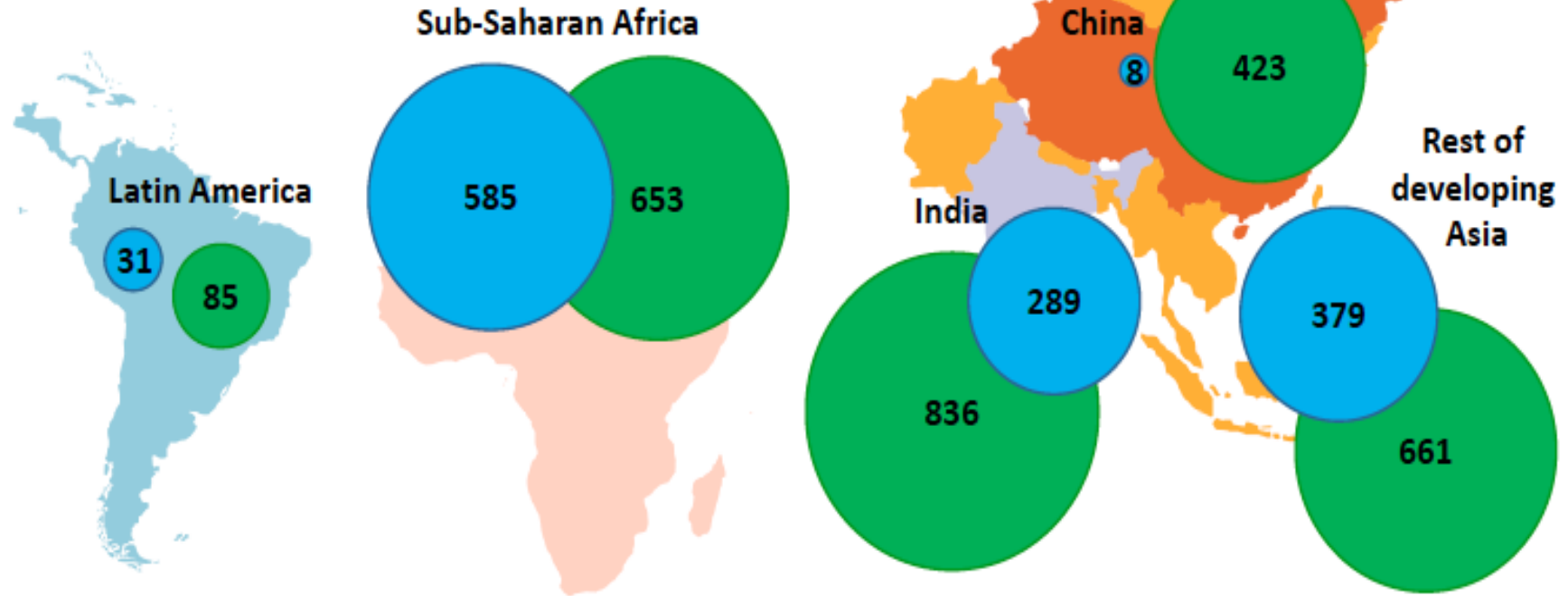
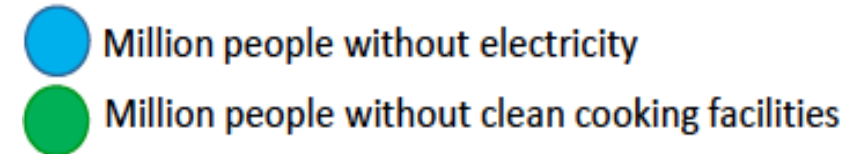


Excluding northern and southern african countries, the main energy source for the remaining african population is wood (>85%)

