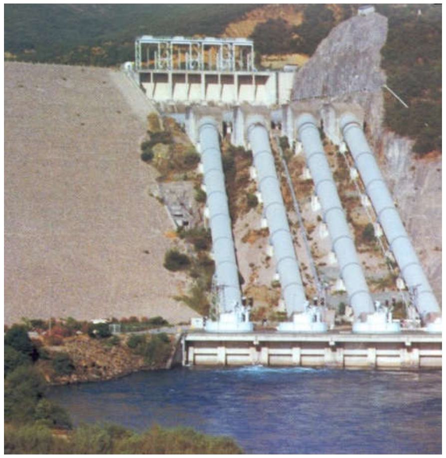
Postgraduate program: Environment and Development

National Technical
University of Athens

Course: Energy and Environment

Water and energy





Nikos Mamassis, Professor
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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?

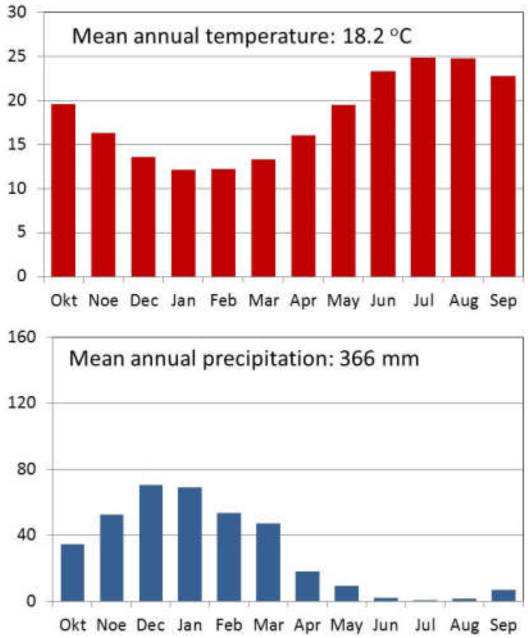
To define the appropriate of hydraulic and energy works and management actions

Water and Energy

Imagine the inhabitance of the Astypalea island

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

Data from Naxos island



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 km^2 =35 hm^3*

To do what ?

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

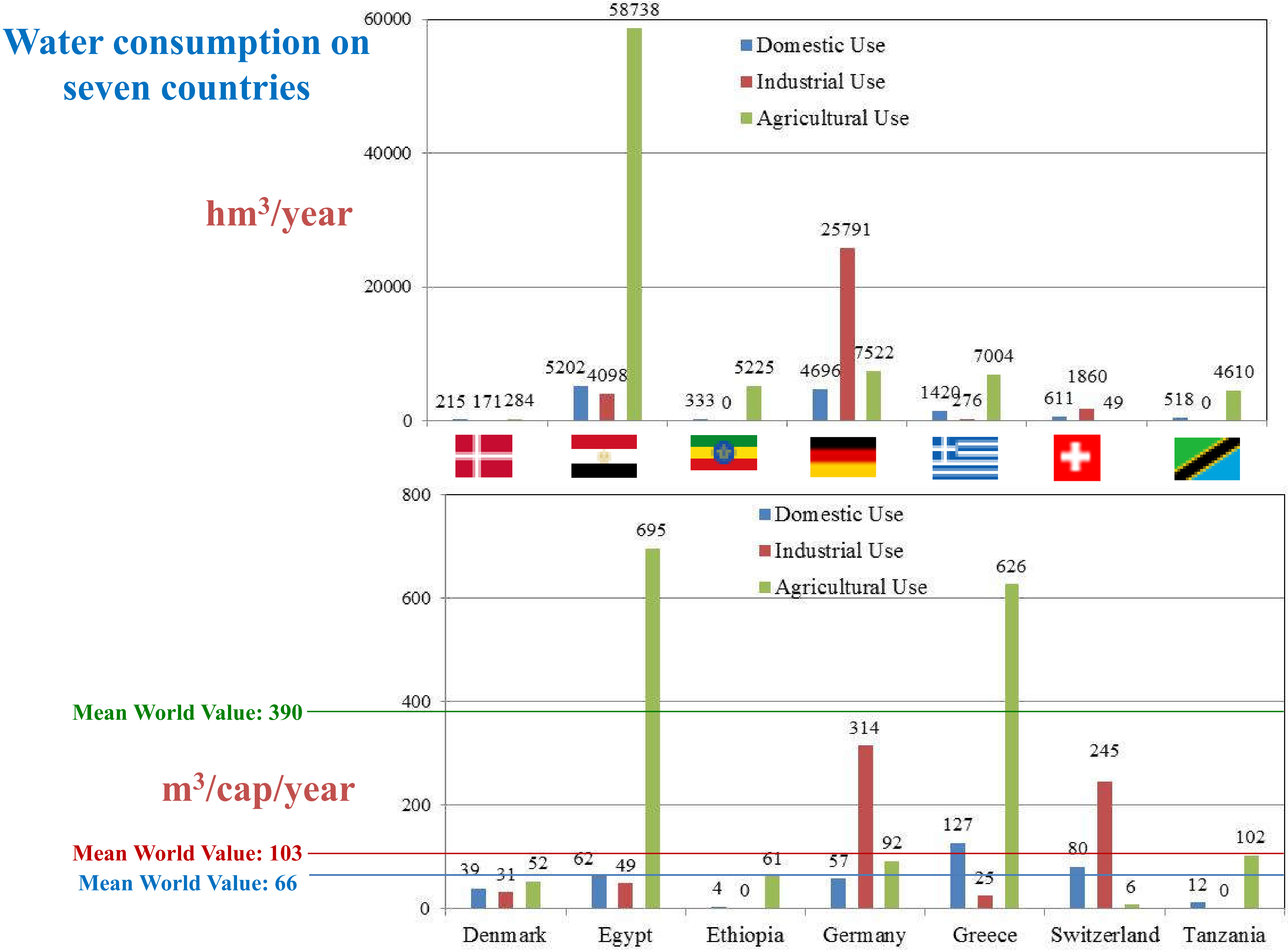
Consumptive water uses (Domestic, Agricultural, Industrial, Livestock)

