Nexus Summer School

Water systems under pressure

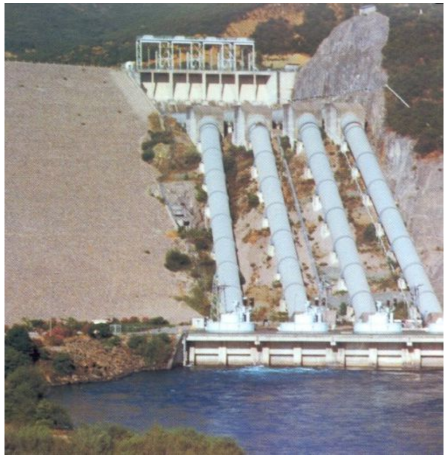
Land use change and impacts on the Water-Food-Energy Nexus

National Technical University of Athens

27/8/2016

Technical University of Munich

Views on water and energy recourses mix. The importance of hydroelectric power plants.



Nikos Mamassis, Assistant Professor

School of Civil Engineering, National Technical University of Athens

Water and Energy

Imagine the inhabitance of an isolated Greek island !!!

What will be the engineering plan?

To find water.

How to find water?
To do what?
How much water we need?

To find energy.

How to find energy?
To do what?
How much energy we need?

To produce electricity.

How to produce electricity?
How much electricity we need?

To manage the water-energy system.

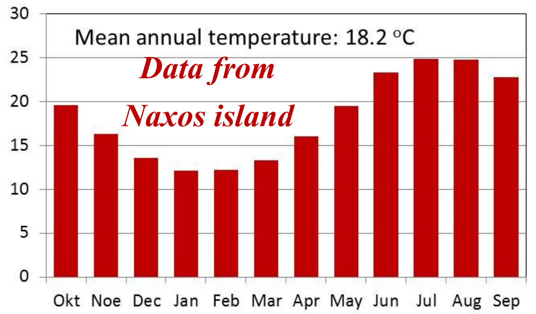
What will be the water recourses?
What will be the energy recourses?
What will be the electric energy mix?
How can I storage water and electricity for later use?

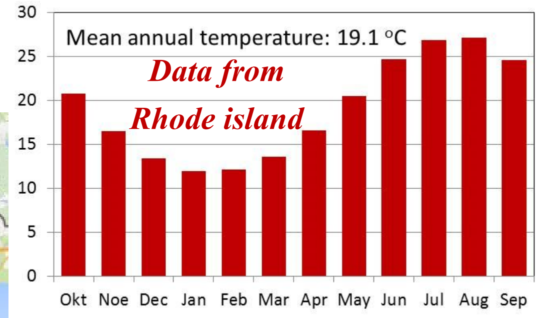
To define the appropriate of hydraulic and energy works and management actions

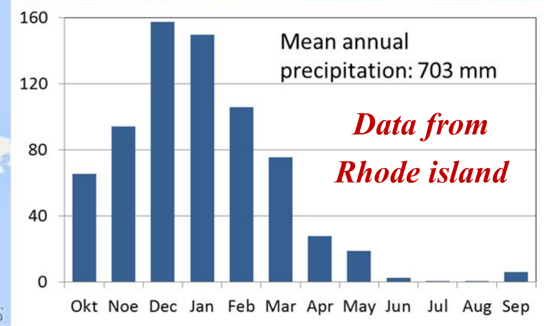
Water and Energy

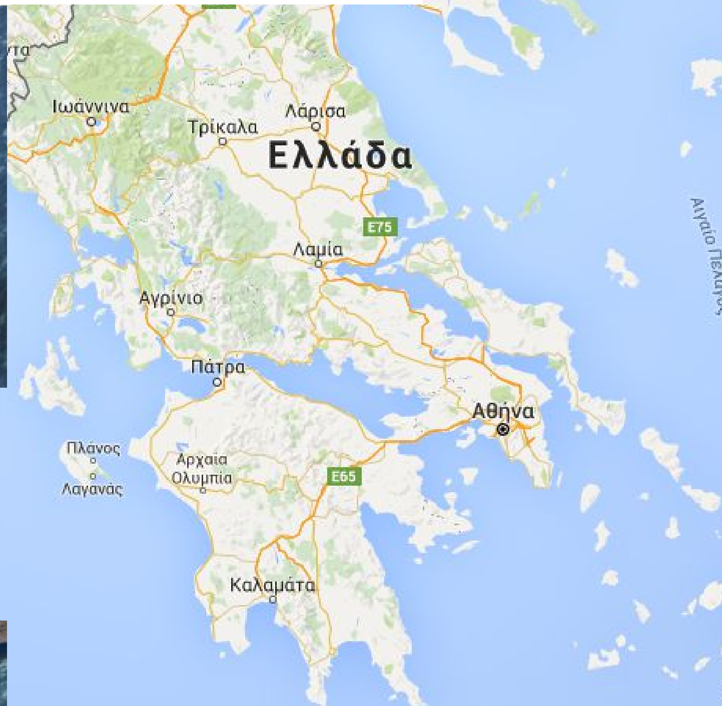
Imagine the inhabitance of the an island like:

Astypalaia
Population (2011) ≈ 1334
Area ≈ 97 km²
Highest elevation ≈ 482 m

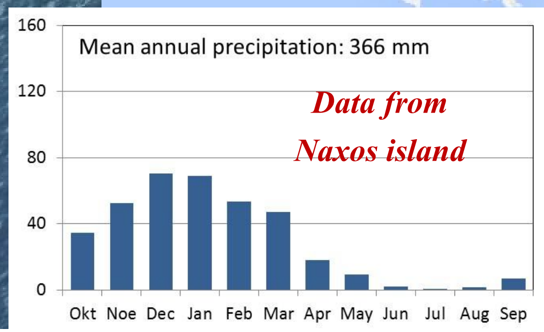








Nisyros
Population (2011)≈987
Area≈41 km²
Highest elevation≈698 m



How to find water?

- Ground water (wells, springs)
- Surface water (rivers, torrents, lakes)
- Rainwater (harvesting)
- Sea water (desalination)
- Atmospheric water (condensation)
- Conveyance
- Reuse

Calculations for our island

Mean annual rainfall volume

Astypalaia: 366 mm * *97 km² =35 hm³*

Nisyros: 703 mm * *41 km² =29 hm³*

To do what ?

- Domestic
- Agricultural
- Industrial
- Livestock
- Energy
- Recreational
- River navigation
- Environmental flow

Consumptive water uses (Domestic, Agricultural, Industrial, Livestock)

Non consumptive water uses (Energy, Recreational, River navigation, Environmental flow)

Mean world consumption: 559 (m^3/cap/y)

Domestic: 66 (12%)

Agricultural: 390 (70%)

Industrial: 103 (18%)

Calculations for our island

Domestic 66 000 m^3/y (180 l/c/d)

Agricultural 390 000 m^3/y

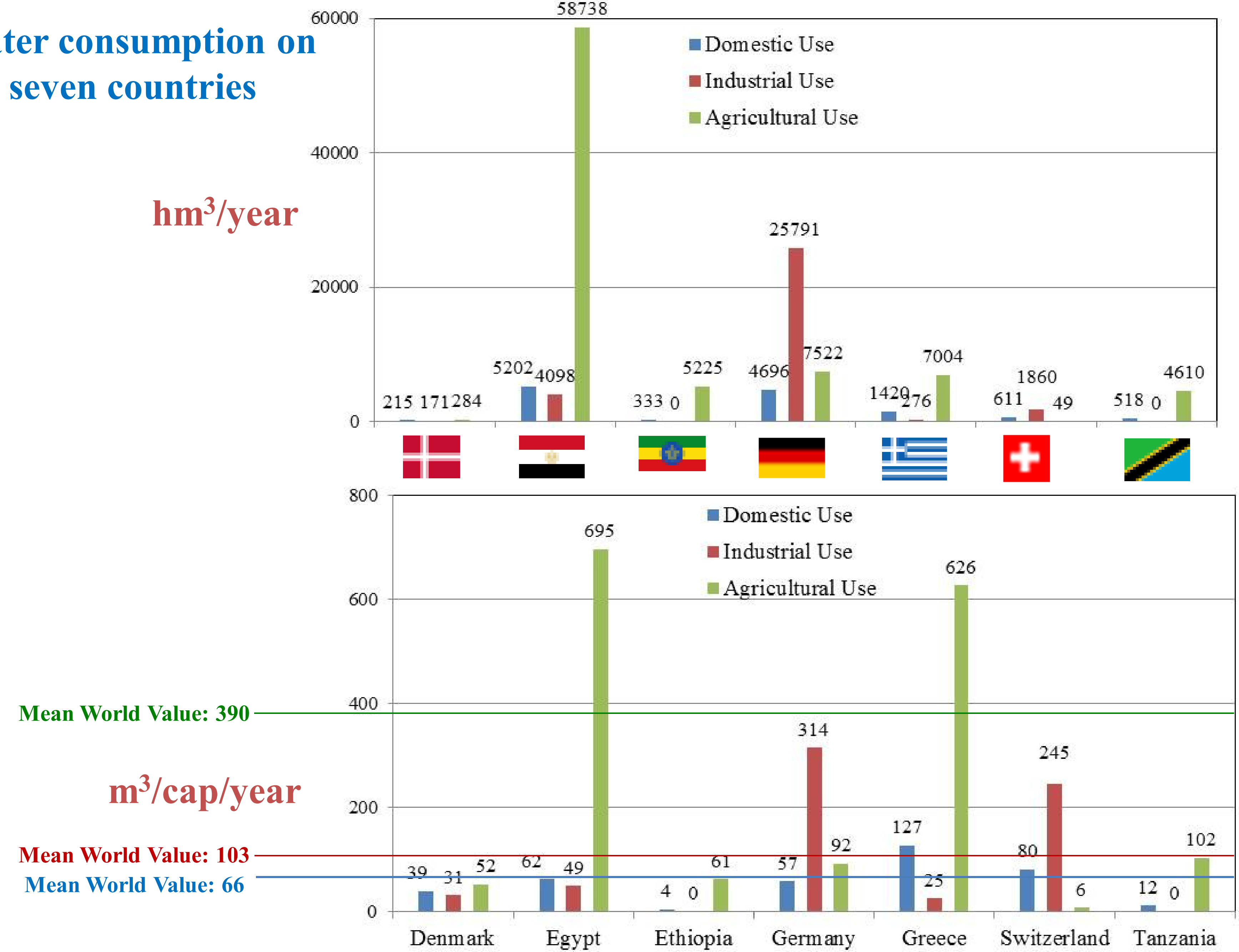
Industrial 103 000 m^3/y

How much water we need?

Water consumption on seven countries

hm³/year

m³/cap/year



Water and Energy

Power and energy

First definition from Aristotle in *Nicomachean Ethics*

Power is the potential that has an object or a living being to be something

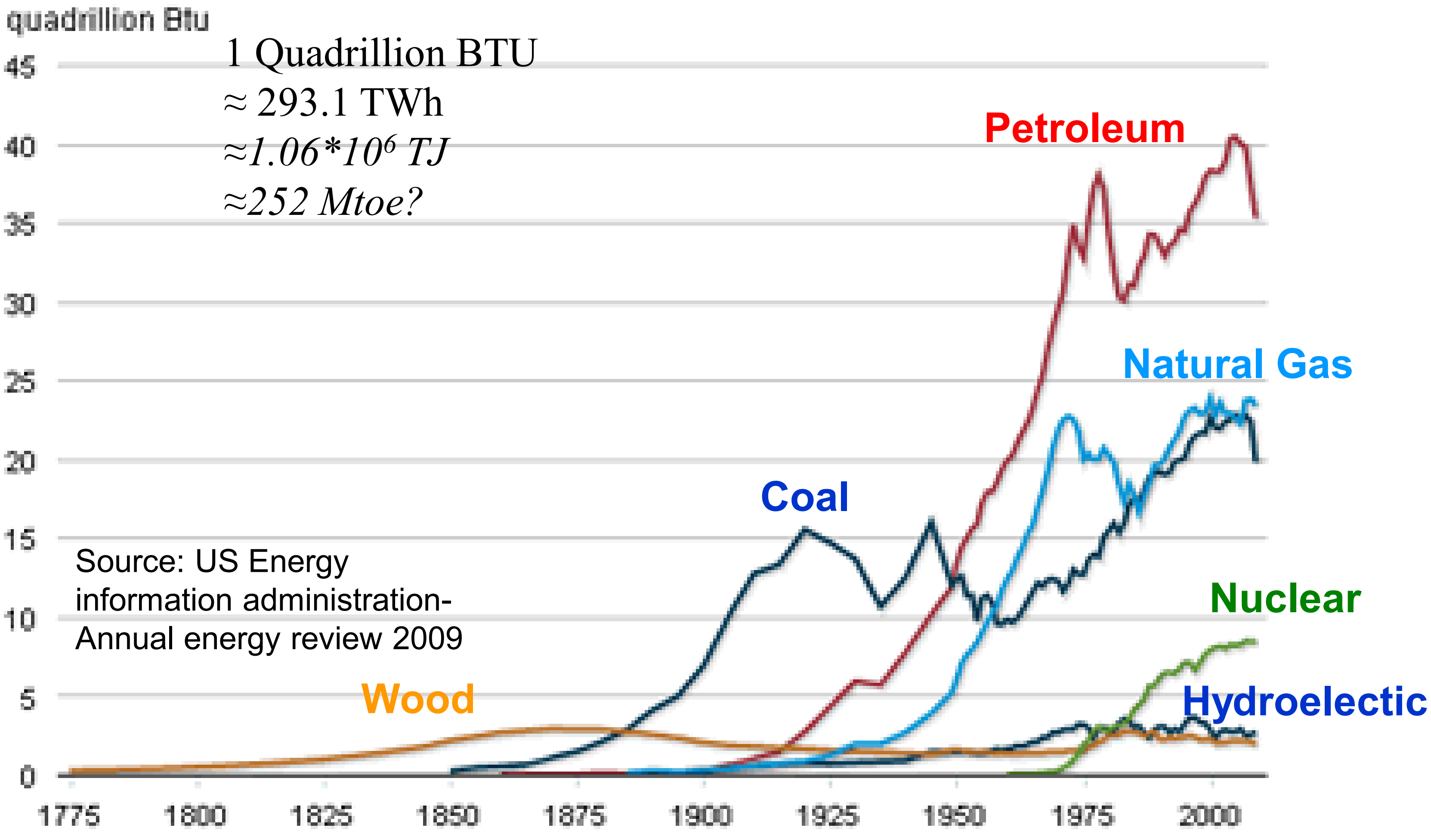
Energy is the making of this potential
the activity that is needed to be action the potential

Electric energy

		Air conditioner consumption	Thermal power plant production
Potential	Installed Power:	1 kW	1 MW
	Hours of operation (in maximum power):	3 hr	3000 hr
Activity	Energy consumed/produced:	3 kWh	3000 MWh=3 GWh

How to find energy?

History of energy consumption in the USA (1775-2009)

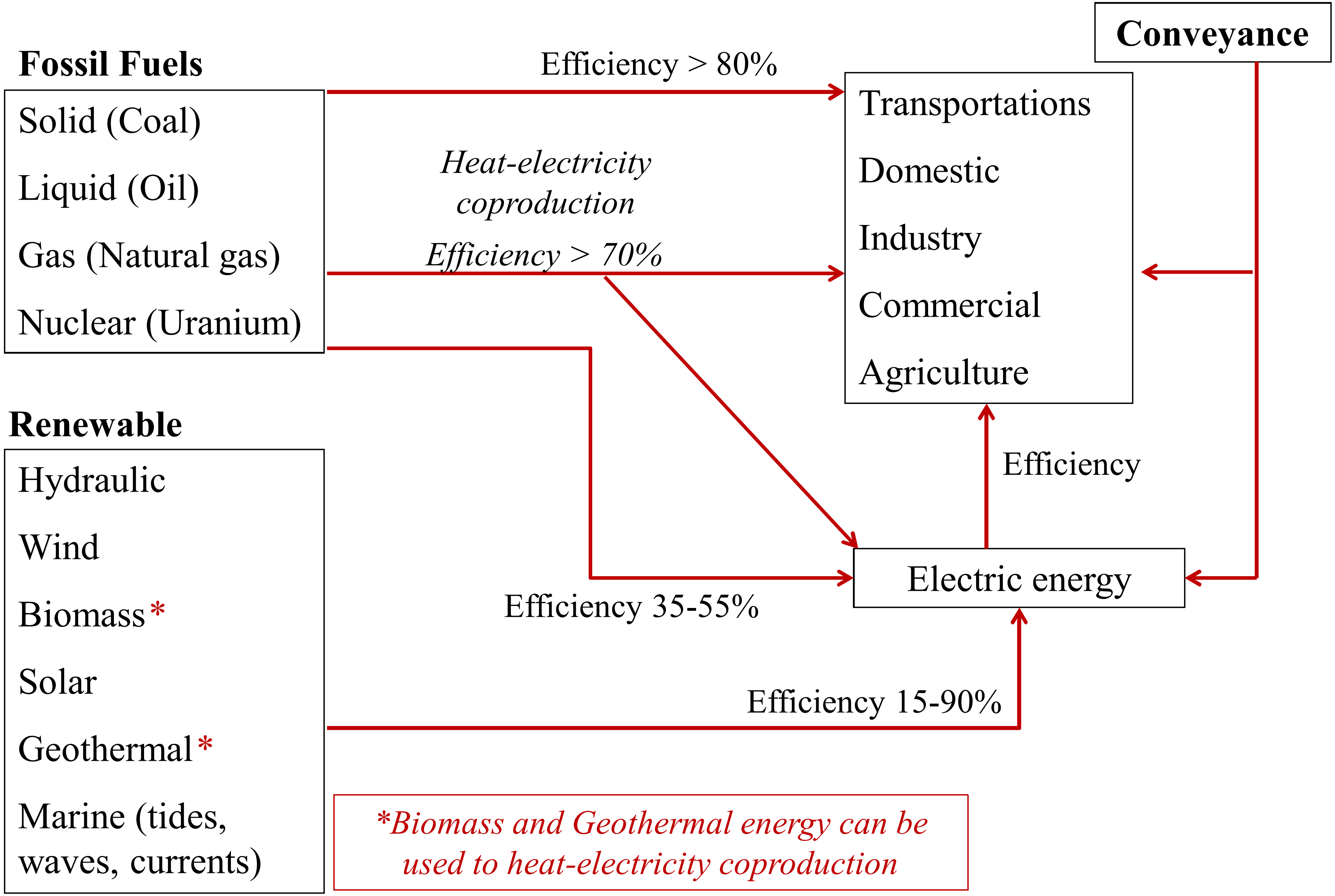


How to find energy?

Energy sources

To do what ?

Energy needs



How to find energy?

Energy from fossil fuels

The energy that exists in fossil fuels is expressed in ***toes*** (tones oil equivalent)

1 toe ≈

10^6 kcal ≈ 42 GJ ≈ $40*10^6$ Btu ≈ 11.6 MWh

The efficiency of fossil fuels to produce is greater than 80% but to produce electricity is about 35-50%.

Quantity of fuel energy that corresponds to energy of 1 toe (42 GJ) from combustion (efficiency 100%)

Fuel	Colorific value	Quantity
Anthracite	33 (MJ/kg)	1.27 tn
Lignite	15 (MJ/kg)	2.80 tn
Wood	14 (MJ/kg)	3.00 tn
Diesel fuel	45 (MJ/kg)	0.93 tn
Petroleum	43 (MJ/kg)	0.98 tn
Natural gas	43 (MJ/m^3)	977 m^3
Gas oil	38 (MJ/lt)	1105 lt
Uranium 235	80 (TJ/kg)	0.532 gr

Calculations for our island

Population: ≈ 1000 people
Primary energy per capita: ≈ 1.5 toe/y
Electric energy per capita : ≈ 3.4 MWh/y
Total primary energy : ≈ 1500 toe/y
Total electric energy: ≈ 3.4 GWh/y

The total primary energy corresponds to the combustion of the following quantities:
1910 tn of anthracite
4200 tn of lignite
4500 tn of wood
1400 tn (10300 barrels) of diesel
1.46 Mm3 (1000 tn LNG) of natural gas
10400 barrels of gas oil
782 gr of Uranium 235

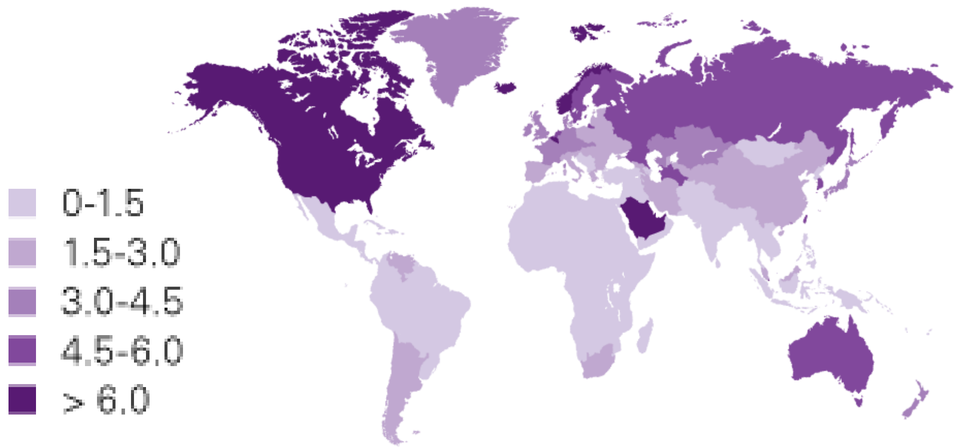
To produce the electric energy only from fossil fuels considering a mean efficiency 40% we will need thermal energy of ≈ 8.5 GWh/y that is equivalent to 8500/11.6 ≈ 732 toe the 48% total energy.