G.Alimonti

## Per capita consumption ...





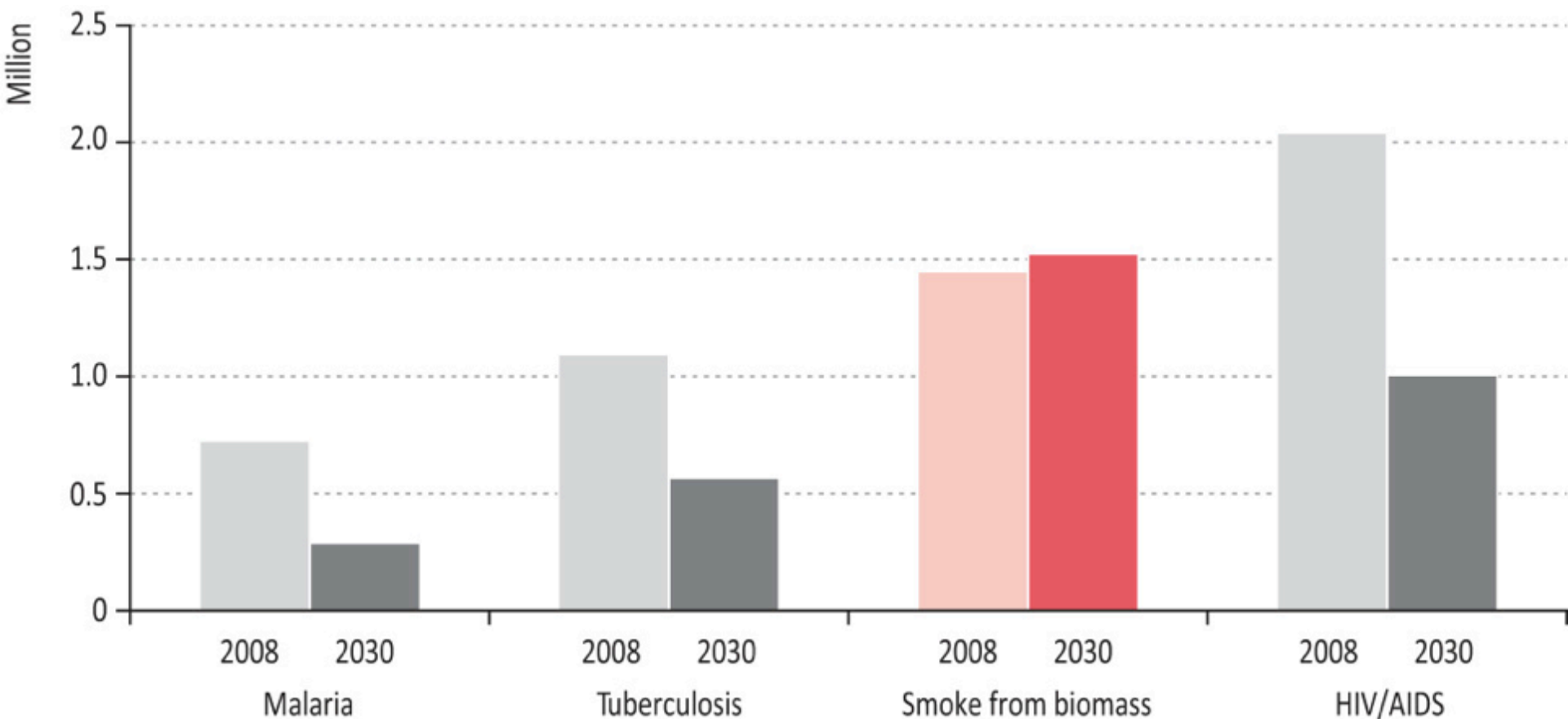
***1.3 billion people in the world live without electricity  
and 2.7 billion live without clean cooking facilities***

WEO 2011, IEA

Access to electricity and to energy in general, is considered to be an essential requirement for human development. IEA evaluates that investments of about 35 \$ billion/year would bring energy access to the whole world population.

# Premature annual deaths from household air pollution and selected diseases in the New Policies Scenario, 2008 and 2030

Note: 2008 is the latest available data in WHO database.



# Current Energy production (>80% FF) limits

Three main limits of the actual energy production:  
(other than the non uniform energy distribution)

- GHG emissions → Climate Change?
- Polluting emissions → Health&Environment impact  
(NO<sub>x</sub>, SO<sub>x</sub>, Particulate, Ozone, CO, VOC, NH<sub>3</sub>)
- Limited resources → What's next?