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%)

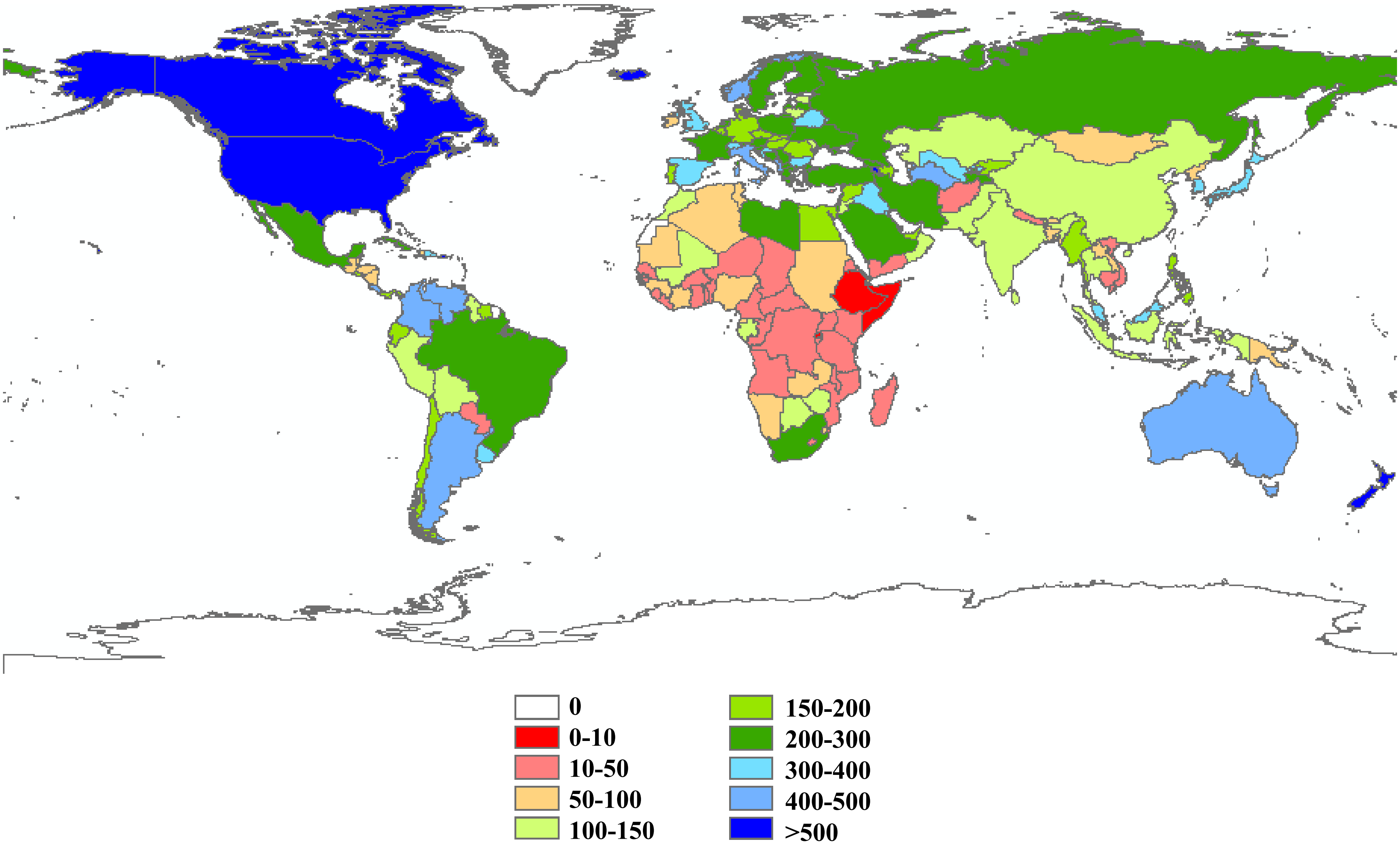
Calculations for our island
Domestic 66 000 m^3/y (180 l/c/d)
Agricultural 390 000 m^3/y
Industrial 103 000 m^3/y

How much water we need?