How much energy?

Primary energy (2014)

Country	Population (10^6)	Primary Energy (Mtoe)	Primary Energy *(toe/cap)*	*Electric energy (TWh)*	*Electric energy (MWh/cap)*	*Electric to primary energy (%)*
Denmark	5.6	17.3	3.1	34.6	6.2	17.3
Egypt	87	86.2	1.0	148.5	1.7	14.9
Ethiopia	88			4.9	0.1	
Germany	81	311.0	3.8	633.2	7.8	17.6
Greece	11.1	26.1	2.4	57.2	5.1	18.9
Switzerland	8.2	28.7	3.5	73.4	9.0	22.0
Tanzania	44.9	4.3	3.1	4.3	0.1	
World	7000	12928.4	1.8	23536.5	3.4	15.7

Primary energy toe/cap (2009)



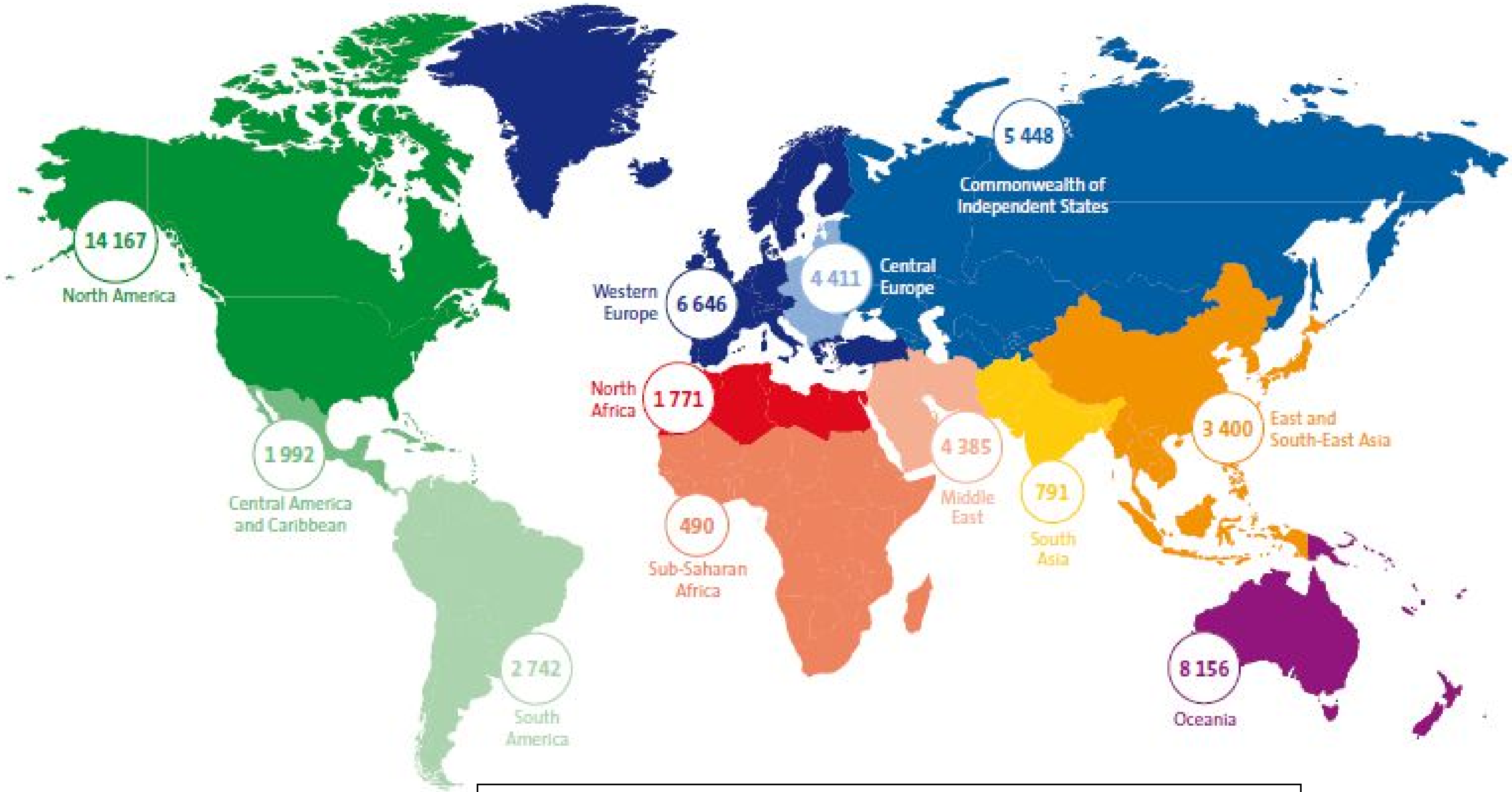
How much electric energy?

Characteristics of electric energy systems (2011)

Country	Population (10^6)	Power (GW)	Energy (TWh)	*Power (kW/cap)*	*Energy (MWh/cap)*	*Capacity factor (%)*
Denmark	**5.6**	**13.71**	**30.4**	*2.45*	*5.4*	*25*
Egypt	**87**	**26.91**	**149**	*0.309*	*1.7*	*63*
Ethiopia	**88**	**2.06**	**4.9**	*0.02*	*0.06*	*27*
Germany	**81**	**153.2**	**633.6**	*1.89*	*7.8*	*47*
Greece	**11.1**	**15.12**	**58.3**	*1.36*	*5.2*	*44*
Switzerland	**8.2**	**18.07**	**73.4**	*2.20*	*9.0*	*46*
Tanzania	**44.9**	**0.84**	**4.3**	*0.02*	*0.1*	*58*

How much electric energy?

Electricity production (kWh/cap) in the various regions (2012)



$22616 * 10^9$ kWh/$6 * 10^9$ cap≈3500 kWh/cap

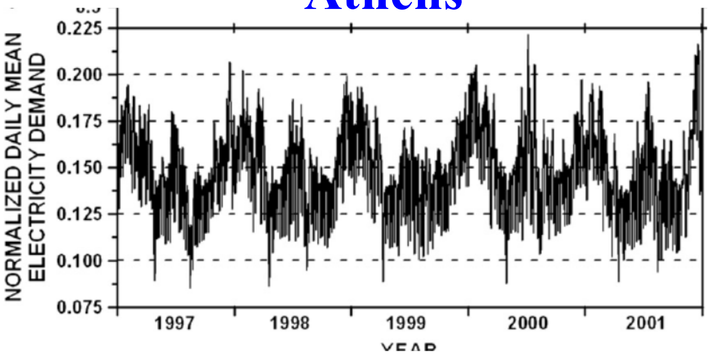
Source: *http://www.energies-renouvelables.org/observ-er/*

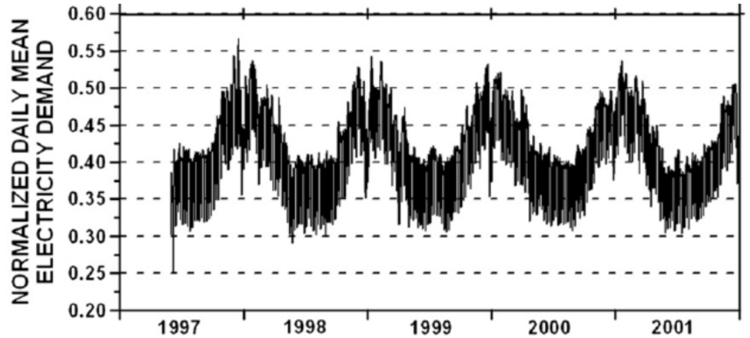
How much energy? The electric energy demand peaks

Athens

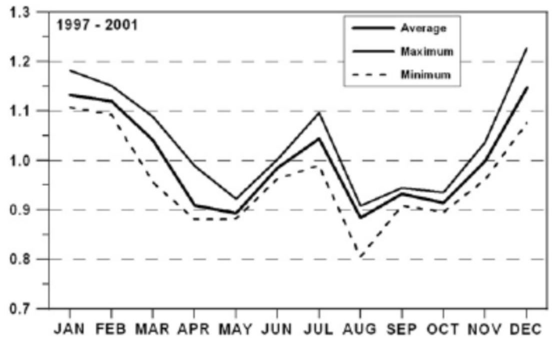
London

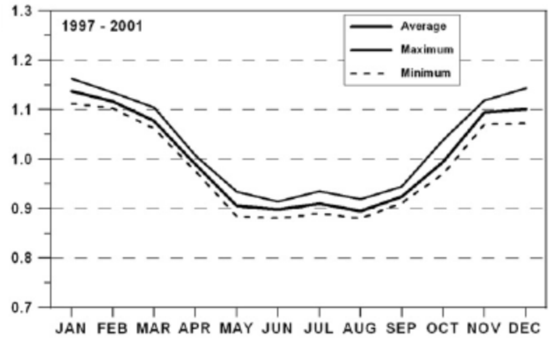
Fluctuation of daily electricity demand (1997-2001)



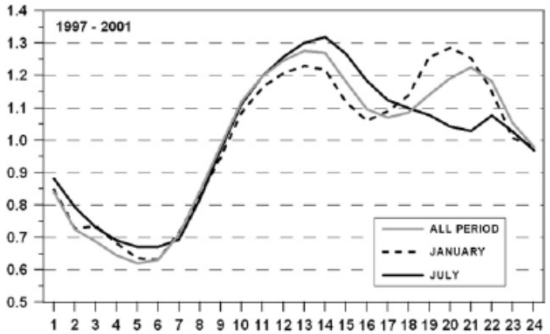


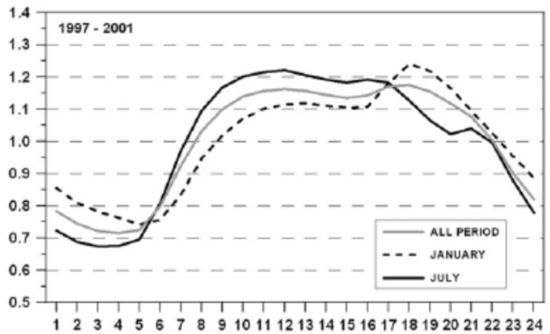
Fluctuation of mean monthly electricity demand (1997-2001)





Fluctuation of mean hourly electricity demand (1997-2001)





In Greece, the mean annual electricity demand of about 55 TWh could be produced by power plants with an installed power of 6.3 GW considering continuous operation (CF=1). The peak hourly demands had reached the 11 GWh (during hot noon summer hours). During these peaks the total installed power of the country was about 14 GW (corresponds to about 1.4 kW/cap)

How to produce electricity?

Some ideas and calculations for our island

Population: ≈ 1000 people
Required electric energy ≈ 3.5 GWh/y
Required installed power considering continuous operation≈ 0.4 MW
Estimate installed power to cover peak demands ≈ 1 MW
Installed electric power considering Greek figures: ≈ 1.5 MW *Denmark figures: ≈ 2.5 MW*

Thermal power plant with petroleum
Installed electric power: ≈ 1 MW
Operation hours (equivalent to full power): 4380 hr (50% of total time)
Electric energy produced: 4.4 GWh/y
Considering efficiency 35% we will need 370 tn/y of petroleum

Thermal power plant that exploits a lignite deposit
The mass of deposit is $1*10^6$ *tn with calorific value 10 MJ/kg*
*Total calorific value of the deposit: 10 MJ/kg*1*10*^{9} *kg=* $10*10^9$ *MJ*
Considering efficiency 35% the potential electric energy is about 970 GWh
Installed electric power: ≈ 1 MW
Operation hours (equivalent to full power): 4380 hr (50% of total time)
Electric energy produced: 4.4 GWh/y
Considering efficiency 35% we will need 1040 tn/y of lignite. The deposit will be exhausted in 220 years

Nuclear power plant with Uranium
Installed electric power: ≈ 1 MW
Operation hours (equivalent to full power): 7010 hr (80% of total time)
Electric energy produced: 7 GWh/y
Considering efficiency 35% we will need 900 g /y of Uranium 235

How to produce electricity?

Some ideas and calculations for our island

Energy from renewable fuels

We can produce the electric energy 3.4 GWh/y from renewable fuels

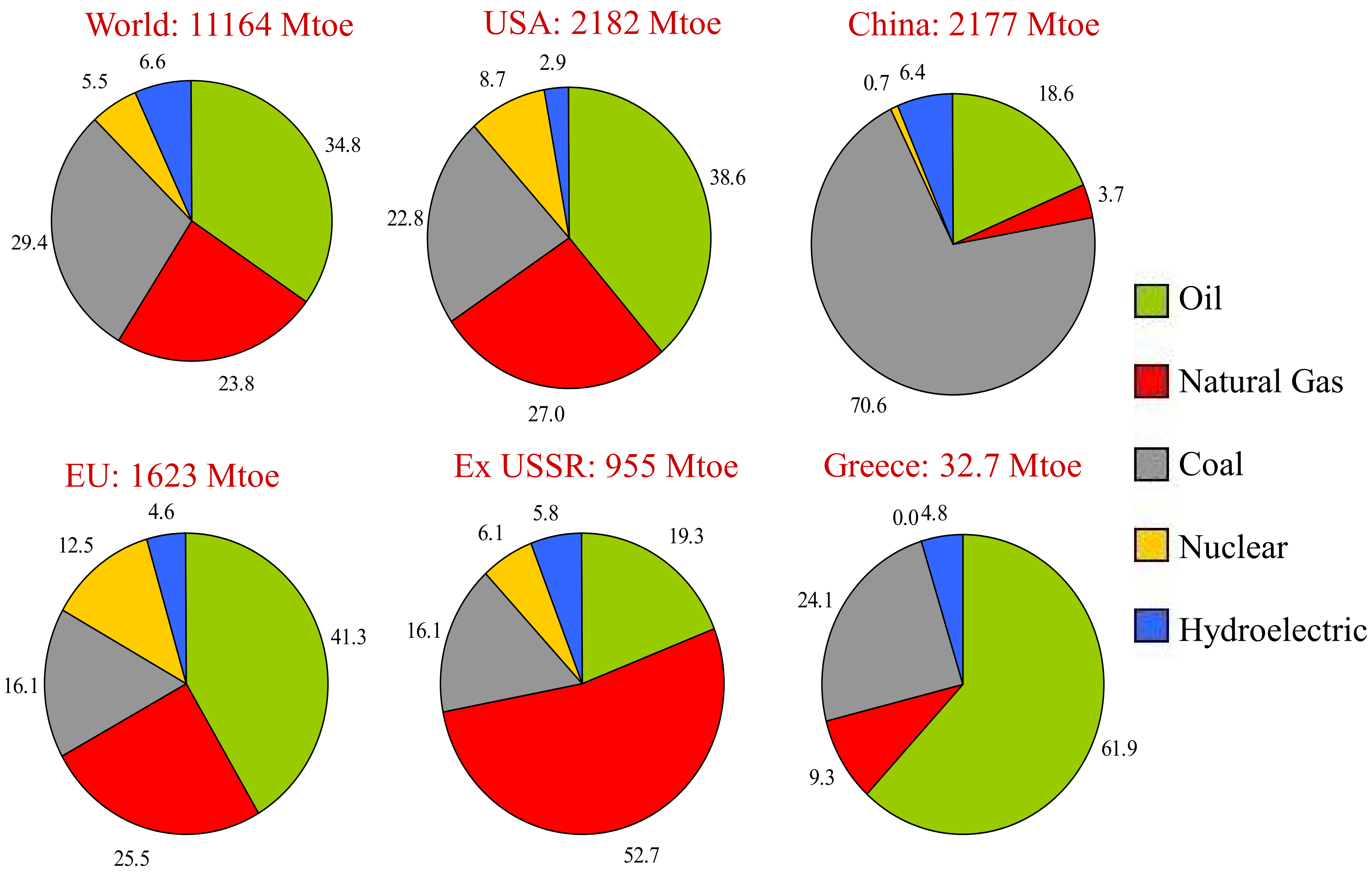
- Wind turbine with installed power of 2 MW (diameter about 80 m) could produce 4 to 7 GWh/y
- Photovoltaic panels of with installed power of 2 MW (panels area about 1.4 ha), could produce 3 to 5 GWh/y
- Biomass installation. 3000 tn wood retails contain 1000 toe of thermal energy and could produce 4.4 MWh of eclectic energy
- A geothermal field can be used a 1 MW installation could produce 5 to 7 GWh/y
- A tide effect in our island of about 7 meters with the appropriate installation of a 4 MW turbine could produce about 6 GWh/y
- Hydroelectric plant (fall of 7 hm^3 volume of water per year from 210 m or 30 hm^3 volume of water per year from 50 m) could produce 3.4 GWh/y

What will be the energy recourses?

- What are the available energy recourses?
- Is it possible to control their electricity production in time?
- How fast can feed the electric network in peak demand situations
- Can the electricity be storage for later use?
- What is the kind of related works?
- What is the cost of construction, maintenance and operation
- What is the environmental impact?
- What are the geopolitics in the area related to fuel and energy transfer

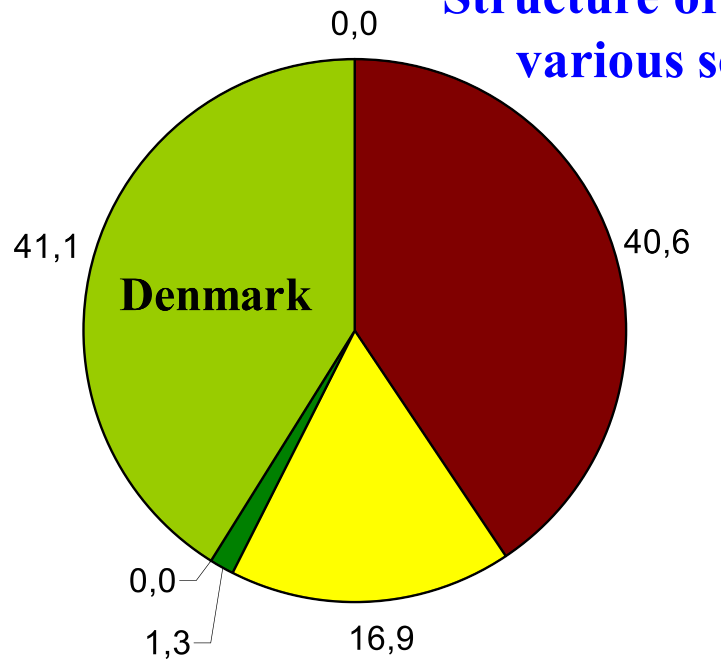
What will be the energy recourses?