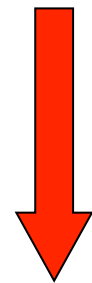
# GHG emissions

The oxidation of C-H bonds generates carbon dioxide and water



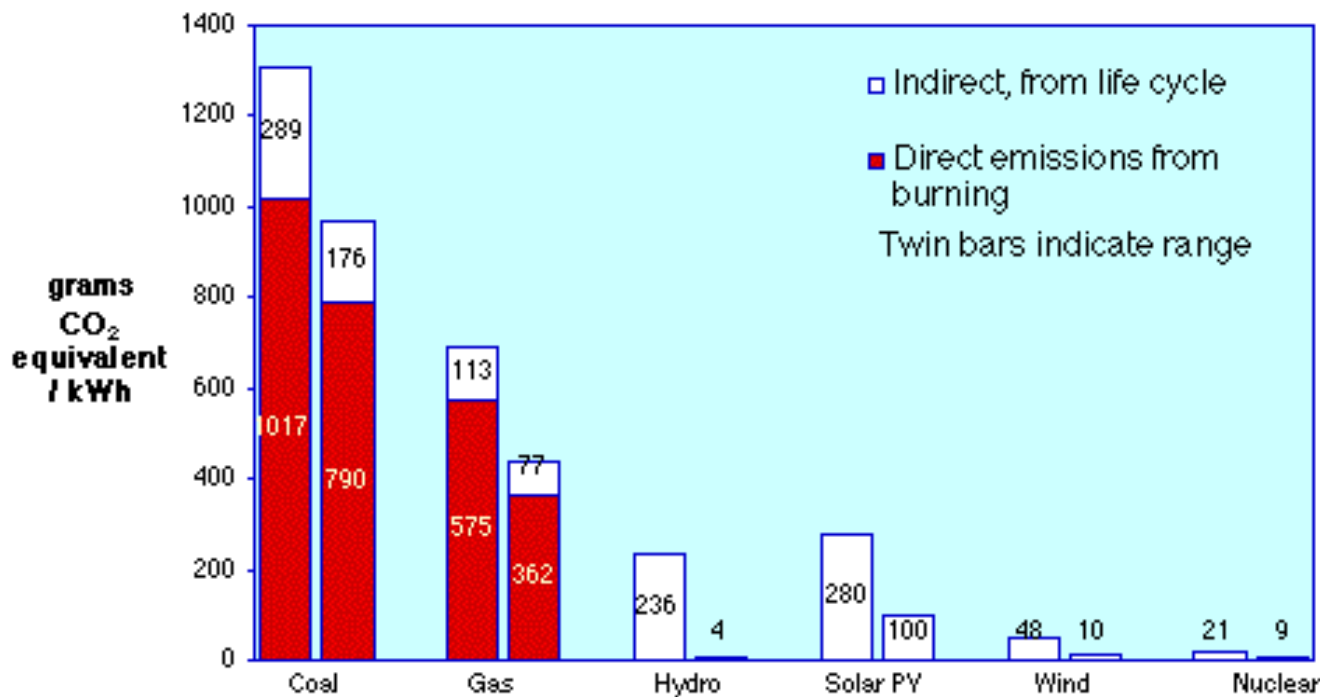
*1 + 2 = 3*

*1 Kg Natural Gas*



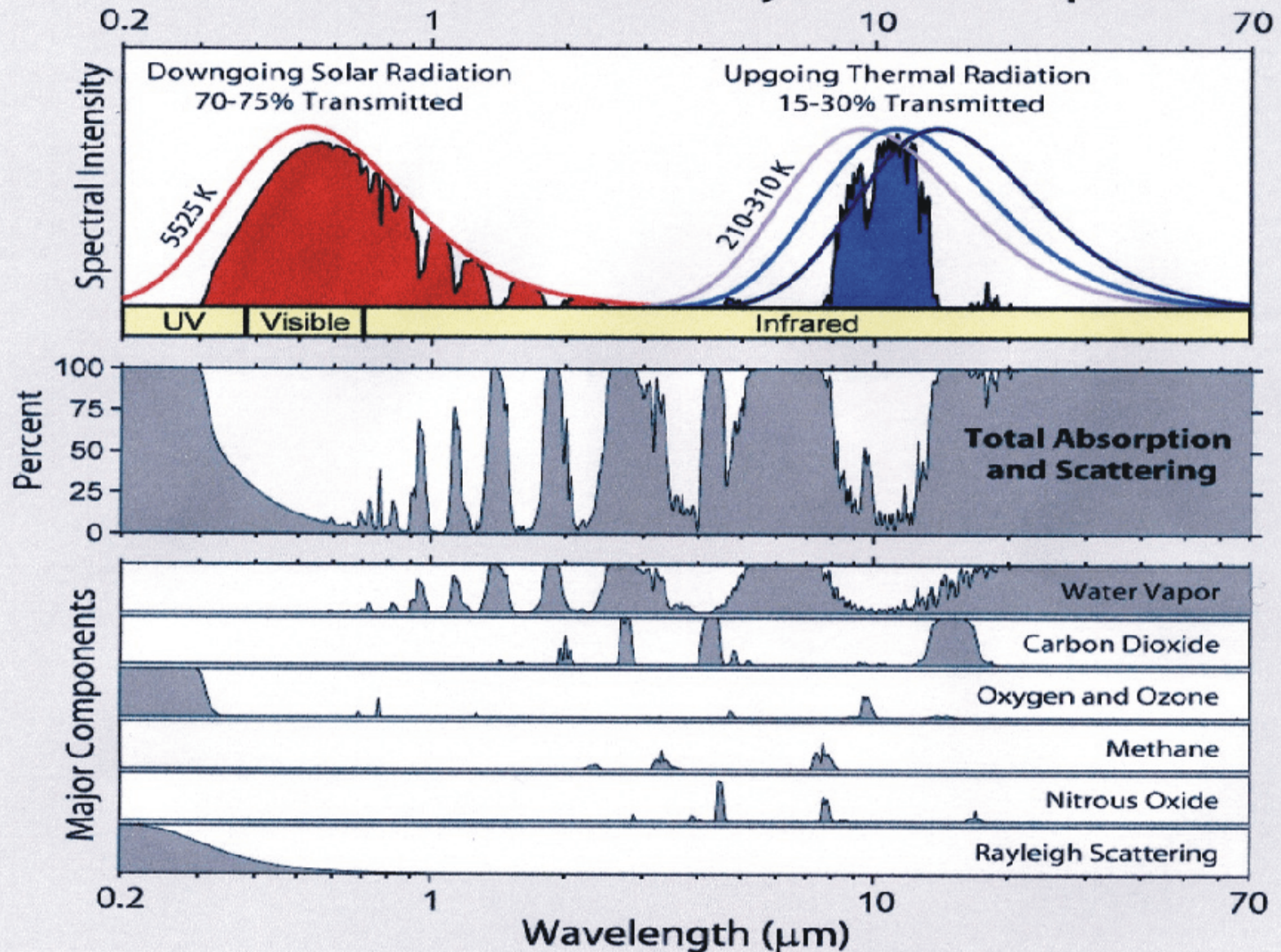
*~3 Kg CO<sub>2</sub>*

**Greenhouse Gas Emissions from Electricity Production**



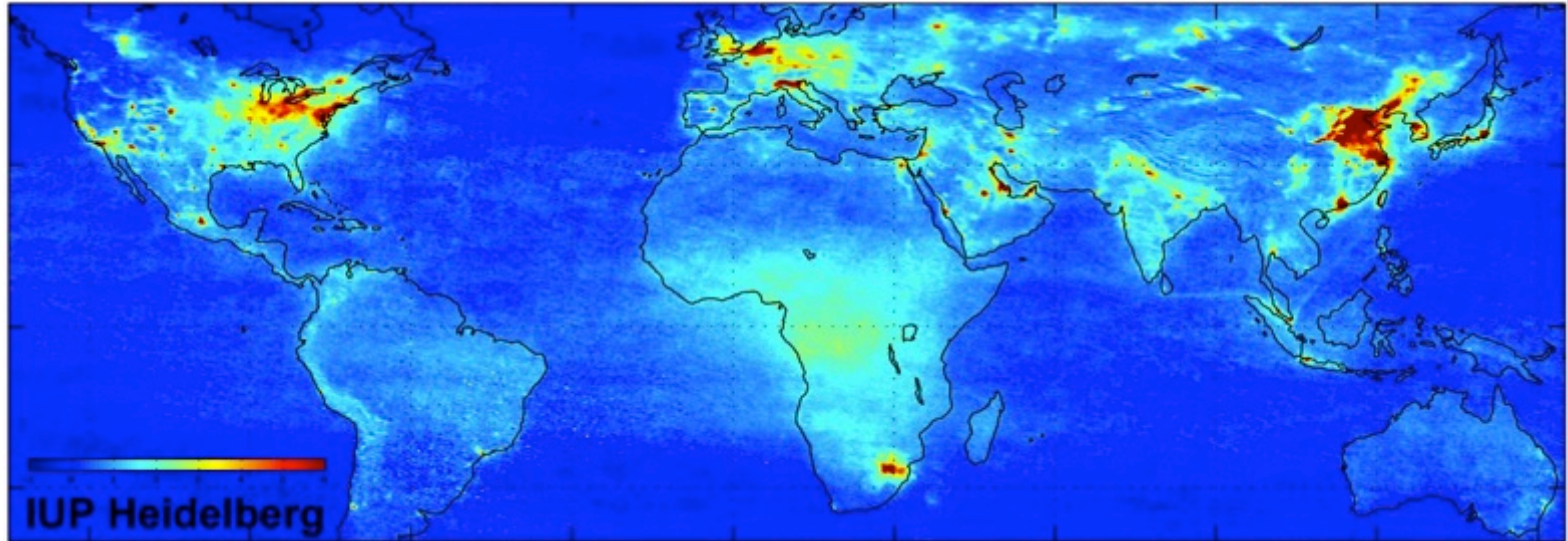


# Radiation Transmitted by the Atmosphere

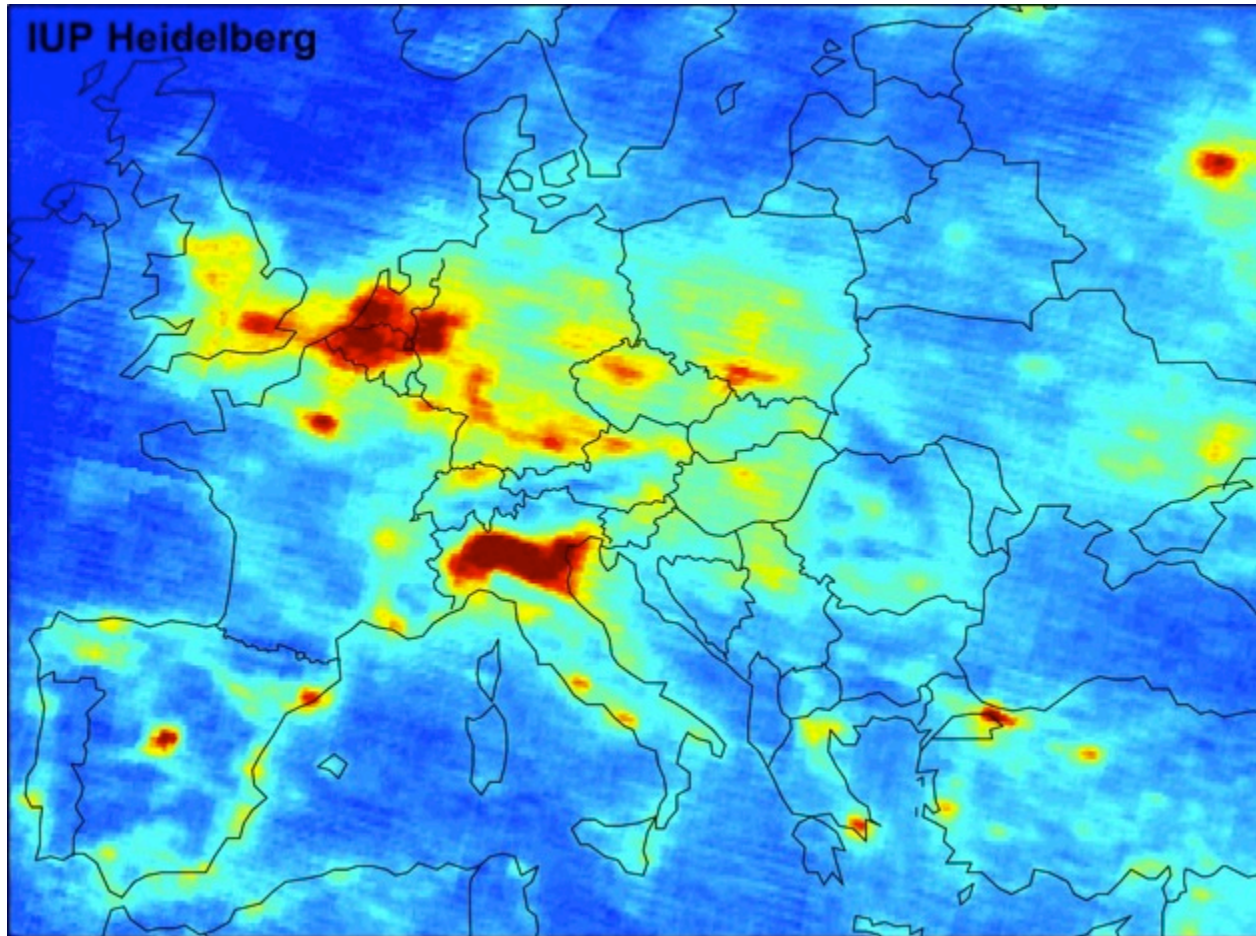




# Polluting emissions ( $\text{NO}_2$ )



Global mean tropospheric nitrogen dioxide ( $\text{NO}_2$ ) vertical column density (VCD) between January 2003 and June 2004, as measured by the SCIAMACHY instrument on ESA's Envisat. Image produced by S. Beirle, U. Platt and T. Wagner of the University of Heidelberg's Institute for Environmental Physics.



A detail from a global image shows the European mean tropospheric nitrogen dioxide (NO<sub>2</sub>) vertical column density (VCD) between January 2003 and June 2004, as measured by the SCIAMACHY instrument on ESA's Envisat. Image produced by S. Beirle, U. Platt and T. Wagner of the University of Heidelberg's Institute for Environmental Physics.

# Polluting emissions (PM)



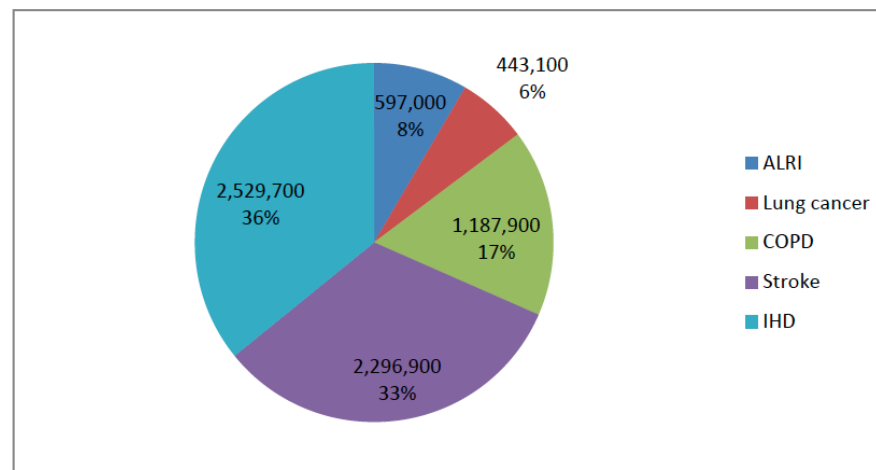
Beijing, China



Courtesy of dr. Lazzarini, ARPA Lombardia

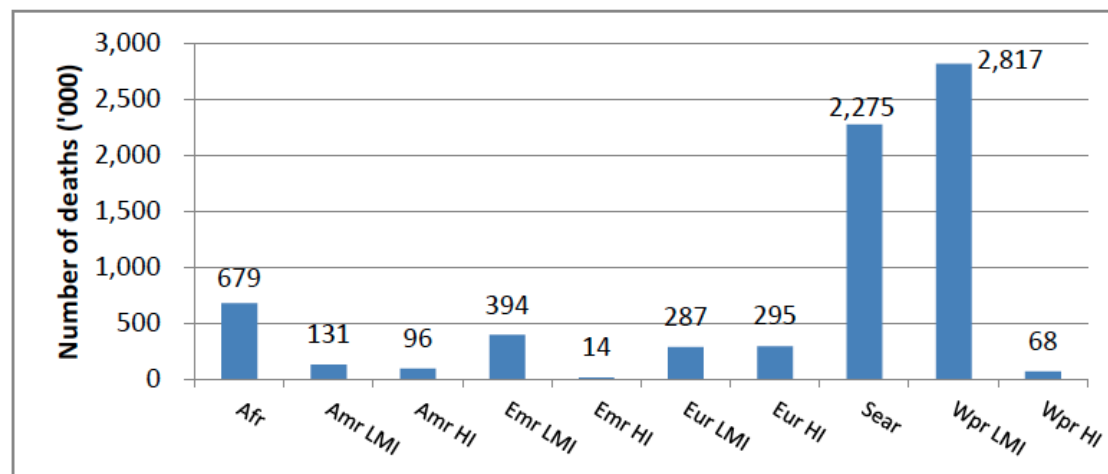
Globally, 7 million deaths were attributable to the joint effects of household (HAP) and ambient air pollution (AAP) in 2012.  
 Fonte: WHO 2014