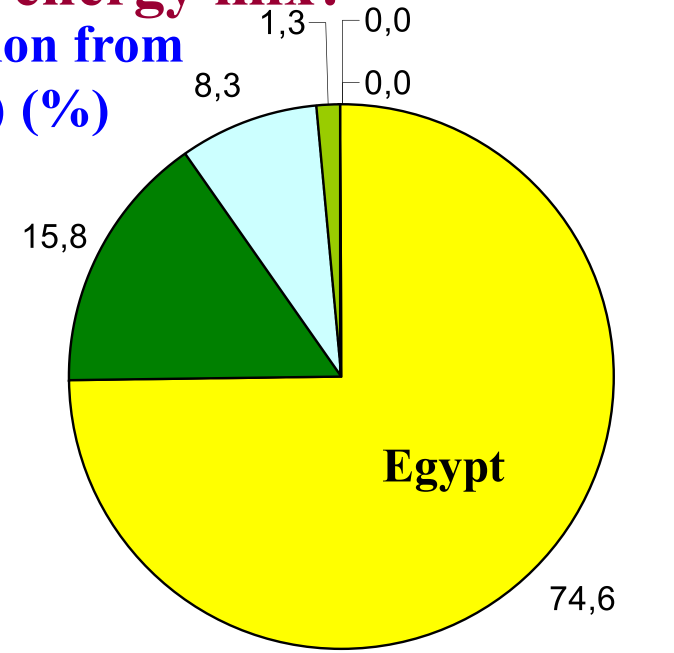
Primary energy- Consumption per fuel- 2009

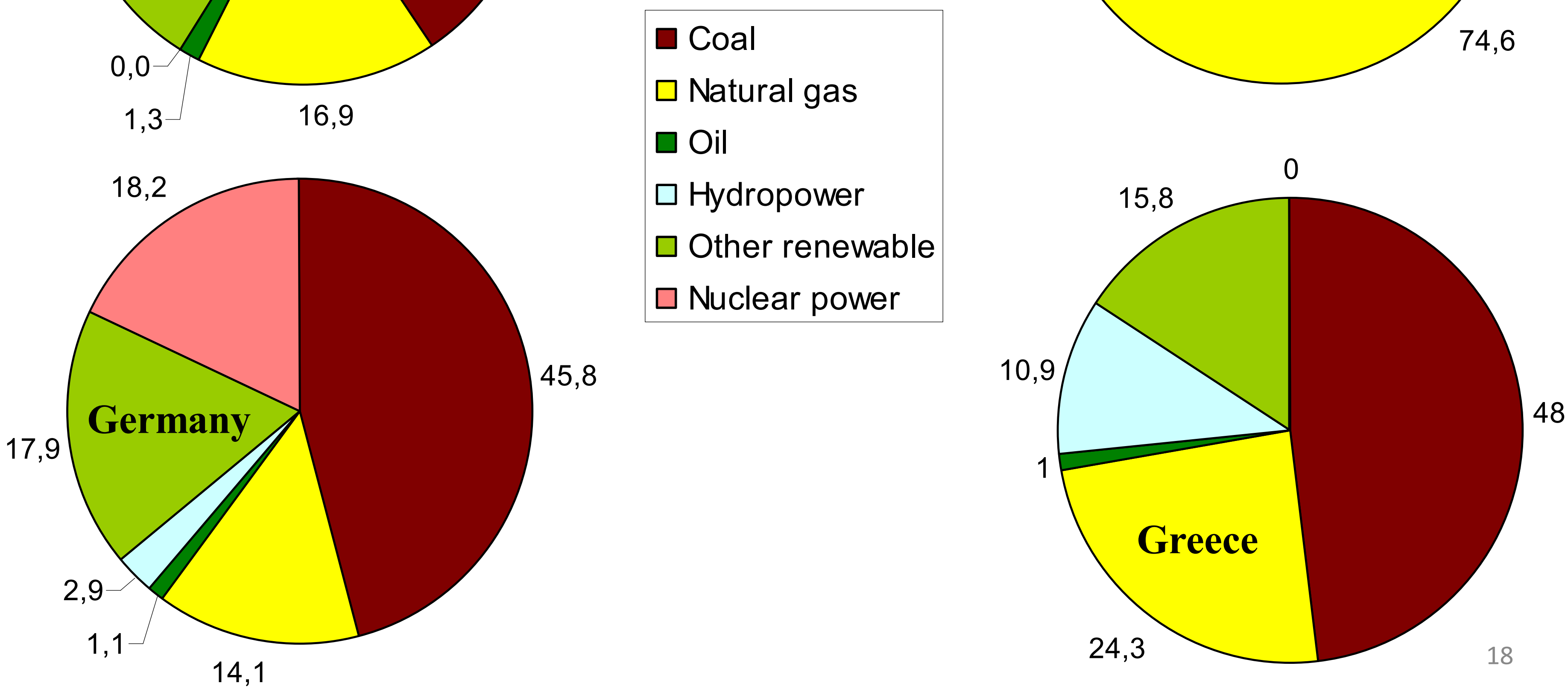


What will be the electric energy mix?

Structure of electricity production from various sources (energy mix) (%)



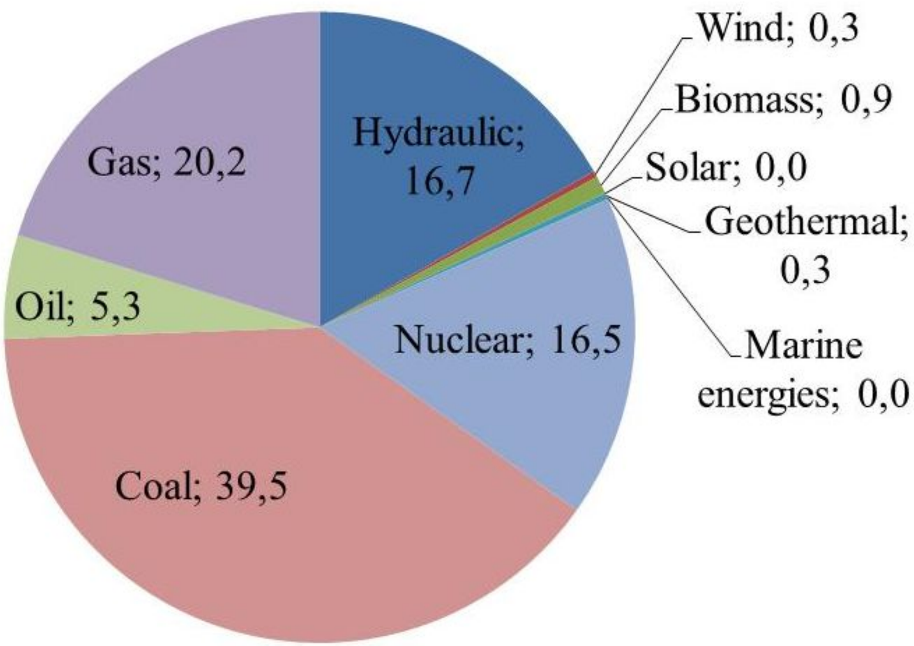




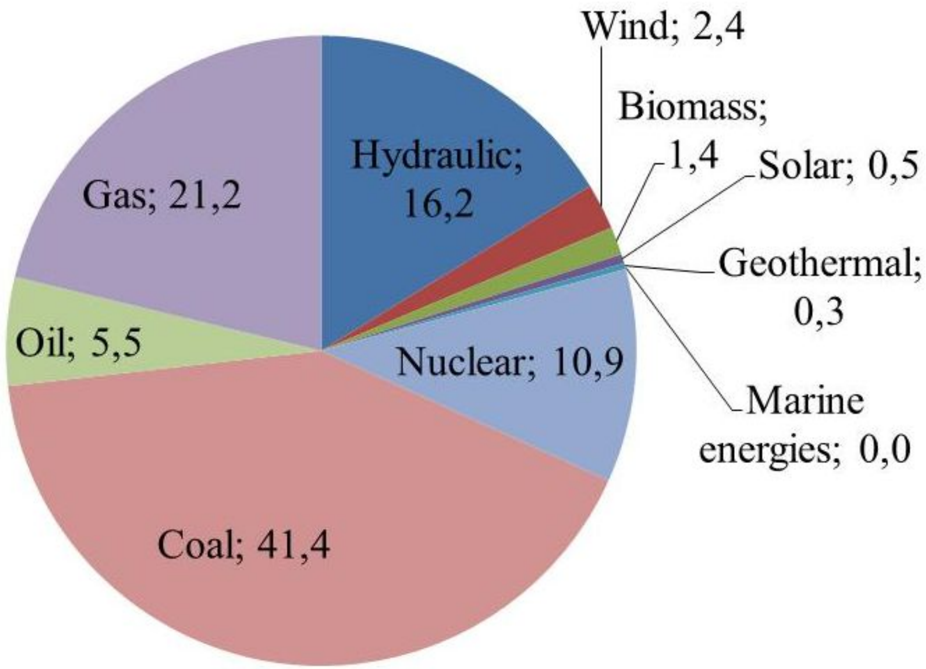
What will be the electric energy mix?

Structure of world electricity production from various sources (energy mix) (%)

2002



2012



TOTAL: 16174 TWh
Renewable**:** 2959 TWh (18.3%)
Nuclear: 2661 TWh (16,5%)
Fossil: *10514* TWh *(65.2%)*

TOTAL: 22616 TWh
Renewable**:** 4699 TWh (20.8%)
Nuclear: 2463 TWh (10.9%)
Fossil: *15394* TWh *(68.3%)*

What will be the electric energy mix?

Capacity factor (CF)

$$\textit{Capacity factor (CF) of a power plant over a period of time} = \frac{\textit{The electric energy produced}}{\textit{The potential electric energy considering continuous operation at full installed power}}$$

Example

Installed Power: 1 MW   Time period: 1 year (8760 hr)

Potential electric energy: 1 MW*8760 hr=8760 MWh

Electric energy produced: 4380 MWh

CF: 4380/8760=0.5

For a power plant of given installed power the potential electric energy is constant. The CF is depended on the quantity of electric energy that actually produced by the project.

- In thermal power plants the CF of a year can be scheduled taking into account the desired operation hours and the active power used. Theoretically a thermal power plant could be have a CF=1 for a time period if it was feed with fuel continuously. An annual CF greater then 0.8 are common.
- The CF of a wind power plant is depended on the wind velocities of a time period. A wind turbine can produce the installed power for velocities between 12-25 m/s. For higher velocities don't operate and for lower velocities produce a faction of the potential energy. A annual CF of about 0.3-0.4 in wind turbine operation is common.
- The CF of a photovoltaic power plant is limited by the sunshine hours. As everywhere in the world the potential sunshine hours are half of the total there is a natural limit to CF of 0.5. Taking into account the solar angles during each day and season and the time with clouds an annual CF of about 0.2-0.3 is common
- In hydroelectric power plants without reservoir the energy produced depended on the wind velocities of a time period. the CF of a year can be scheduled taking into account the desired operation hours and the active power used.

Electric energy from fossil – nuclear fuels and biomass

- *Choose of installed power*
- *As fuels theoretically are available the produced energy in all time scales is controlled by the operators (also the maintenance period)*
- *Evaluate the expected energy with socioeconomic criteria*
- *The evolution of energy produced in small time steps (hours) has a great predictability (except emergency situations, accidents etc)*

Electric energy from wind, sun, waves

- *Choose of installed power*
- *Consider wind and solar radiation data for calculating an approximate annual produced energy*
- *Evaluate the expected energy with socioeconomic criteria*
- *The evolution of energy produced in small time steps (hours) has a great variability and poor predictability*

Electric energy from tides and currents

- *Choose of installed power*
- *Consider tide and current data for calculating an approximate annual produced energy *
- *Evaluate the expected energy with socioeconomic criteria*
- *The evolution of energy produced in small time steps (hours) has a great predictability*

Electric energy from water without reservoir

- *Evaluate the expected energy in large time steps (year) considering the characteristics of the site and socioeconomic criteria*
- *Choose of installed power considering flow time series*
- *The produced energy in all time scales is controlled by the operators*
- *The evolution of energy produced in small time steps (hours) has a great variability and poor predictability*

Electric energy from geothermic field

- *I evaluate the expected energy in large time steps (year) considering the potential of site*
- *Choose of installed power considering socioeconomic criteria*
- *The produced energy in all time scales is controlled by the operators*
- *The evolution of energy produced in small time steps (hours) has a great predictability*

Electric energy from water with reservoir

- *I evaluate the expected energy in large time steps (year) considering the characteristics of the site and socioeconomic criteria*
- *Choose of installed power considering the scope of the plant (base-peak energy)*
- *The produced energy \in all time scales is controlled by the operators*
- *The evolution of energy produced in small time steps (hours) has a great predictability (except emergency situations, accidents etc)*
- *The only system that can storage renewable energy*

What will be the electric energy mix?

Features of various resources

Electric energy from fossil – nuclear fuels and biomass
For a given installed power, the energy produced is controlled. For continuous operation in full power the CF could be 1.
The magnitude of the project is depended on the availability of the fuels and socioeconomic criteria
The future energy produced has a great predictability (except emergency situations, lack of fuels, accidents etc).
The time that is needed to change the power is several hours so these plants covers primary energy

Electric energy from wind, sun, waves
For a given installed power, the energy produced is depended on the values of the related meteorological parameters (wind and solar radiation). As these plants produce energy for a given range of wind and radiation values, a significant amount of time are inactive. So the CF theoretically could not be 1 and commonly is under 0.5
The magnitude of the project is depended mainly on socioeconomic criteria
The future energy produced can not be controlled and has a poor predictability in small time steps (hours)
The poor predictability usually leads to the absorption by priority by the electric network

Electric energy from tides and currents
For a given installed power, the energy produced is depended on the values of the related parameters (tide levels, current flows). As these plants produce energy in specific time periods amount of time are inactive. So the CF theoretically could not be 1 and commonly is under 0.3
The magnitude of the project is depended mainly on socioeconomic criteria
The future energy produced has a great predictability
\

What will be the electric energy mix?

Features of various resources

Electric energy from geothermic field
For a given of geothermic field the potential is evaluated and the installed power is decided considering almost continuous operation
The produced energy in all time scales is controlled by the operators

- *The evolution of energy produced in small time steps (hours) has a great predictability*

Electric energy from water without reservoir

- *Evaluate the expected energy in large time steps (year) considering the characteristics of the site and socioeconomic criteria*
- *Choose of installed power considering flow time series*
- *The produced energy in all time scales is controlled by the operators*
- *The evolution of energy produced in small time steps (hours) has a great variability and poor predictability*

Electric energy from water with reservoir

- *I evaluate the expected energy in large time steps (year) considering the characteristics of the site and socioeconomic criteria*
- *Choose of installed power considering the scope of the plant (base-peak energy)*
- *The produced energy \in all time scales is controlled by the operators*
- *The evolution of energy produced in small time steps (hours) has a great predictability (except emergency situations, accidents etc)*
- *The only system that can storage renewable energy*

Decision of our mix (to be filled)

Population ≈ 1000 people
Electric energy demanded: ≈ 3.4 GWh/y
Peak energy demanded: ≈ 1 MW

	Installed power	***Expected electric energy produced***	***Capacity factor***
Solid (Coal)			
Liquid (Oil)			
Gas (Natural gas)			
Nuclear (Uranium) Hydraulic			
Wind			
Biomass			
Solar			
Geothermal			
Marine (tides, waves, currents)			
Conveyance			

The reality in our island: Astypalaia

Water consumption
Domestic: 130 000 m^3/y (includes visitors)
Agricultural: 250 000 m^3/y (includes livestock)
Industrial: 4 000 m^3/y

Livadi dam
Height: 32 m
Reservoir volume: 900 000 m^3
Watershed area: 8 km^2
Mean annual inflow: 480 000 m^3 (60 mm)

Electric energy power plant
Thermal power plant with petroleum

Installed electric power: ≈ 1.6 MW

Electric energy produced: 3.8 GWh/y

Peak electric energy demanded: 1.3 MW

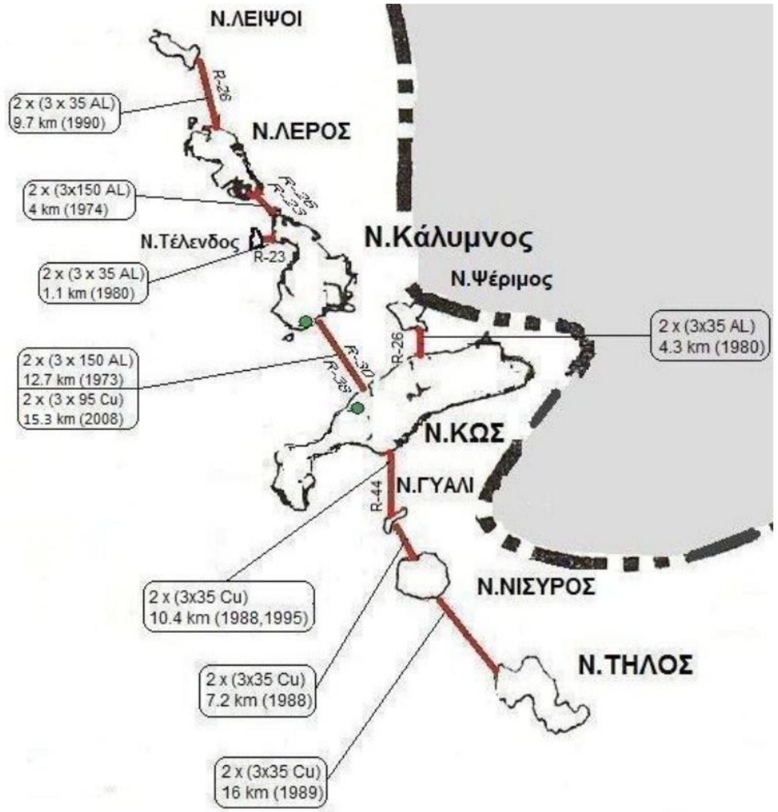
The reality in our island Nisyros

Water consumption
Domestic: 110 000 m^3/y (includes visitors)
Agricultural: 40 000 m^3/y (includes livestock)
Industrial: 600 m^3/y

During summer months
Desalination: 24 000 m^3
Conveyance: 20-40 000 m^3

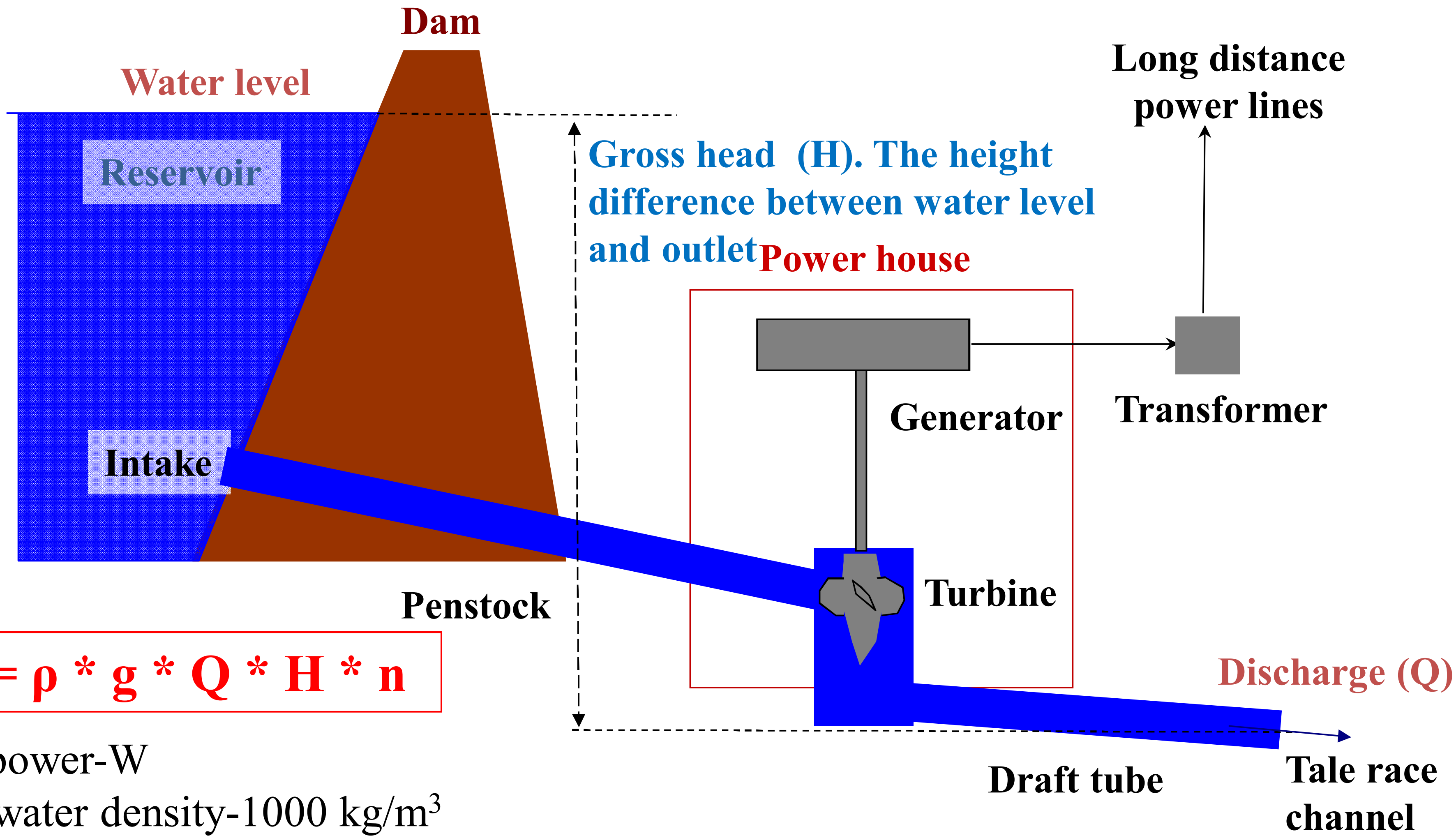
There is unexploited geothermic field with potential of about 2 MW

Electric energy power plant
Connected with other islands (population: ≈ 60000 people
Installed electric power: ≈ 69.6 MW
Electric energy produced: 218 GWh/y
Peak electric energy demanded : 57.3 MW



How can I storage water and electricity for later use?