Figure 3. Deaths attributable to the joint effects of HAP and AAP in 2012, by disease



Percentage represents percent of total HAP burden (add up to 100%).  
 HAP: Household air pollution; AAP: Ambient air pollution; ALRI: Acute lower respiratory disease; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease.

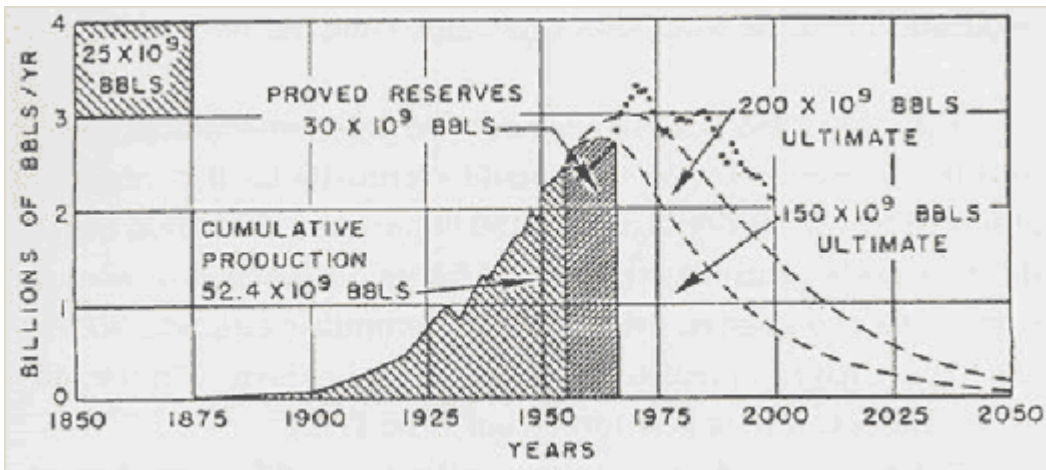
Figure 1. Total deaths attributable to the joint effects of HAP and AAP in 2012, by region



HAP: Household air pollution; AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.



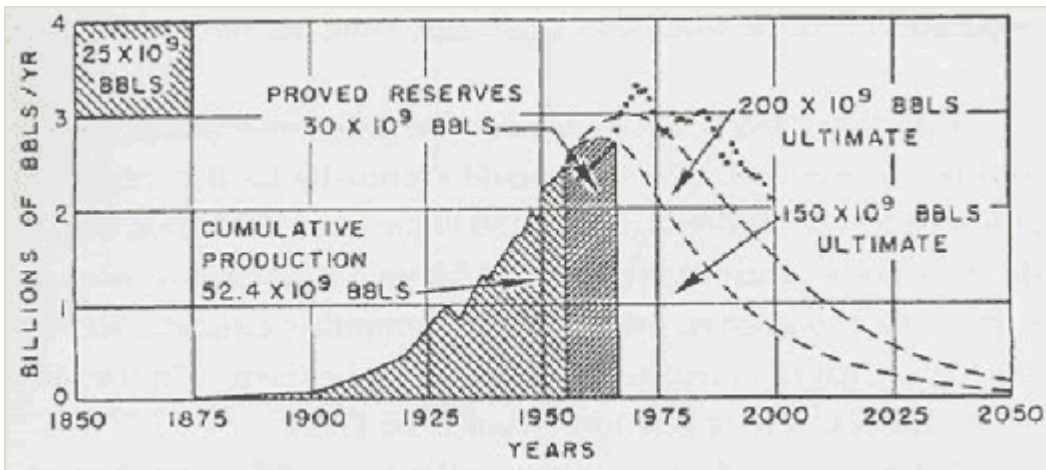
# Limited resources



“Nuclear energy and the fossil fuels”,  
M.King Hubbert, June 1956

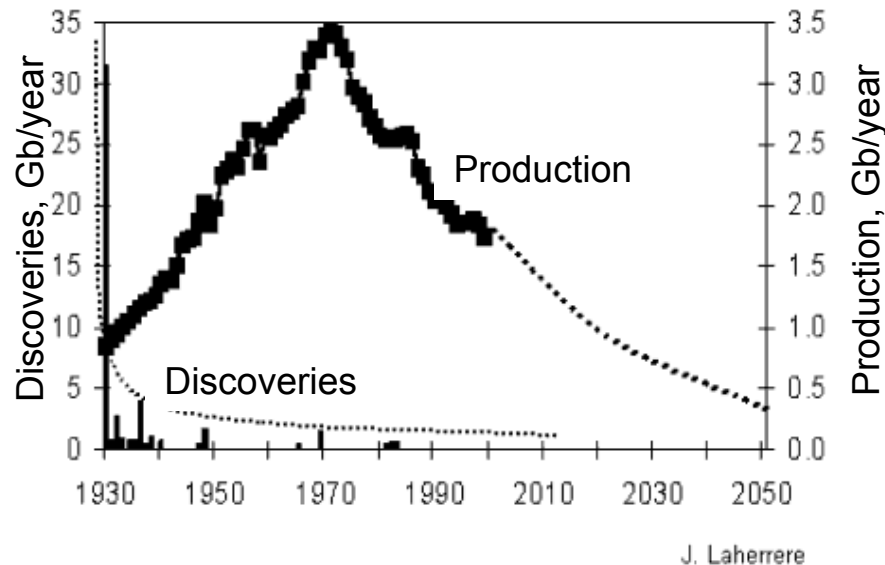
**Hubbert** is best known for his studies on the size of oil fields. He predicted that, for any given geographical area, from an individual oil field to the planet as a whole, the rate of petroleum production of the reserve over time would resemble a bell curve. Based on his theory, he presented a paper to the 1956 meeting of the American Petroleum Institute in San Antonio, Texas, which predicted that overall petroleum production would peak in the United States between 1965 and 1970. At first his prediction received much criticism; Hubbert became famous when his prediction proved correct in 1970.

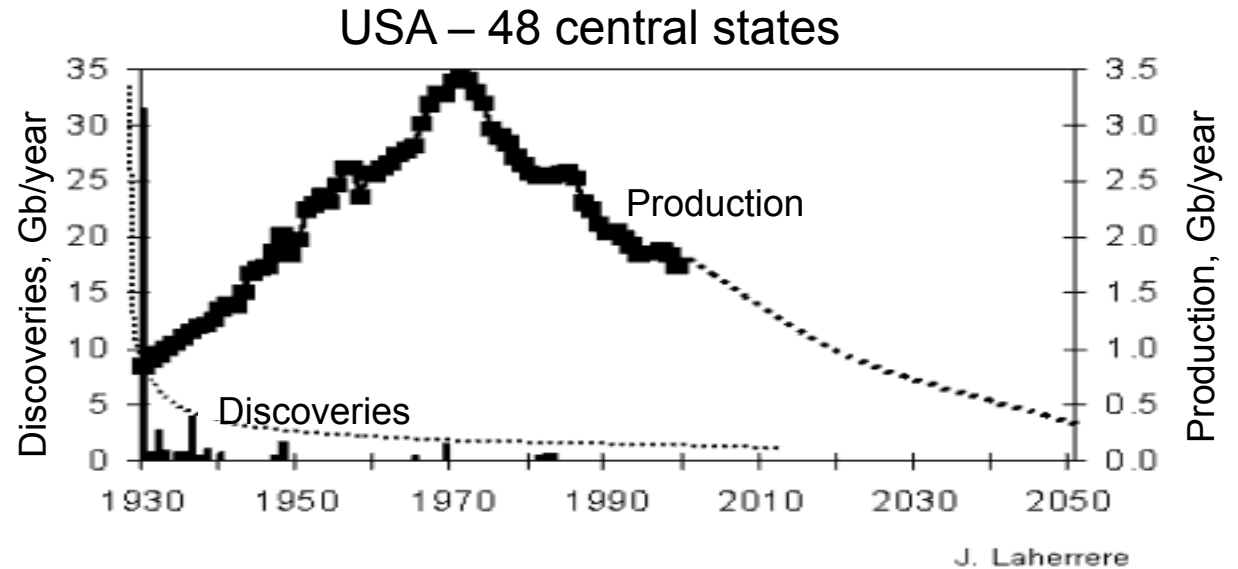
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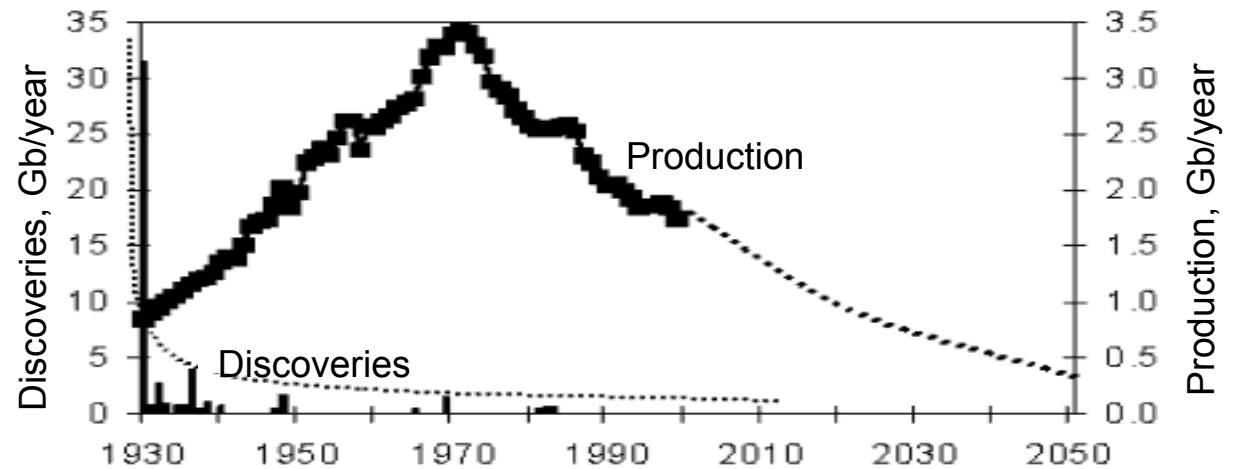
## USA – 48 central states