Main elements of a hydroelectric project

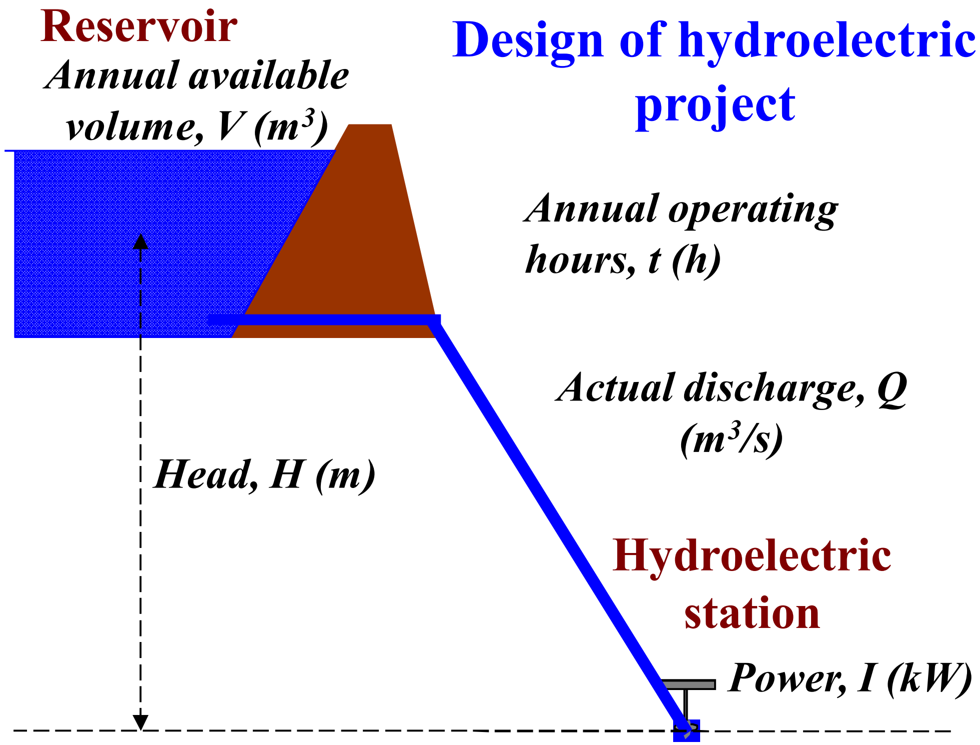


$$I = \rho * g * Q * H * n$$

I: power-W
ρ: water density-1000 kg/m^3
g: acceleration due to gravity-9.81 m/s^2
Q: discharge-m^3/s
H: head-m
n: efficiency-dimensionless

$$I\ (kW) = 9.81 * Q\ (m^3/s) * H\ (m) * n$$

Design of hydroelectric project



Mean annual actual discharge

$$Q\ (m^3/h) = V(m^3)/t(h)$$

$$Q\ (m^3/h) = Q(m^3/s) * 3600$$

$$Q\ (m^3/s) * t(h) = V(m^3)/3600$$

Annual electric energy calculations

$$E\ (kWh) = g * n * H\ (m) * Q\ (m^3/s) * t(h)$$

$$E\ (kWh) = \frac{g * n * H\ (m) * V(m^3)}{3600}$$

$$E\ (kWh) \approx \frac{n * H\ (m) * V(m^3)}{367}$$

Power (I) and Energy (E)

$$I = \rho * g * n * H * Q$$

I: power (W)
ρ: water density 1000 kg/m^3
g: acceleration 9.81 m/s^2
n: efficiency dimensionless

$$\mathbf{I\ (kW) = g * n * H\ (m) * Q\ (m^3/s)}$$

$$\mathbf{E\ (kWh) = I\ (kW) * t\ (hr)}$$

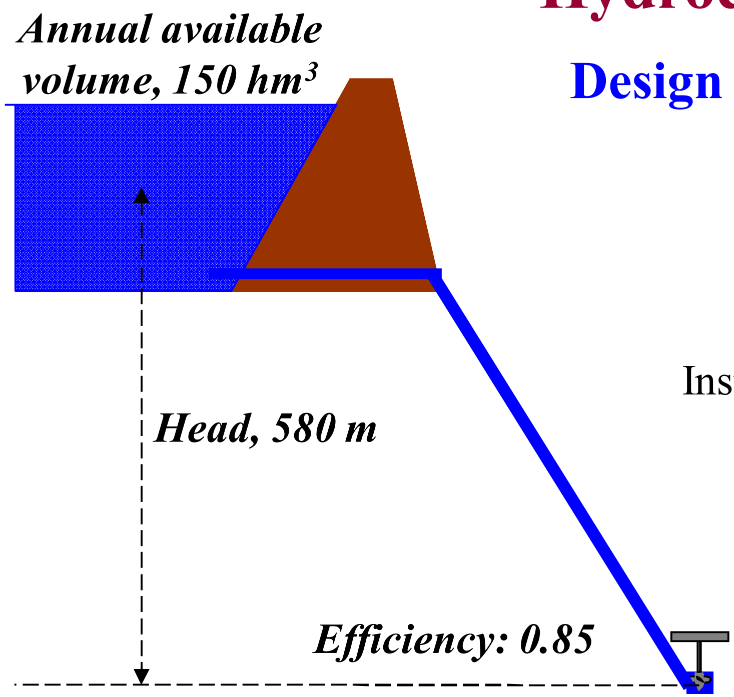
Example (using Plastiras' data)

Annual available volume: ***150 hm³***
Head: ***580 m***
Efficiency: ***0.85***
Potential annual electric energy: ***201.5 GWh***

Operating hours	Percentage of time that operates	Actual Discharge (m³/s)	Installed power capacity (MW)
1500	0,17	27,8	134,3
3000	0,34	13,9	67,2
4500	0,51	9,3	44,8
8760	1,00	4,8	23,0

Hydroelectric power plants

Design of hydroelectric project



Case 1

Actual discharge: **4.8 m^3/s=17.280 m^3/hr**

Installed Power=9.81*4.8 m^3/s*580 m*0.85 ≈**23000 kW=23 MW**

Annual operating hours=
150.000.000 m^3/(17.280 m^3/hr)**≈8760 hr per year**

Annual produced electric energy=
23 MW*8760 hr =**201.500 MWh=201.5 GWh**

Case 2

Actual discharge: **27.8 m^3/s=100.080 m^3/hr**

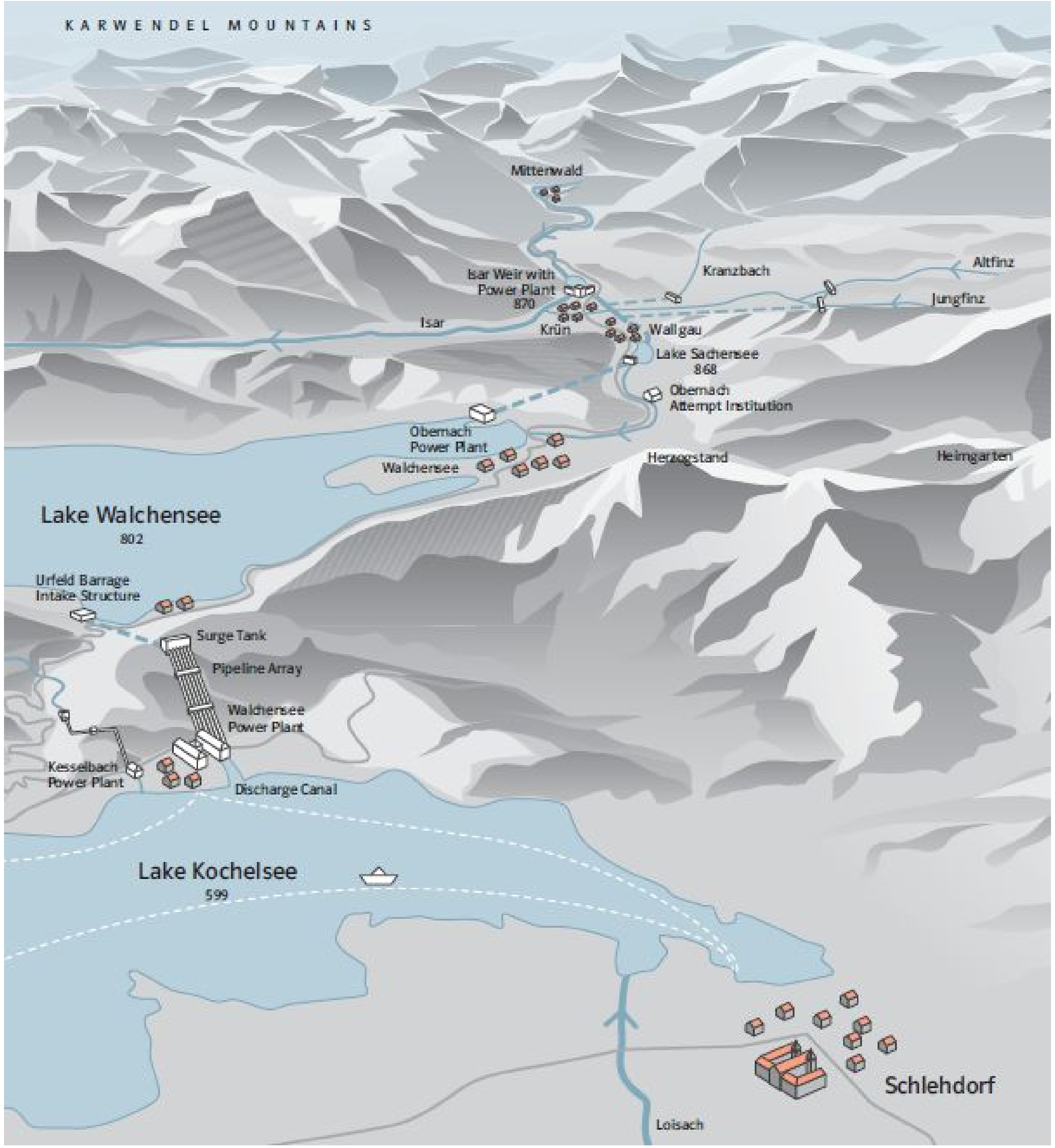
Installed Power=9.81*27.8 m^3/s*580 m*0.85 ≈**134.300 kW=134.3 MW**

Annual operating hours=
150.000.000 m^3/(100.080 m^3/hr)**≈1500 hr per year**

Annual produced electric energy=
134.3 MW*1500 hr =**201.500 MWh=201.5 GWh**

Hydroelectric power plants

Walchenseekraftwerk



With an installed capacity of **124 MW** it is one the largest of its kind in Germany. The storage power station uses the head of about **200 m** between the Walchensee (acting as the upper reservoir, at 802 m above sea level) and the Kochelsee (599 m a.s.l.) to generate electricity. Through **six 450 m pipes** connecting the two natural lakes, the water flows to the turbines of the hydroelectric plant **four Pelton** water turbines with single-phase generators and **four Francis** water turbines with three-phase generators and then into the Kochelsee. Because of the resulting variation in water level, neither lake freezes fully in the winter: the ice in each of the bays is thin and should not be walked upon. The natural outflow of the Walchensee at Niedernach—over the Jachen to the River Isar—is blocked by a weir, but the natural inflow to the lake is still insufficient to provide enough water for the operation of the storage power station, so the waters of the Ribach river are also used.

Hydroelectric power plants

Walchenseekraftwerk

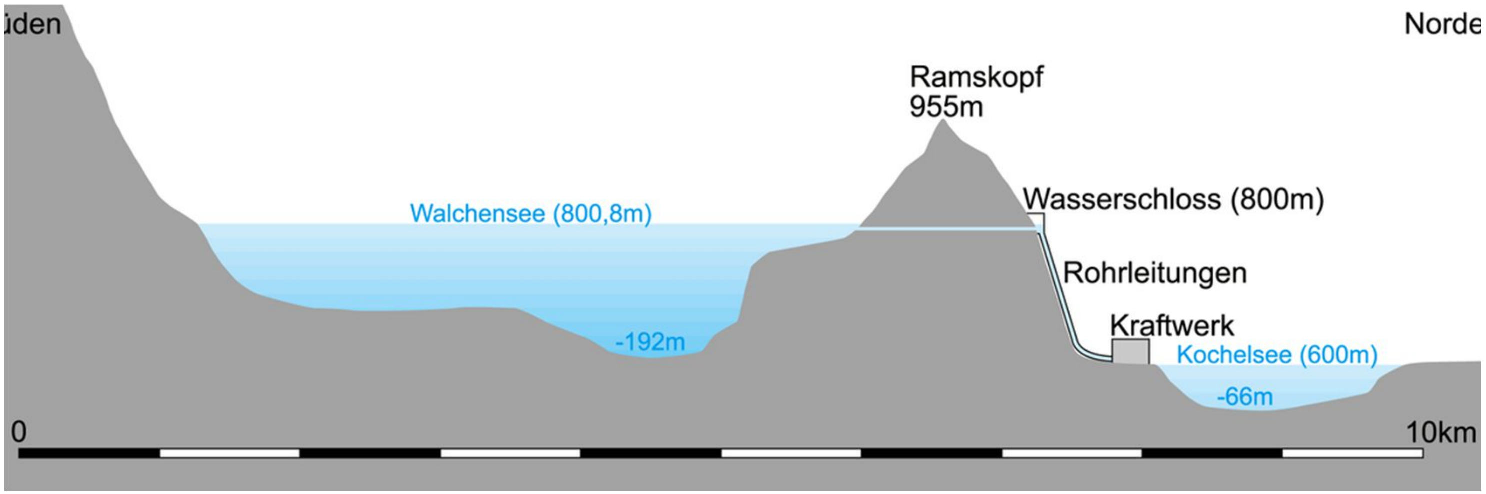
Technical data (from leaflet)

Installed capacity: **124 MW**
Annual energy production: **300 GWh**
Drop (head): **200 m**
Discharge: **84 m³/s**

Our calculations

Operating hours per year=300.000 MWh/124 MW=
2420 hr per year
27.5% of the year

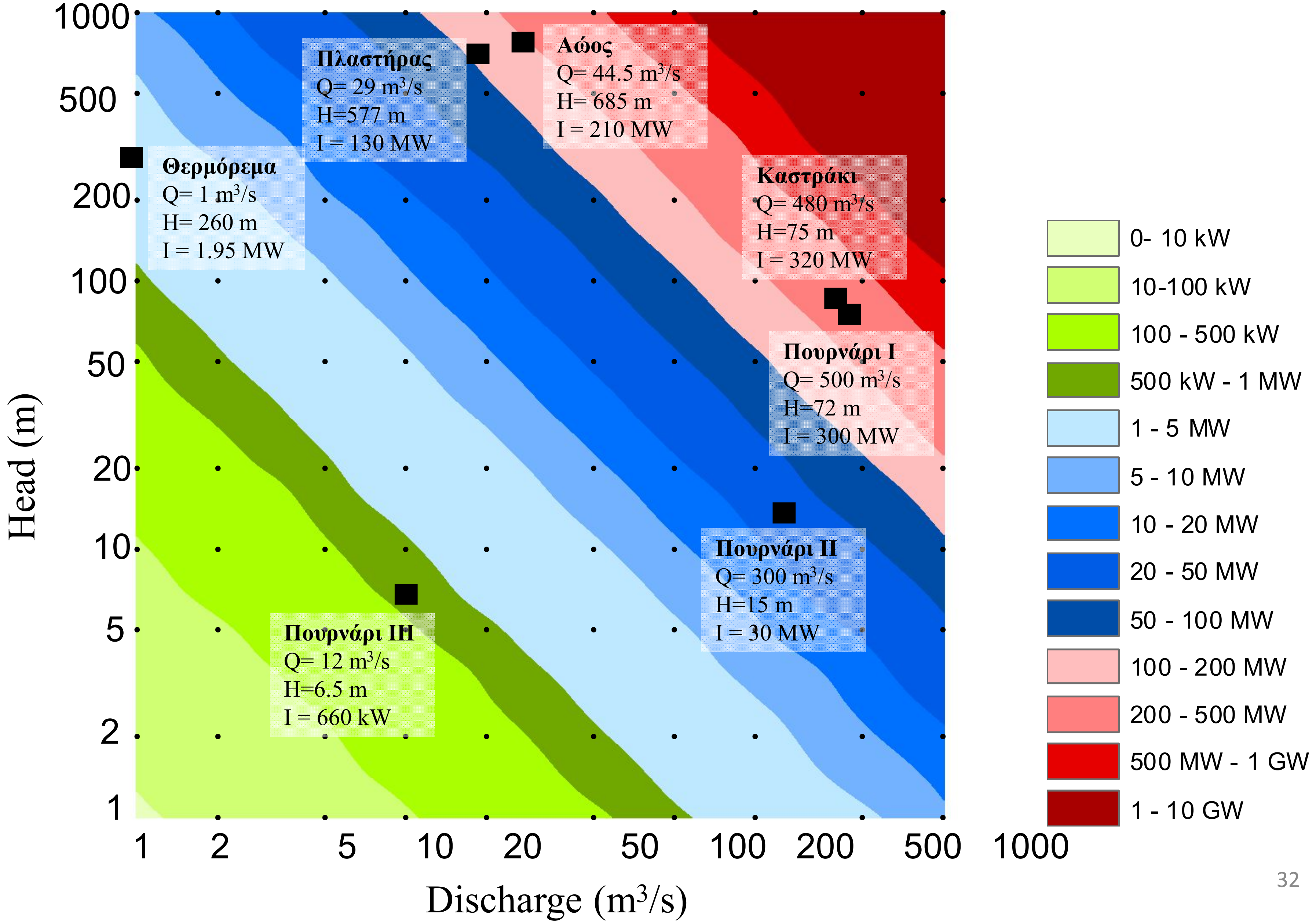
124.000 kW=9.81*84 m³/s*200 m****n***
=>***n (efficiency)=0.75***



Hydroelectric power plants

Head-Discharge-Power of hydroelectric projects in Greece

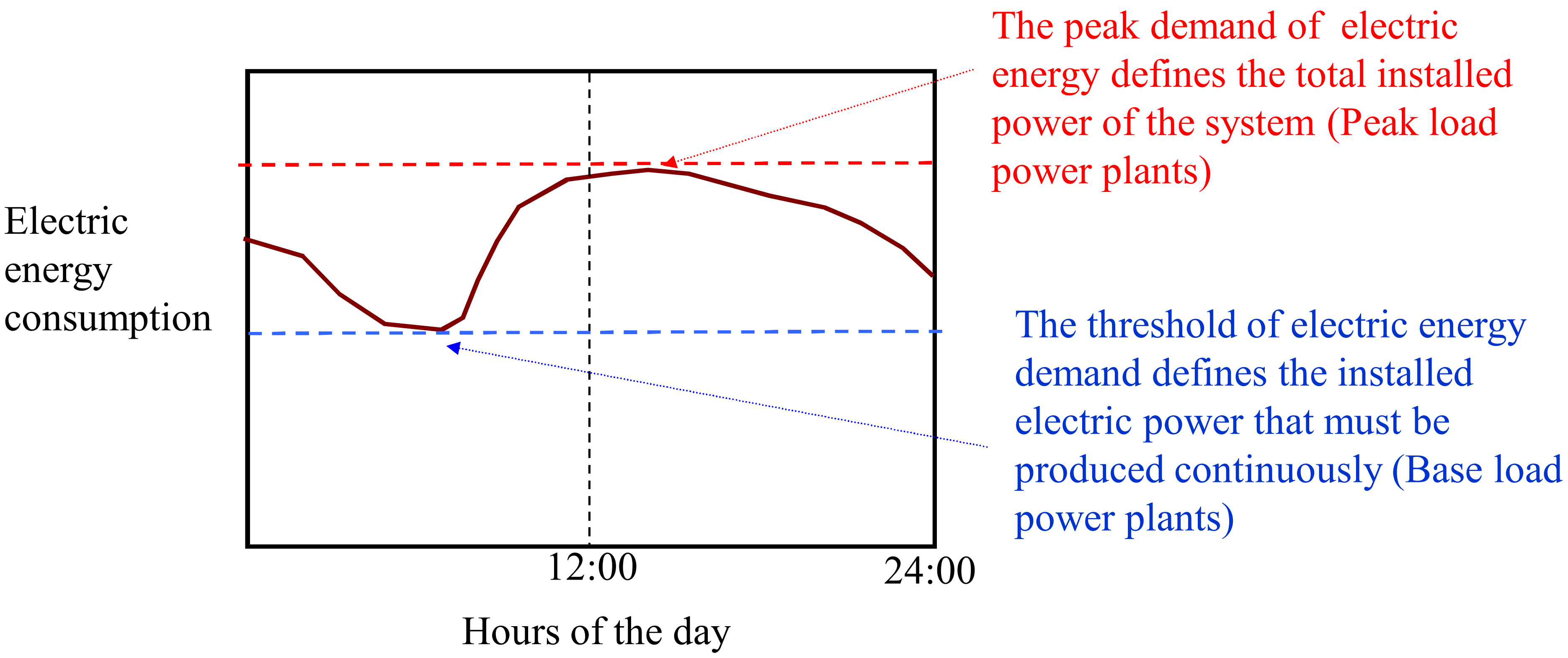
Theoretical power



Electric energy management

The feeding of electrical grid with energy has two main limitations:

- The grid must be fed with the same amount of energy that is consumed, thus the electric energy production must be continuously reformed
- The time span for alteration of energy production, is different for various power plant. This time is several hours for the thermal stations (coal and natural gas) and minutes for hydroelectric stations

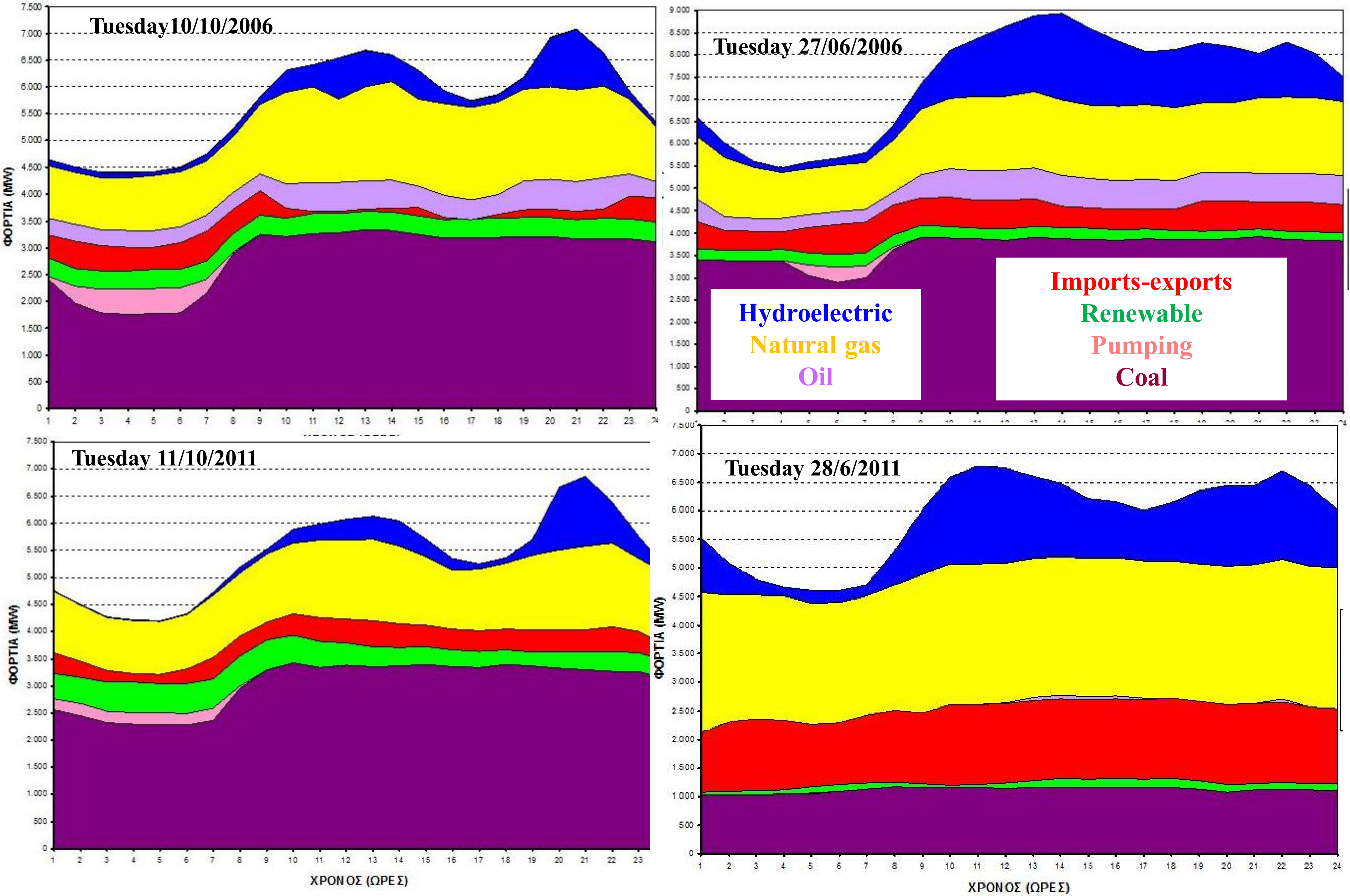


Electric energy management

Hourly energy power (MW) in Greece for specific days

Fall

Summer



Electric energy management

Electric energy production schedule in Greece:

- For next months. Monthly consumption of electric energy is estimated, using existing data. At this time step, agreements for energy trading with the neighboring grids, are done.
- For next days. Daily and hourly consumption of electric energy is estimated, using existing data and weather predictions or special events. At this time step the base load power plants (mainly lignite-coal) can adapt the produced energy to demand.
- For next hours. At this time step the thermal power plants that use natural gas, can adapt the produced energy to demand quite quickly
- For next minutes. At this time step **only hydroelectric plants** can adapt the produced energy to demand almost instantly.

The hydroelectric projects mainly are used in peak loads, so the produced energy is more valuable

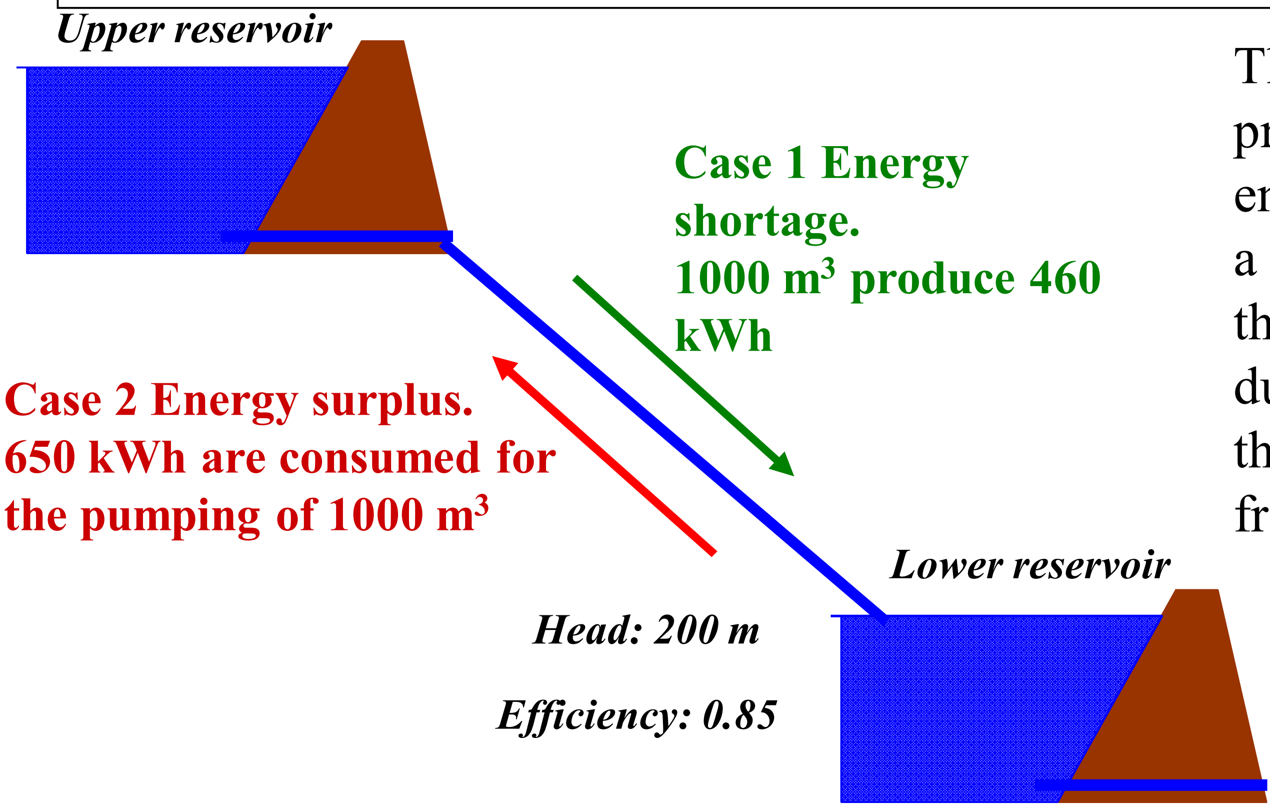
Electric energy management

Storage of electric energy. Pump-storage systems

Case 1 Energy shortage in the electric network. *There is need for energy production.*
1000 m^3 are transported from the upper to lower reservoir and produce about **460 kWh**

Case 2 Energy surplus in the electric network. *There is need for energy storage.*
1000 m^3 are pumped from lower to upper reservoir and about **650 kWh** are consumed

> In the electric networks the energy can not be stored and also the base units (coal, nuclear) can not interrupt their function immediately in case that there is not energy demand (for example during night hours).



The pump storage systems practically store the surplus energy of the network, loosing a 30%. Taking into account that the price of energy is half during surplus situations, there is a significant profit from this procedure

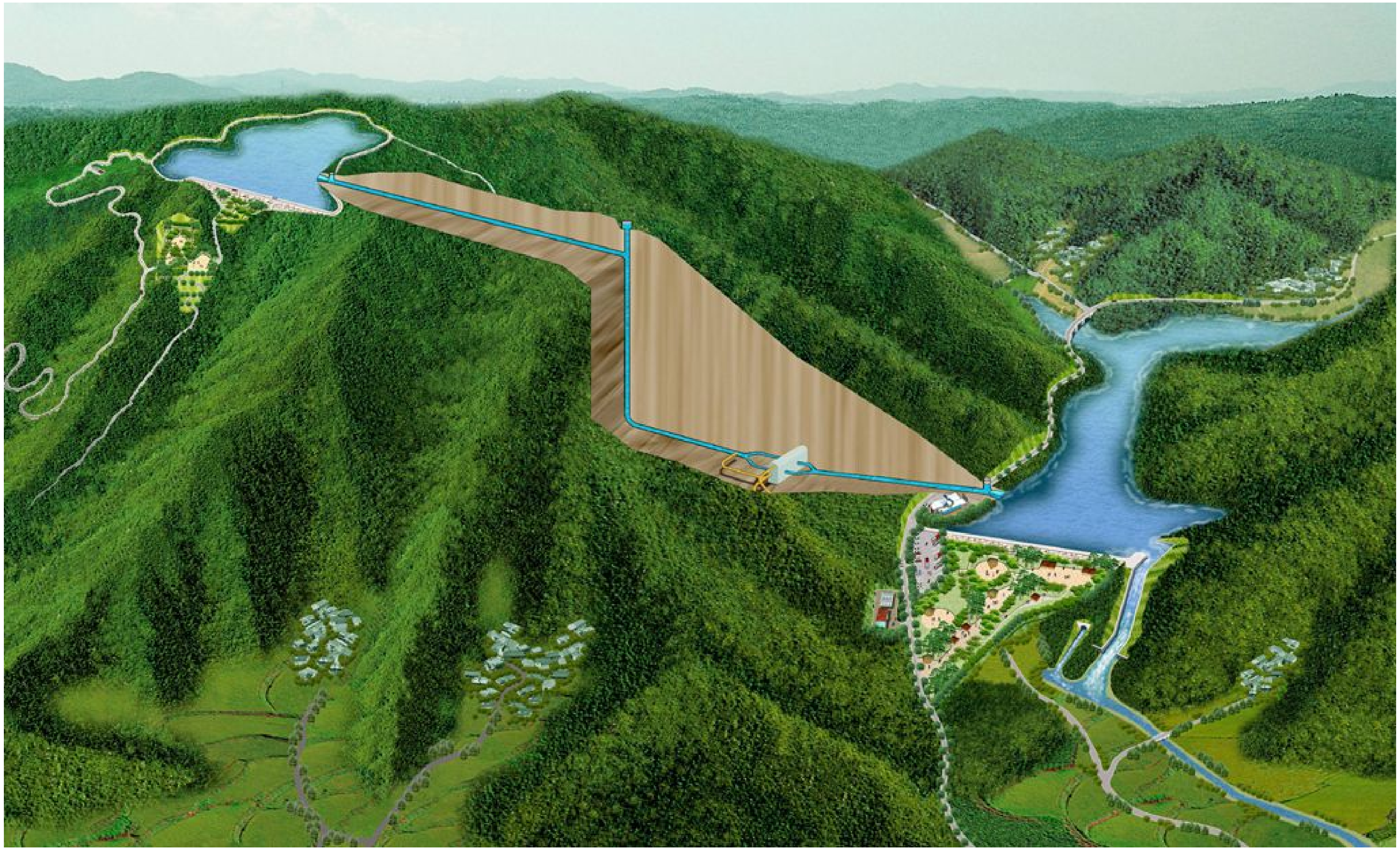
Electric energy management

Pump storage systems

Upper reservoir: Kamihikawa
Capacity 11.5 hm^3

Lower reservoir: Kazunogawa
Capacity 11.5 hm^3

Hydraulic head: 779 m
Pump-generators: 3 x 400 MW reversible Francis



Electric energy management

Pump storage systems

The first pump storage project that uses sea water, there is located in **Okinawa, Japan** and operates since 1999. Its installed power capacity is **30 MW**.

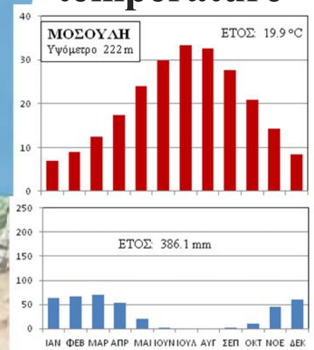
There is an upper artificial reservoir, about 600 m away from the seashore and **150 m** above the sea level with an effective storage capacity of **564.000 m³**, and the sea operates as the lower reservoir

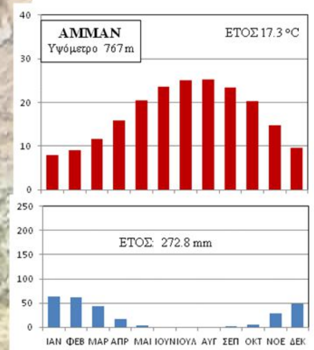
The effective head is **136 m** and the maximum discharge **26 m³/s**

Appendices

Early civilizations and water

Mean monthly precipitation and temperature





- During Neolithic period and after the last Ice Age, groups of people concentrated in a zone of hills extended from Syria-Palestine to the foot of Taurus and Zagros mountains, an area that is called **Fertile crescent**. In this area the winter rainfalls favored the natural grow of wild grains, such as barley and wheat.
- About 9000 BC, when the climate had almost been stabilized, these first residents came down from the hills to begin early cultivation of grains and cereals. These communities developed the first agricultural methods, animal domestication and constructed the first small hydraulic works.
- The population began to increase and was spread to nearby alluvial valleys of large rivers during a period of 7500 to 4500 BC so called as the Neolithic revolution

Early civilizations and water

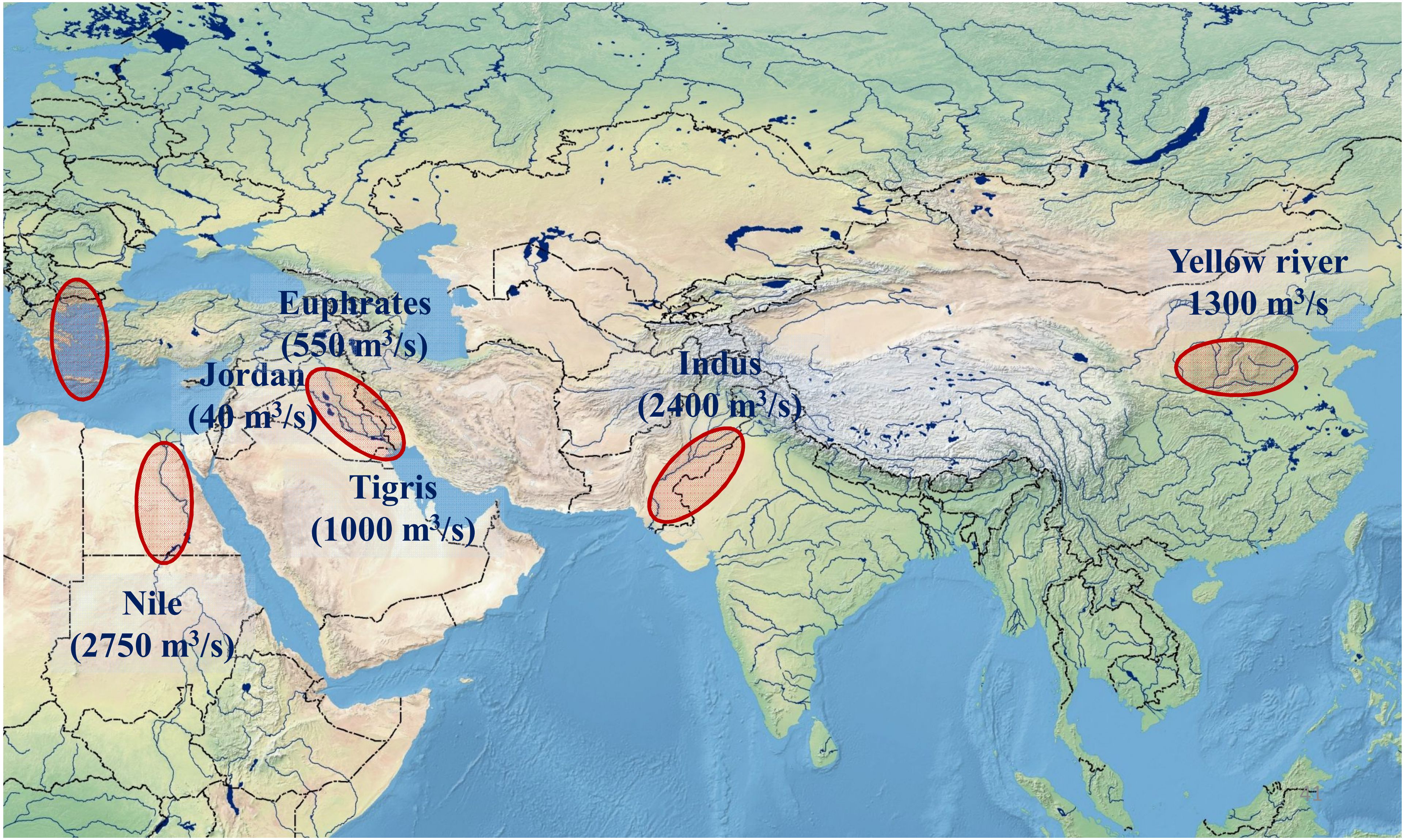
Ancient civilizations and hydrologic regime (mean annual discharge)

Minoan Civilization, Mycenaean Greece

Mesopotamia (Sumer, Acadian, Babylonian, Assyrian)

The Indus Valley Civilization (Harappa)