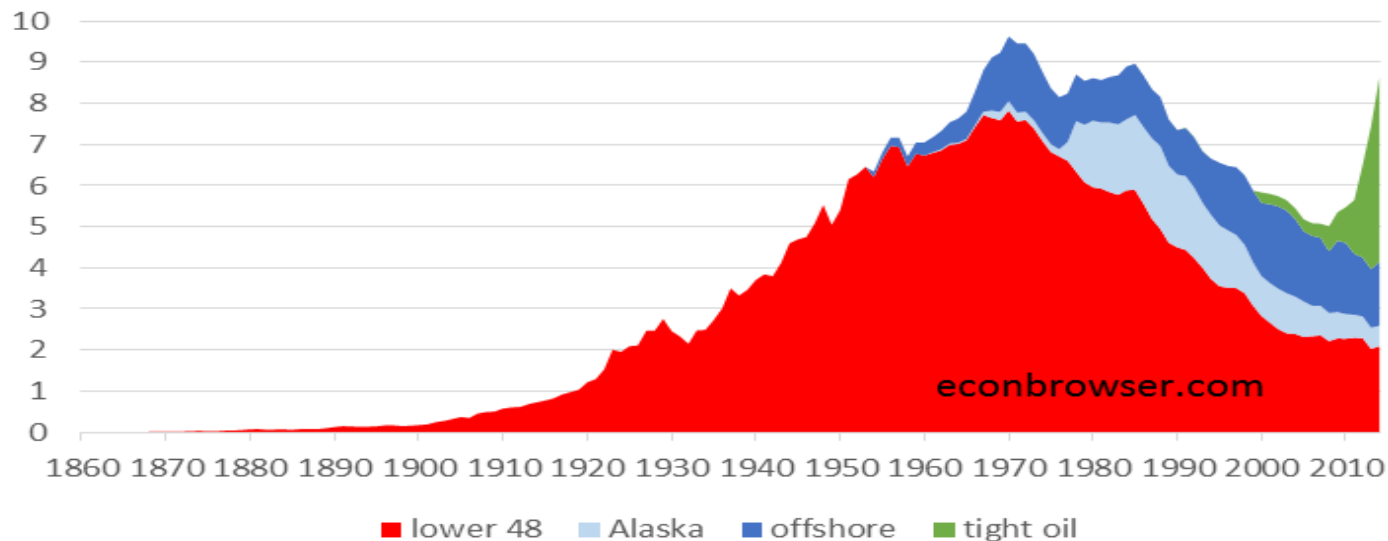
In 1974, Hubbert projected that global oil production would peak in 1995 "if current trends continue". Various subsequent predictions have been made by others as trends have fluctuated in the intervening years. But technologies evolve and new oil reserves can be exploited....

## USA – 48 central states



J. Laherrere

## U.S. oil production by source

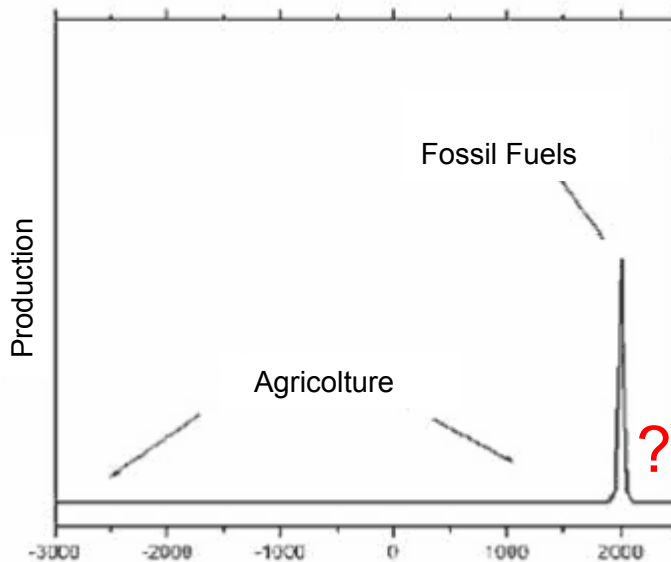


We are using  
limited  
resources  
that will not  
finish  
tomorrow...

G.Alimonti



# Past & Future: what's next?



During the Roman empire, a slave eating about  $2000 \div 2500$  kcal/day, could produce a work output around 3-400 Wh/day, equal to about 100 grams of oil: every European citizen, who now consumes about 10 kg of oil a day, is exploiting the job of 100 to 150 slaves.

Energy is essential for all organic and inorganic activities: history of human evolution reflects history of mankind ability to control and transform Energy.  
Hubbert, 1962

Thank you for your attention!



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