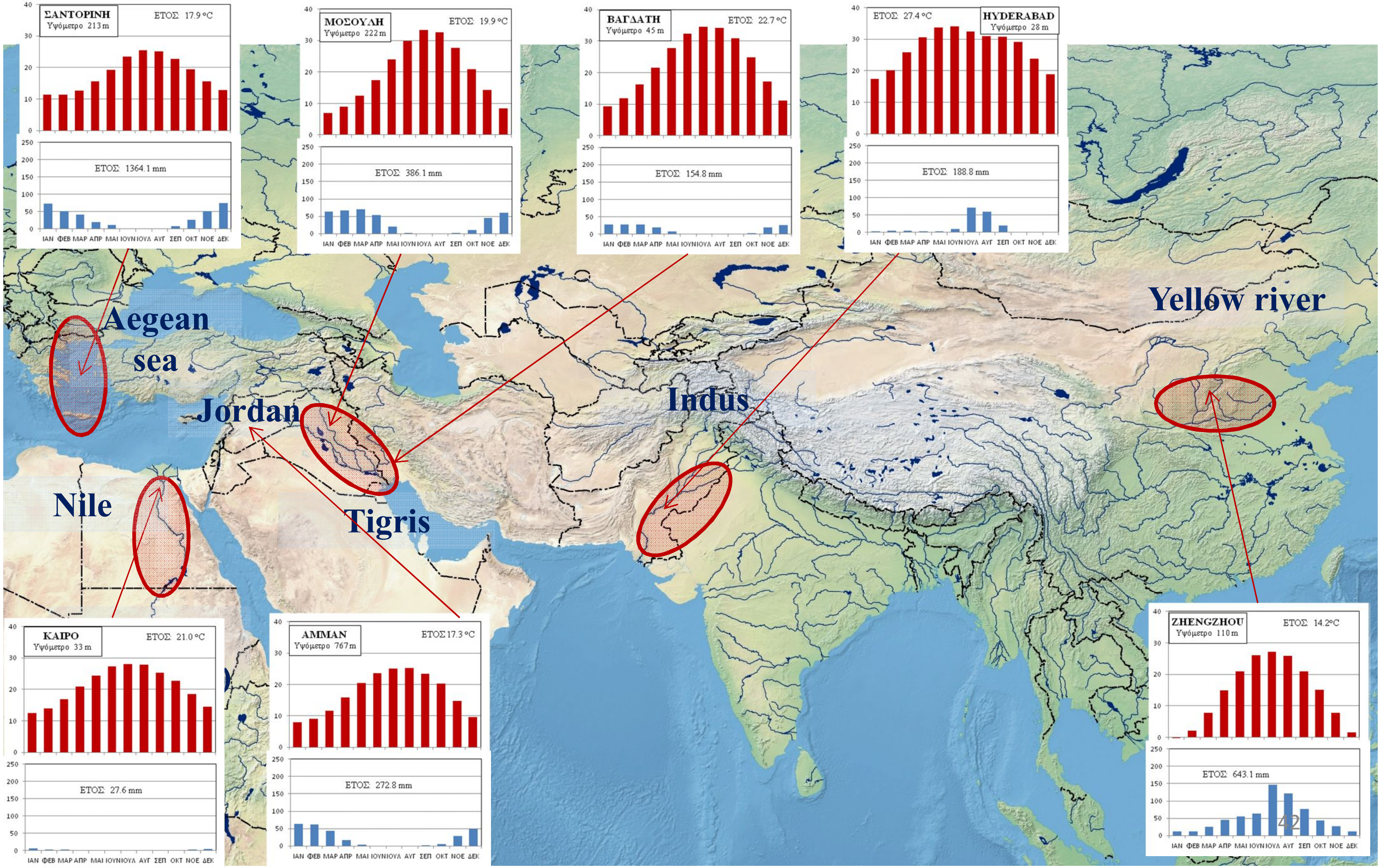
The Chinese Civilization



Early civilizations and water

Ancient civilizations and climatologic regime

Mean monthly precipitation and temperature

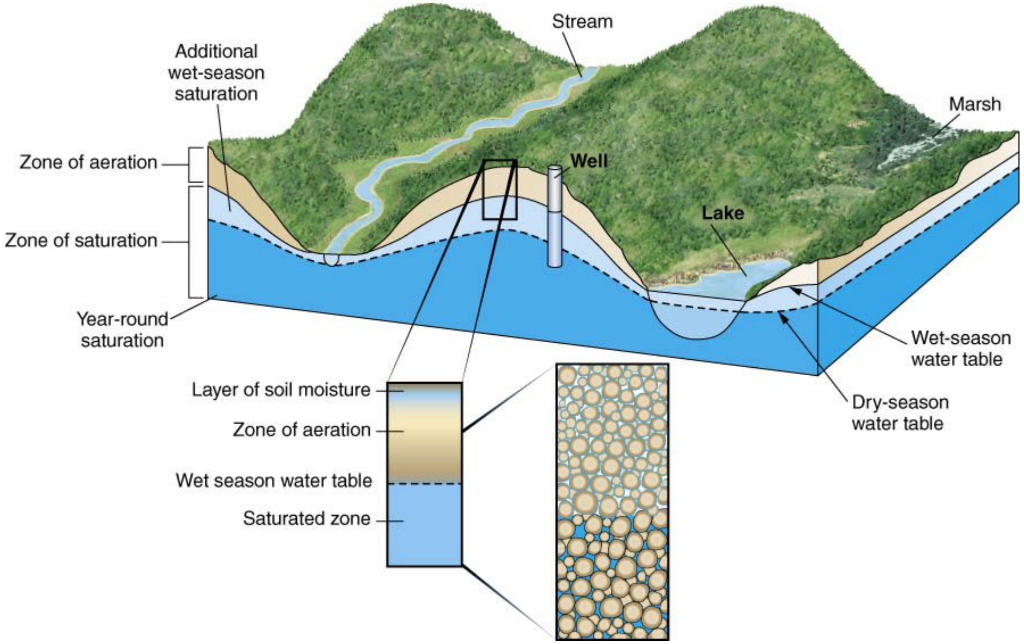


Main water control procedures and related hydraulic works

Initially the water was used at his source (river, spring, lake etc) or was transported in small quantities by hands. The necessity to control the water came with the development of the first civilizations. The main procedures for water control are given below with the related hydraulic works:

1. **Catchment** from the sources. Ground water exploitations works (wells, qanats), dams, water intakes from rivers and springs.
2. **Conveyance** of water to the site of demand (a procedure that in most cases includes **lifting** of water). Canals, pumping devices, distribution networks.
3. **Storage** of water for later use (next season or year). Cisterns, reservoirs.
4. **Protection** from water (floods). Levees, drainage networks, reservoirs.
5. **Waste water** management. Pits, networks.
6. Ensuring river **navigation.** Canals.
7. Exploitation of **water power.** Water mills.
8. **Cleaning** of potable water. Sand filters.
9. **Sediment** management. Dredging, dams.

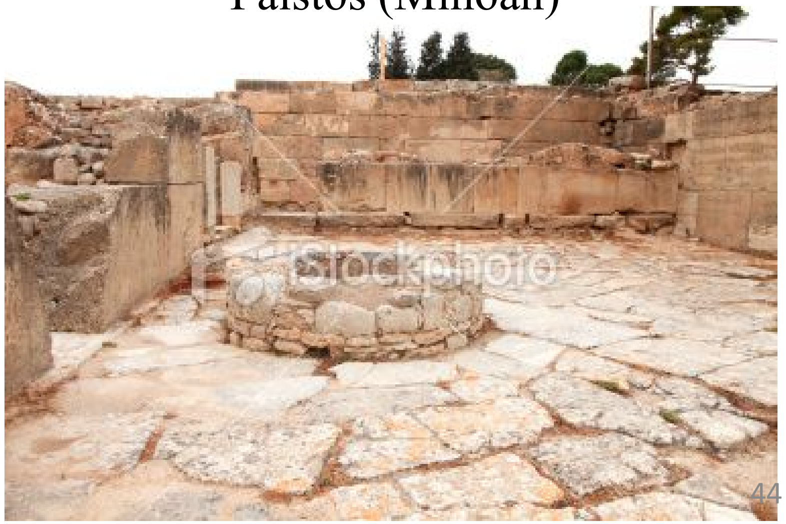
Water exploitation
Wells in unconfined aquifers



Mohenjo Daro (Indus Valley)

Palekastro (Minoan)

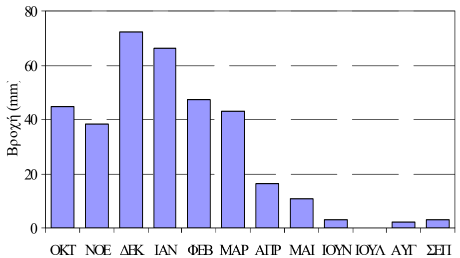
Faistos (Minoan)



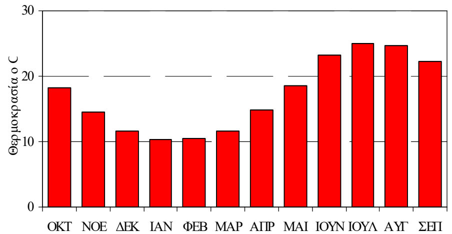
Water exploitation

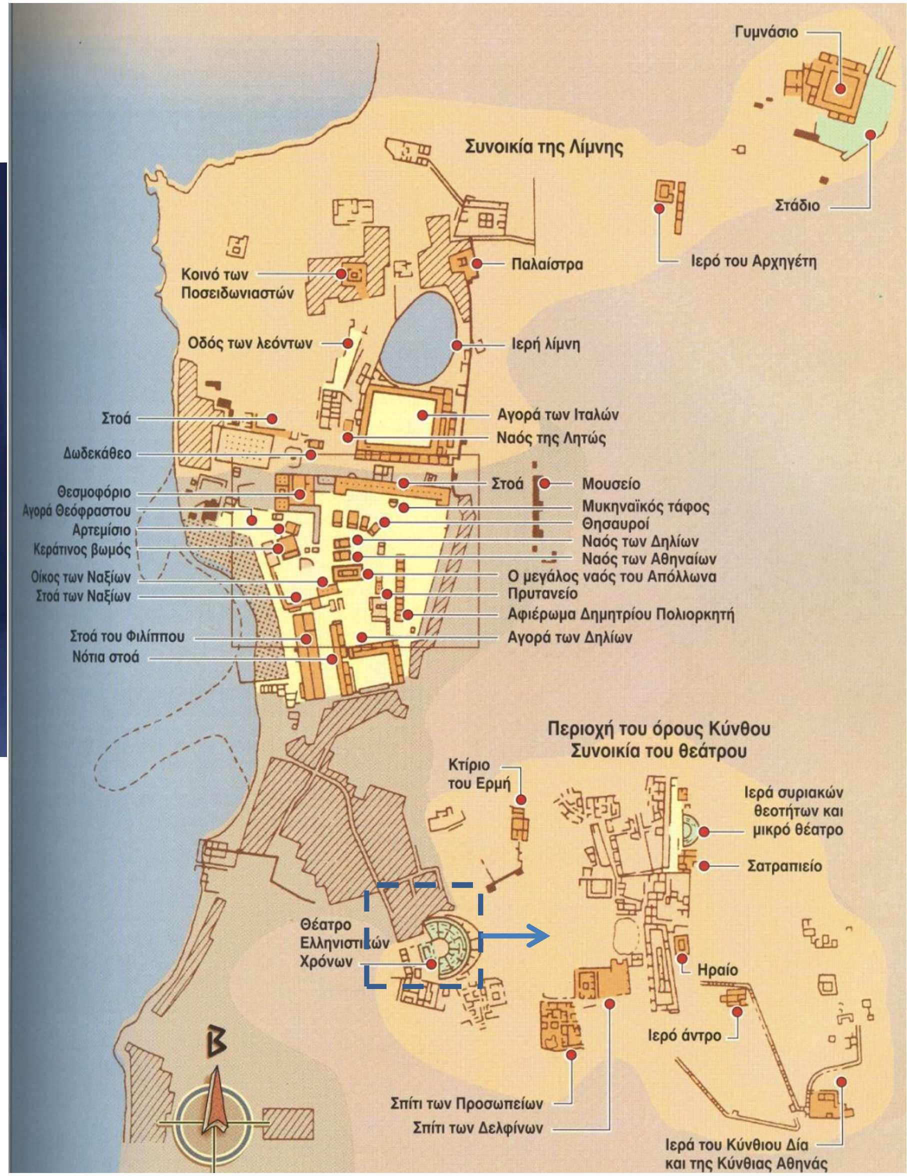
Delos island

Mean annual precipitation: 347 mm



Mean annual temperature 17.1 ºC





Delos island located in the center of Aegean sea and has an area of 3.4 km^2. It was the sacred island of the Greeks and during Hellenistic and Roman period ($4\text{-}1^{th}$ century BC) it was very crowed (archeologists estimate about 30000 residents). In antiquity there were wells and many cisterns to collect rain water.

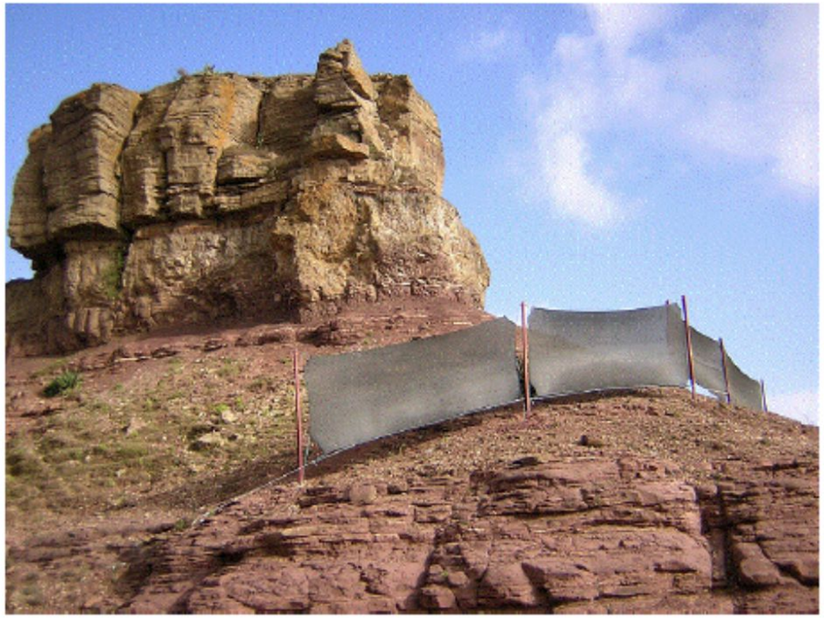
Water exploitation

Cistern of theater at Delos island

Dimensions: 22.5×6×3 m
It constructed in 3th century BC with the theater. It was covered with a wooden roof and collected the rain water of the koilon and orchestra (total area about 5000 m^2).

Water exploitation

Desperate for water? Fog collectors



Fog collectors in Yemen

70 cm by 70 cm Tal Ya tray has the perfect size for pepper plants. Its cost is **\$1 per plant**. When a change of 12 ^{o}C occurs, dew forms on the tray, which funnels the dew and condensation straight to the plant. The trays do not degrade in the sun or after the application of fertilizers. They have an estimated life time of **10 years**.

Fog collection potential

Several measurements in various locations in the world have shown annual average values from 1-5 l/m^2/day and seasonal average values from 3-70 l/m^2/day

Cost of water using fog collectors

Although is difficult to calculate the cost in a project in Chile was estimated about 1\$ per m^3 for collection and another 1\$ per m^3 for transportation to the end users

The primitive hydraulic works design

Three ancient engineering problems

What is the annual water quantity that is expected to be collected by the roof?

Operation and optimization of complex hydrosystems

The Athens water supply system

Evinos
Annual inflow: 320 hm^3
Reservoir capacity: 104 hm^3

Evinos: High Spill

Mornos
Annual inflow: 320 hm^3
Reservoir capacity: 645 hm^3

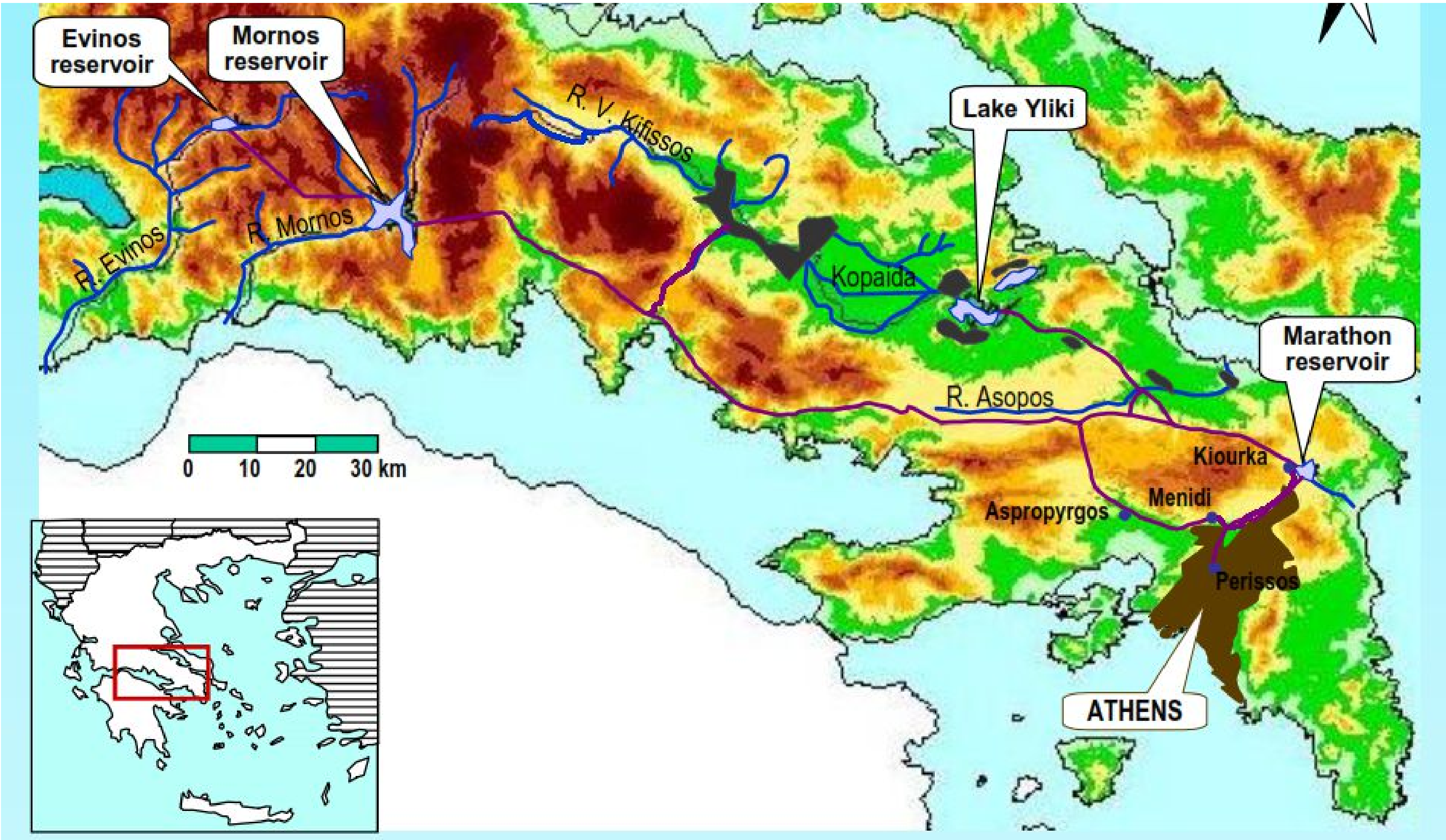
Annual demand: 430 hm^3

Yliki
Annual inflow: 350 hm^3
Reservoir capacity: 587 hm^3

Yliki: High Leakage

Yliki: Need for Pumping

Marathonas
Annual inflow: 20 hm^3
Reservoir capacity: 40 hm^3



Operating rules

1. Convey water for Evinos to Mornos (to prevent spill)
2. Convey water from Mornos to Athens (there is no need for energy
3. Operate Yliki when the total storage of the system is low (in order to avoid leakage)
4. Matathonas is used as safety reservoir (cover the demand of 1 month)

Present-day situation

Water Environment

Variables

Precipitation

Discharge

Evaporation

Interaction

Variation of hydrometeorological variables in space and time → Disturbances to hydrosystems

Water quality degradation ← (back to variation of variables in space and time)

Human society

Main water uses

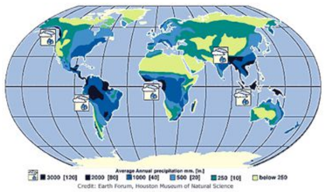
Domestic

Agricultural

Industrial

Water related problems

Unequal distribution of water availability and demand in space and time



Floods

Droughts

Quality

Problems handling

Hydraulic works-Hydrosystems

- ***Study*** (Evaluation of water availability and demand, Design)
- ***Construction*** (Dams, Drainage, Sewage etc)
- ***Management*** (Simulation, optimization)

Philosophy

- Environmental modeling
- Hydrosystem management
- Confrontation of hazards

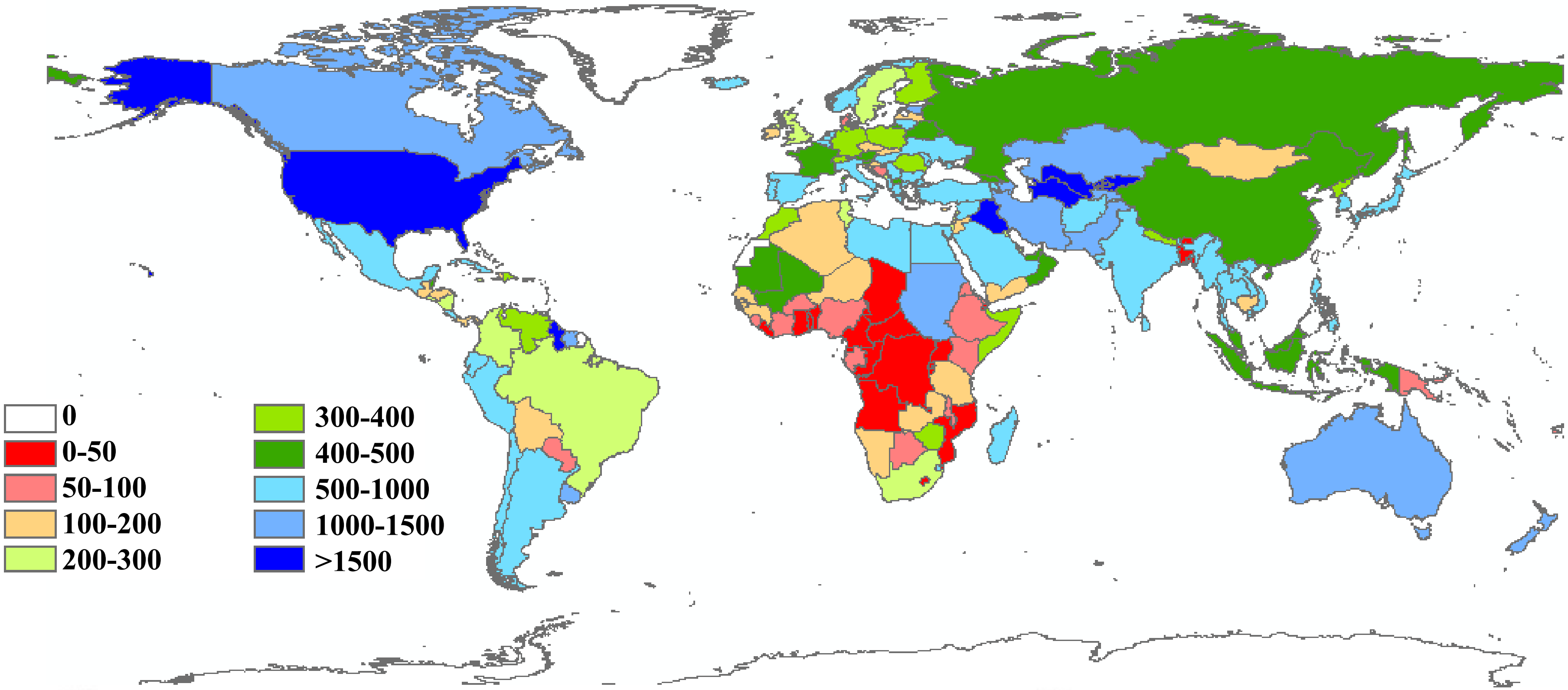
Actions

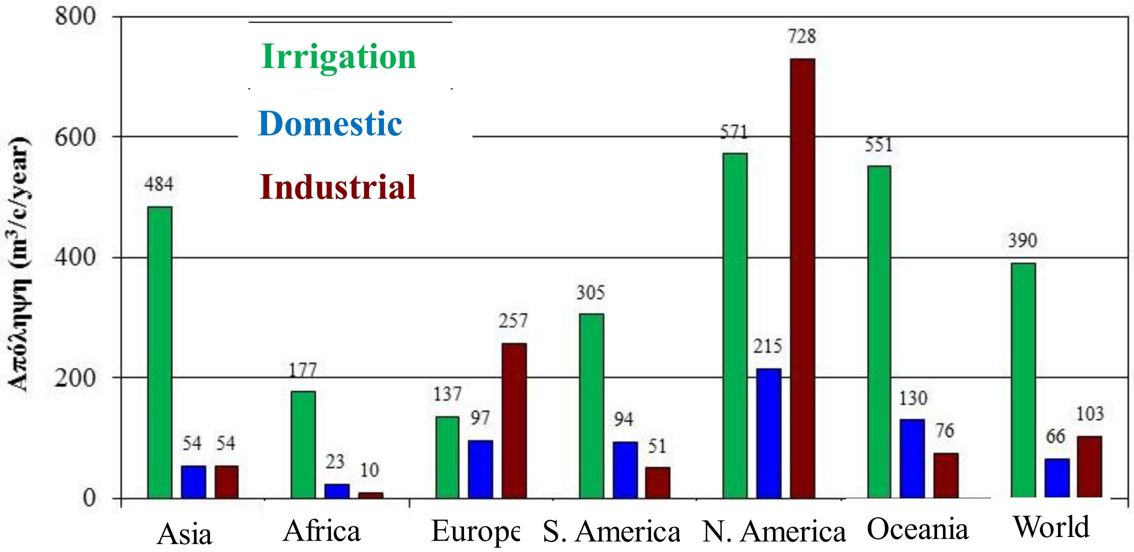
Institutional, Technological, Economical, Social, Environmental

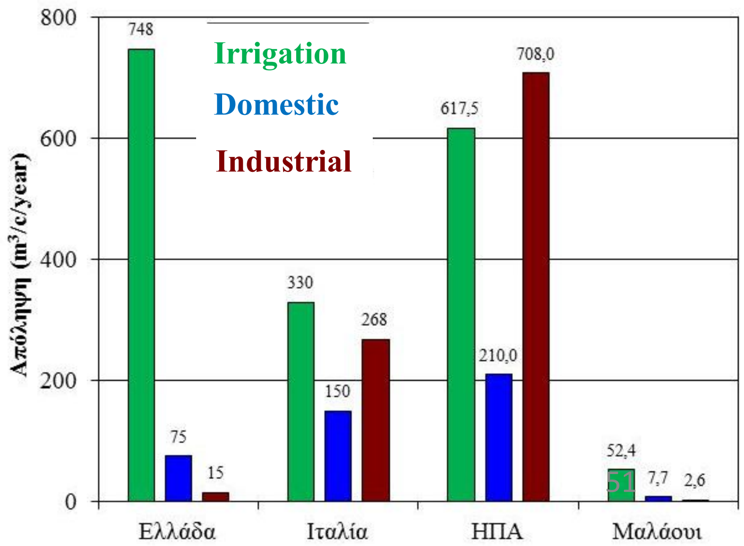
Directives, Water management plants, Flood Risk and hazard maps, Public awareness

Present-day situation

Total water withdrawal (m^3/cap/y)

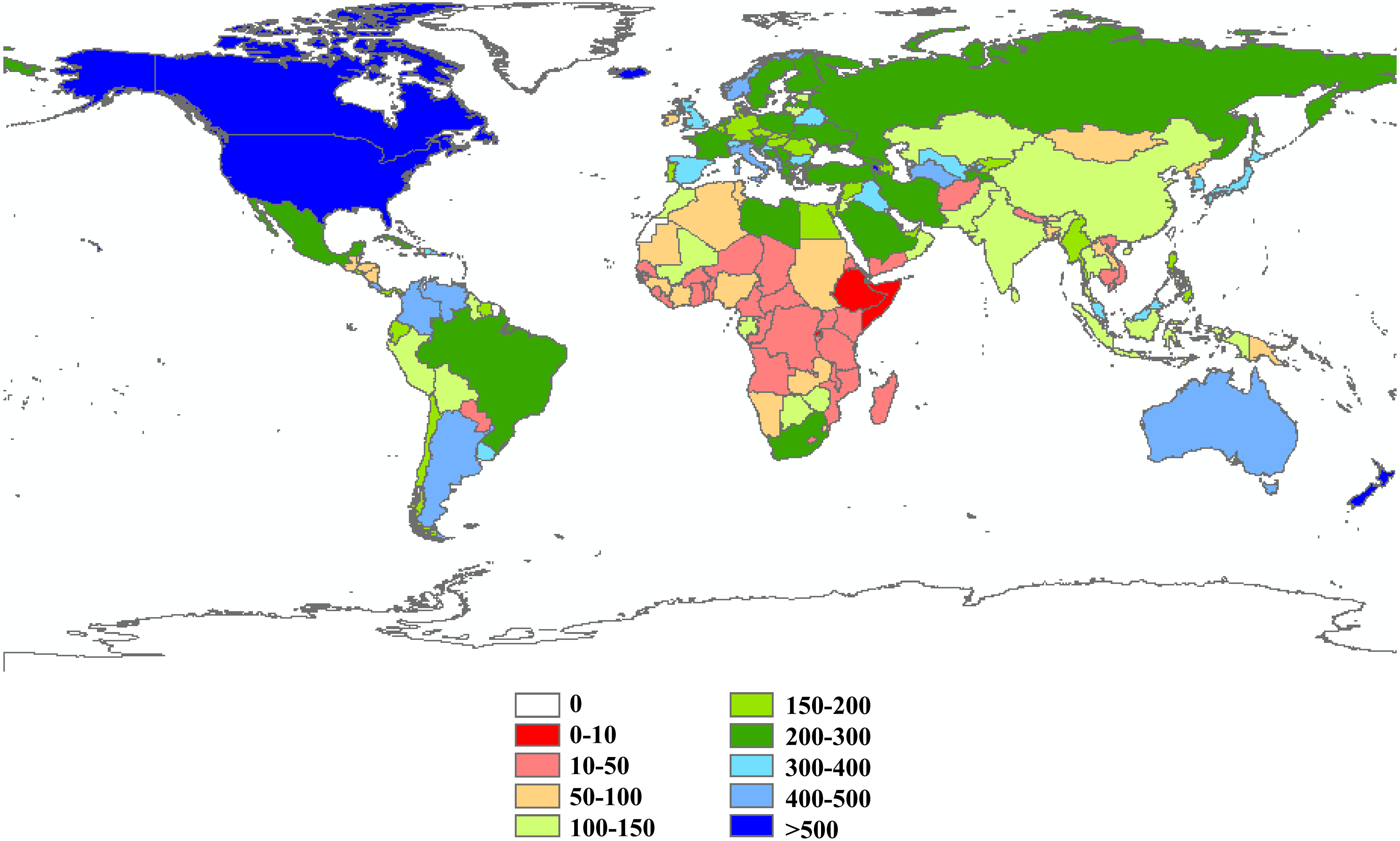






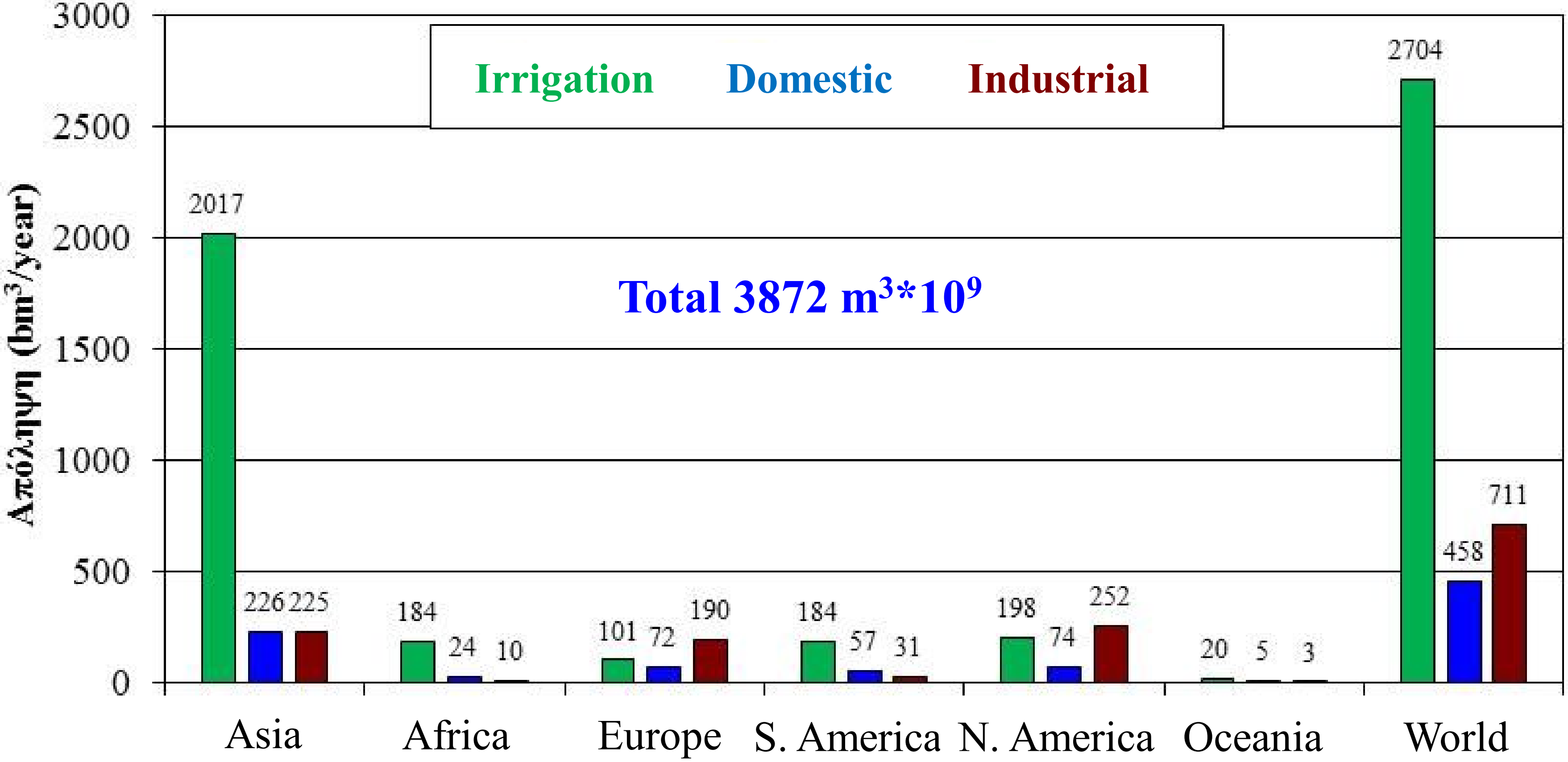
Present-day situation

Domestic use l/cap/d



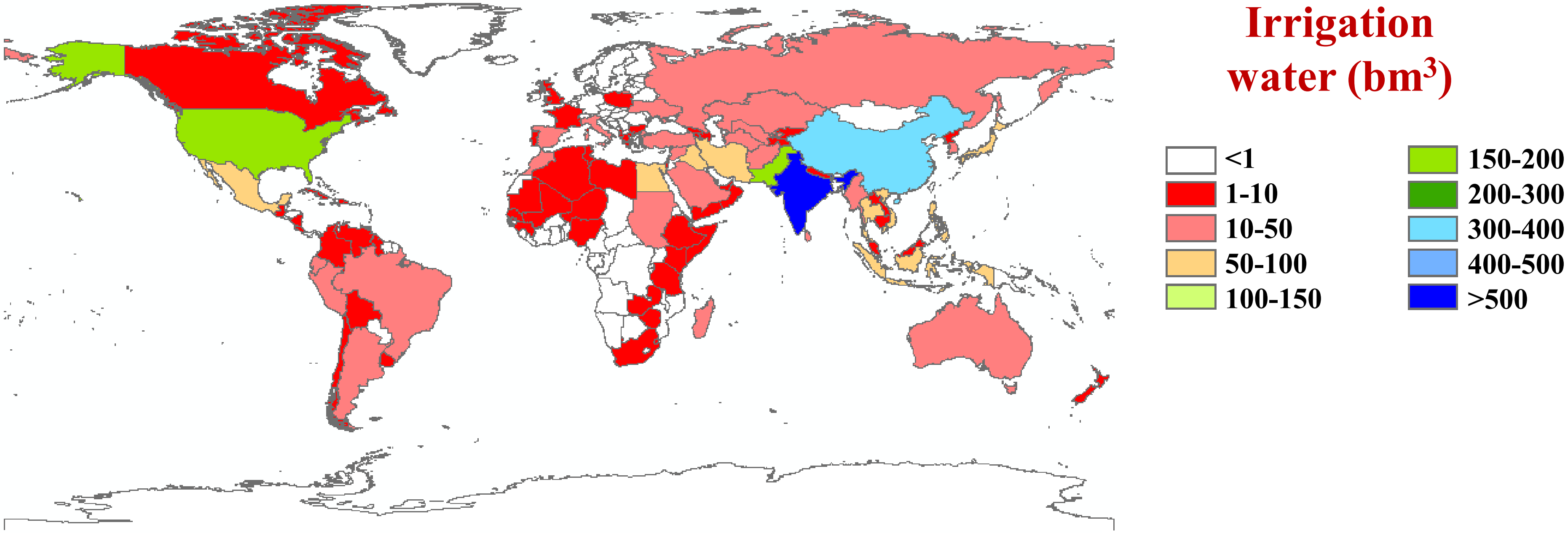
Present-day situation

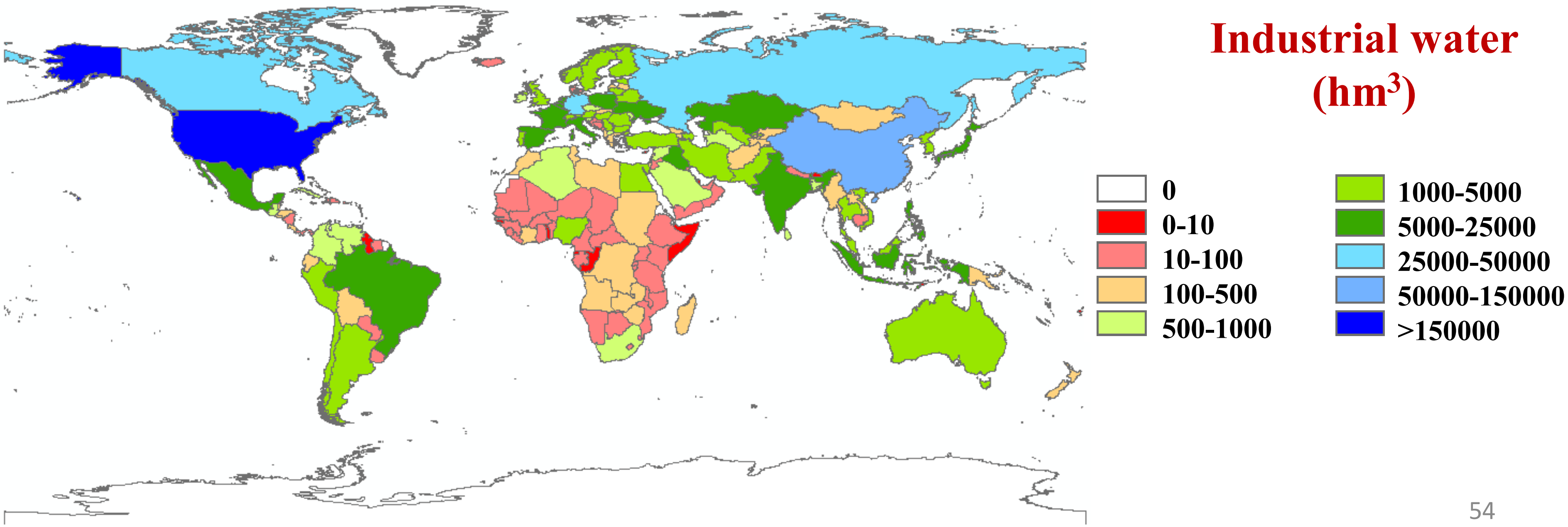
Annual water withdrawal m^3*10^9



Area	Asia	Africa	Europe	S. America	N. America	Oceania	World
Number of countries	50	57	51	48	5	25	236
Population (10^9)	4.16	1.04	0.74	0.60	0.35	0.04	6.93
Area km^2*10^6	30.9	29.4	22.1	20.1	18.7	8.5	129.7

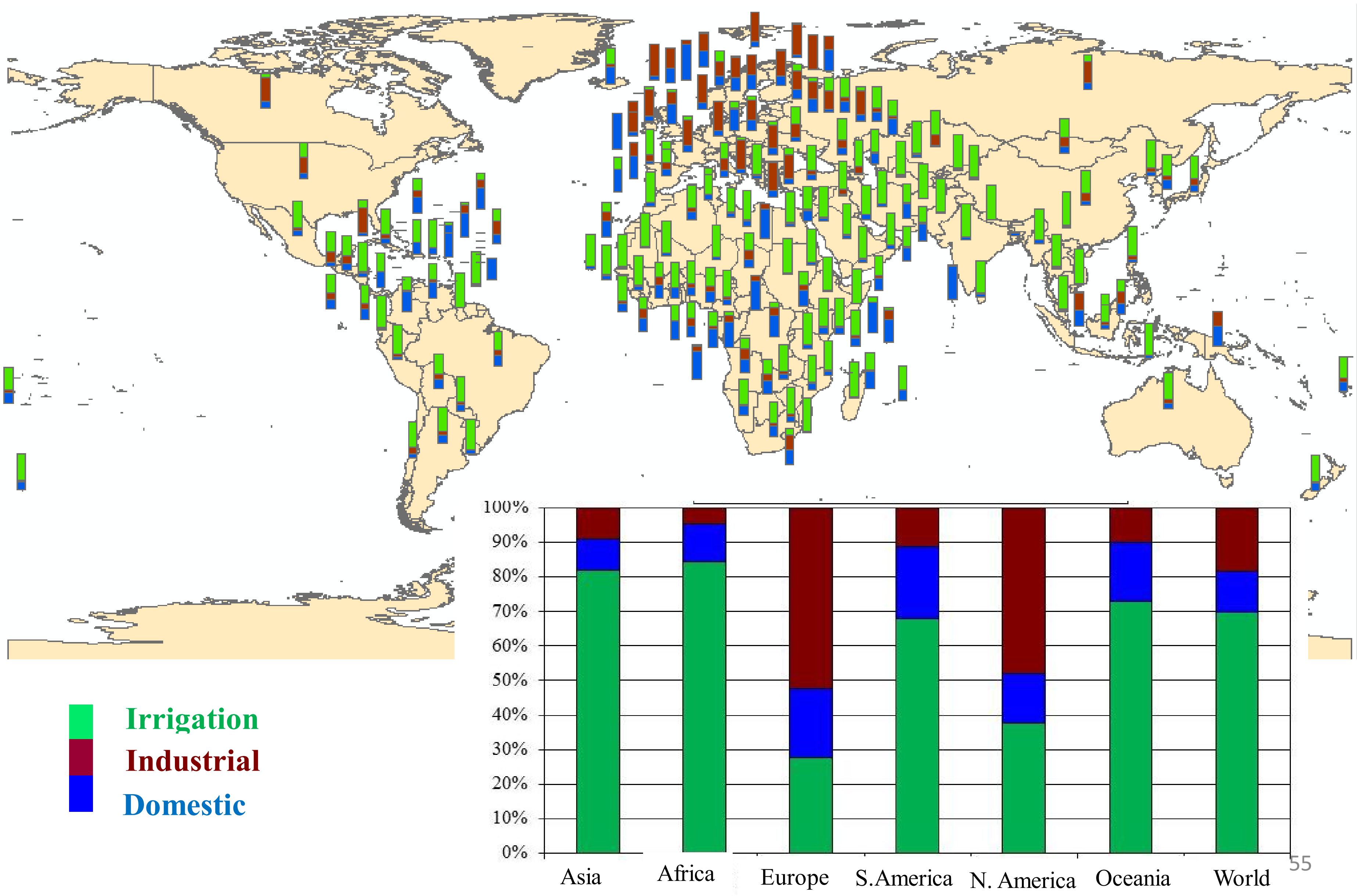
Present-day situation





Present-day situation

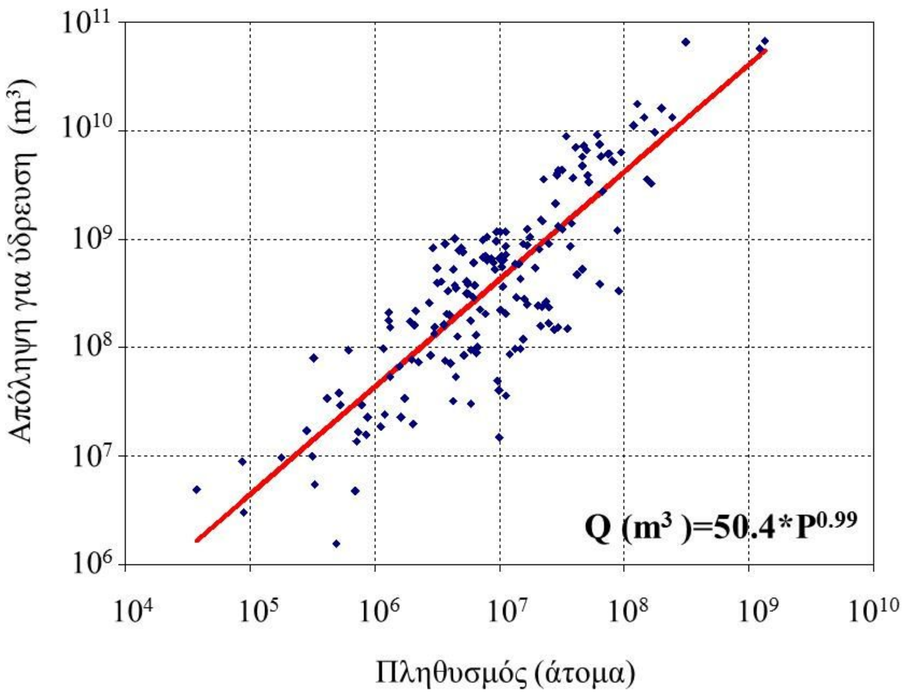
Percentage of water for irrigation, industrial and domestic use



Present-day situation

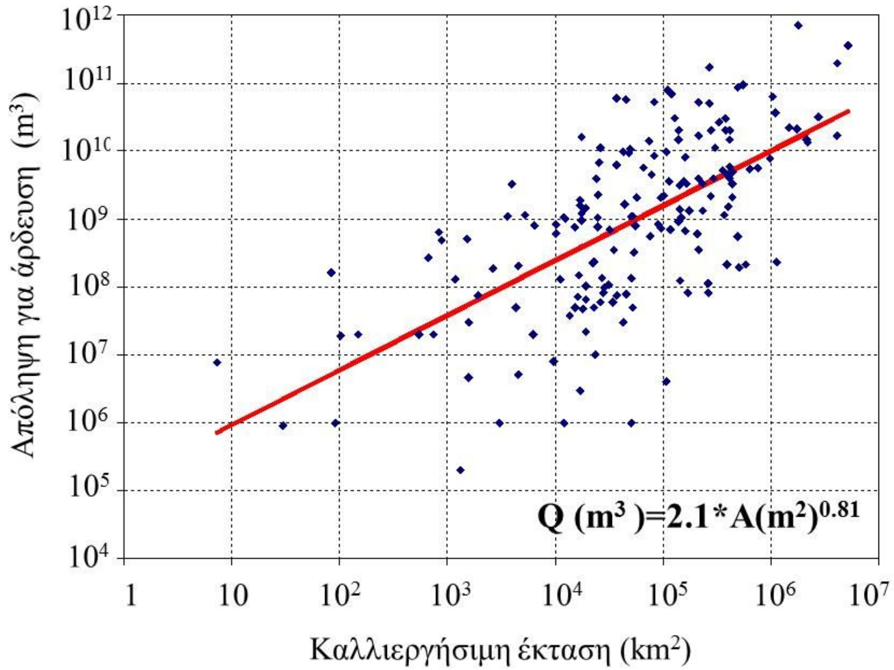
Correlation of water consumption

Domestic use versus population



174 countries

Irrigation use versus cultivated areas



166 countries

Present-day situation

Floods in Bangladesh…

Brahmaputra
Length: 2900 km
Basin: 651334 km^2
Average discharge: 19300 m^3/s

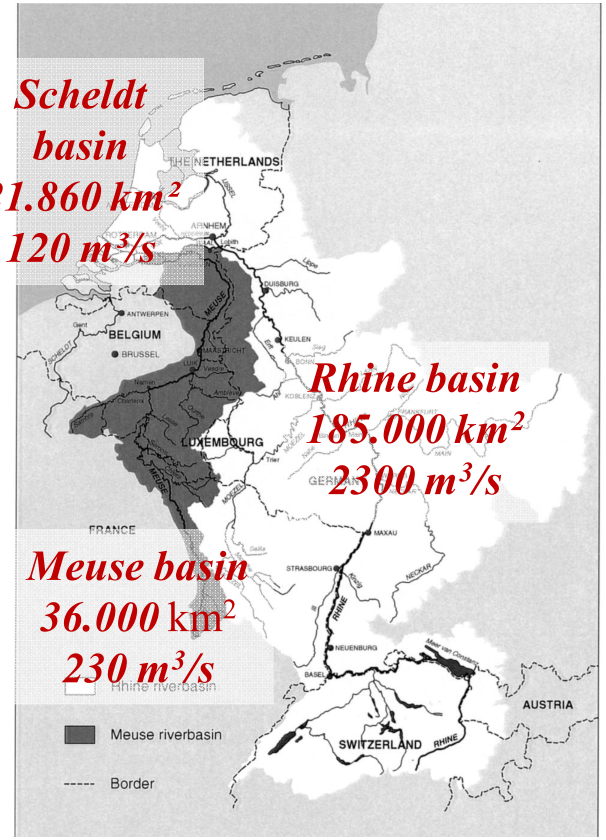
Ganges
Length: 2525 km
Basin: 1080000 km^2
Average discharge (Farakka Barrage): 16648 m^3/s

Main flood causes

- Three huge rivers converge in Bangladesh (Ganges, Brahmaputra, Meghna)
- Cyclones from the Bay of Bengal cause coastal flooding
- Monsoon rainfall, some parts of the Ganges basin receive 500 mm of daily rainfall
- Sediment deposition in Bangladesh, that blocks the river channels making them insufficient to convey flood waters

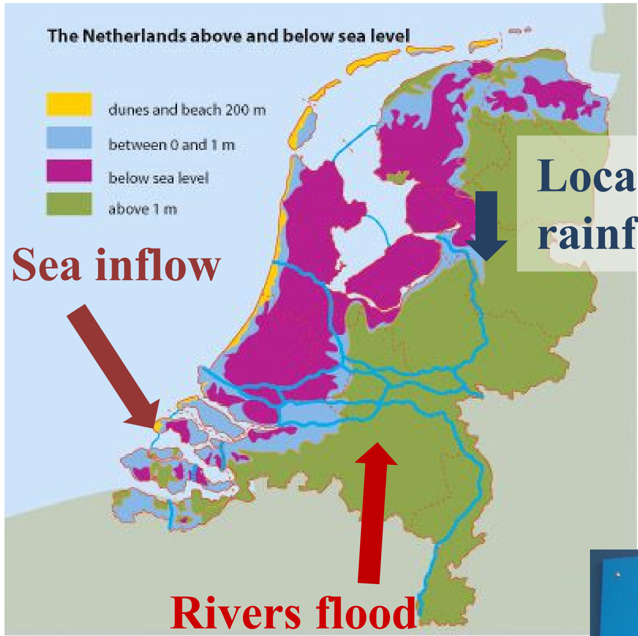
In years 1974, 1987 and 1988 about 29000, 2000 and 2500 deaths, have been reported.

More recently in 7/8/2007 the monsoon rains have caused human suffering in Bangladesh. More than half of the country's 64 districts (population 150 millions) are severely affected. Vast areas of land and crops are submerged, and millions of people have been left homeless. Parts of eastern Dhaka are also being inundated. Government figures show that a total of about 8 million people have been displaced and also 120 deaths have been reported.



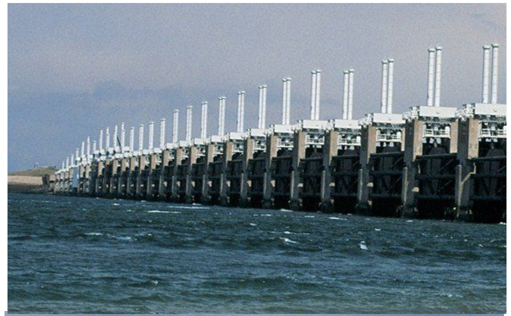
Present-day situation

The rivers' delta has an area of 7500 km^2 with the main part altitude under the sea level (up to 6 m)



… and floods in Holland

Delta Works



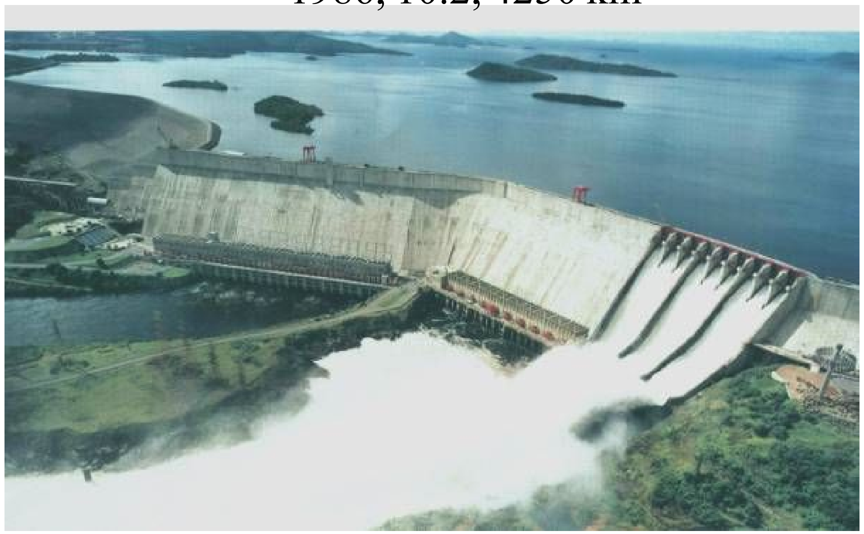
The flood of 1953 caused the death of more than 2000 people and the inundation of 1500 km^2. Soon the old idea of building dams in the rivers' mouths started to move. In 1959, the Delta Law was passed, in order to organize the construction of the dams. Although safety was the main priority, some seaways would have to stay open, because of the economic importance of the ports of Rotterdam and Antwerp. Also some auxiliary dams would first have to be built in the Zandkreek, the Krammer, the Grevelingen, and the Volkerak. The building of the Delta Works was an enormous project except the 14 large dams also incudes sluices, locks, dykes and levees.

Present-day situation

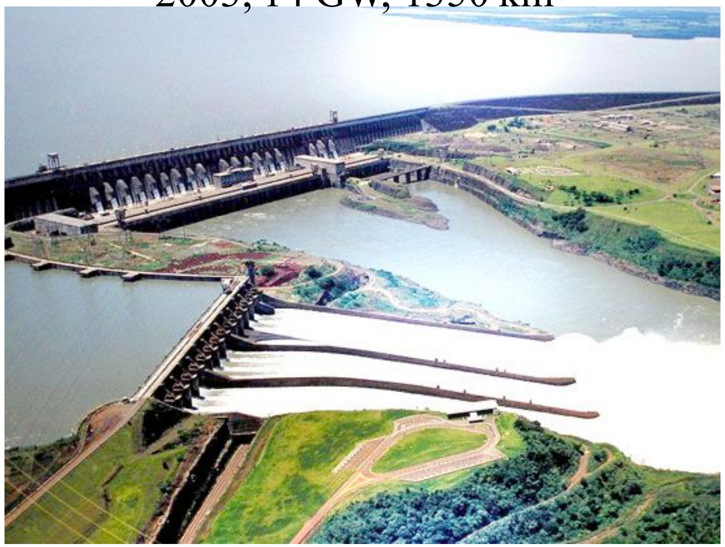
The four larger hydroelectric plants (name-country-year of construction, installed power, reservoir area)

Tucurui dam, Brasil,
1984, 8.37 GW, 3014 km^2

Guri (Simón Bolívar), Venezuela,
1986, 10.2, 4250 km^2



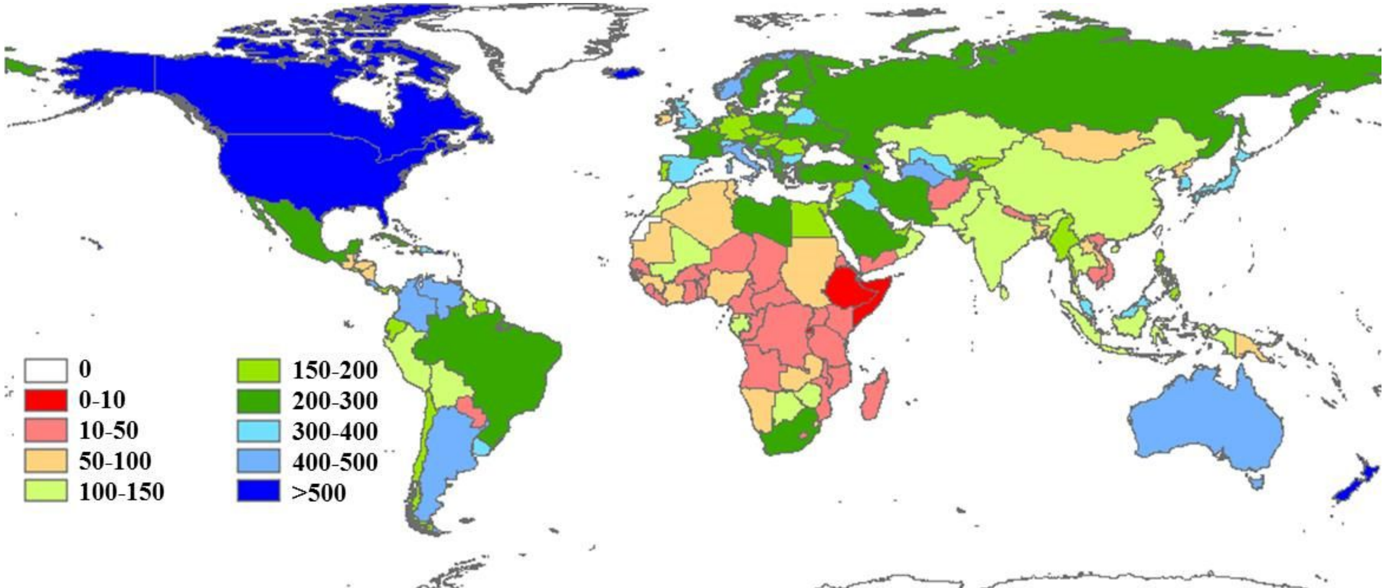
Itaipu, Brasil-Paraguay,
2003, 14 GW, 1350 km^2



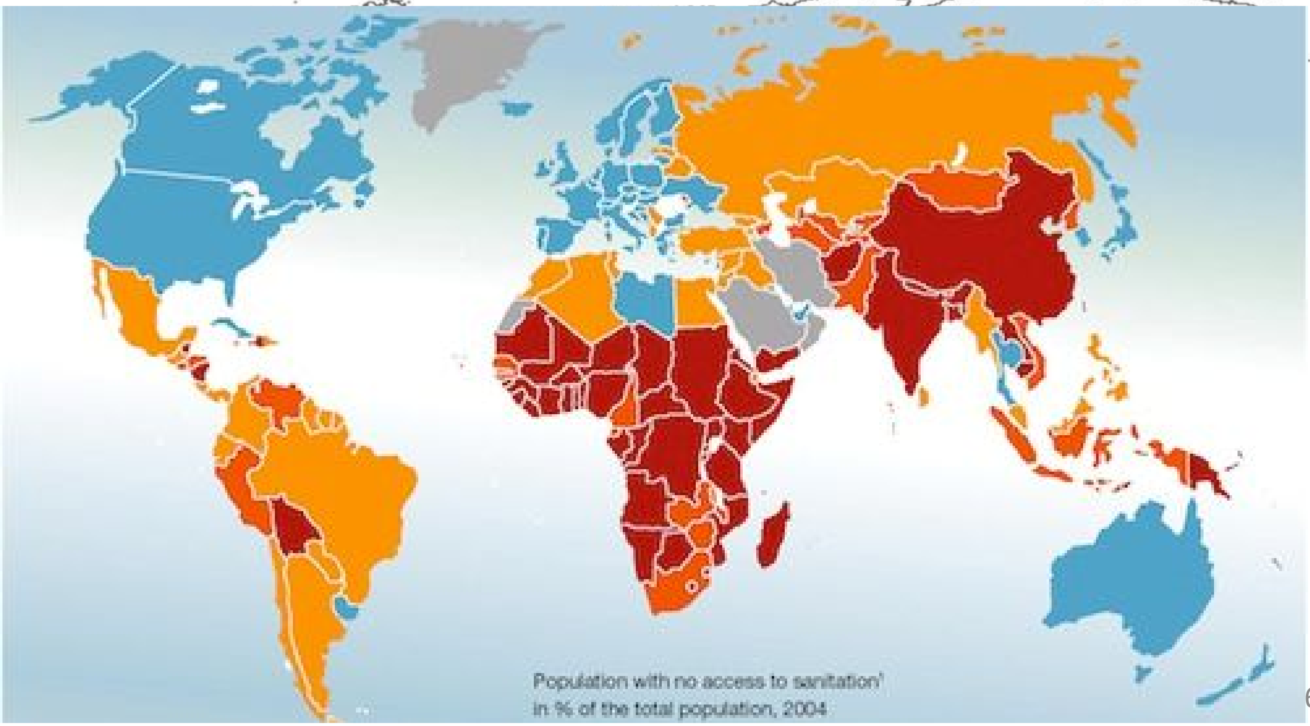
Three Gorges, China,
2011, 18.3-22.5 GW, 532 km^2

Ancient situations in present-day world;

Domestic use l/cap/d



Without access to sewage network (% of the population)



Ancient situations in present-day world;

Ethiopia

China

Uganda

768 million have no access to safe domestic water-11% (2011)
2.5 billion have no access to sewage network-36% (2011)
3.4 million people die each year **(more than 6 per min)** from water related diseases (99% of them to third world). ***United Nations report***

India

Haiti

Nigeria