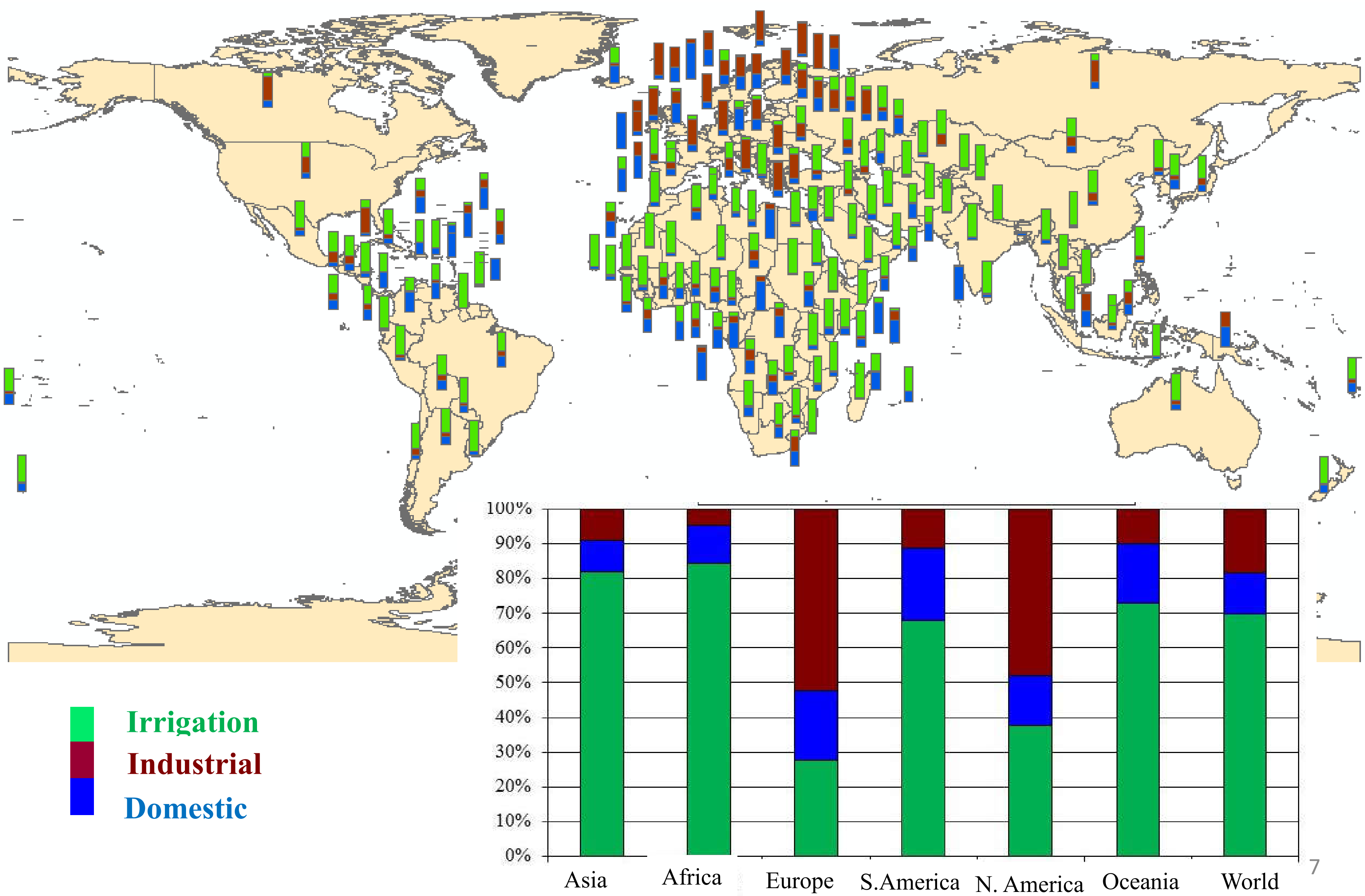
Present-day situation

Domestic use l/cap/d



Present-day situation

Percentage of water for irrigation, industrial and domestic use

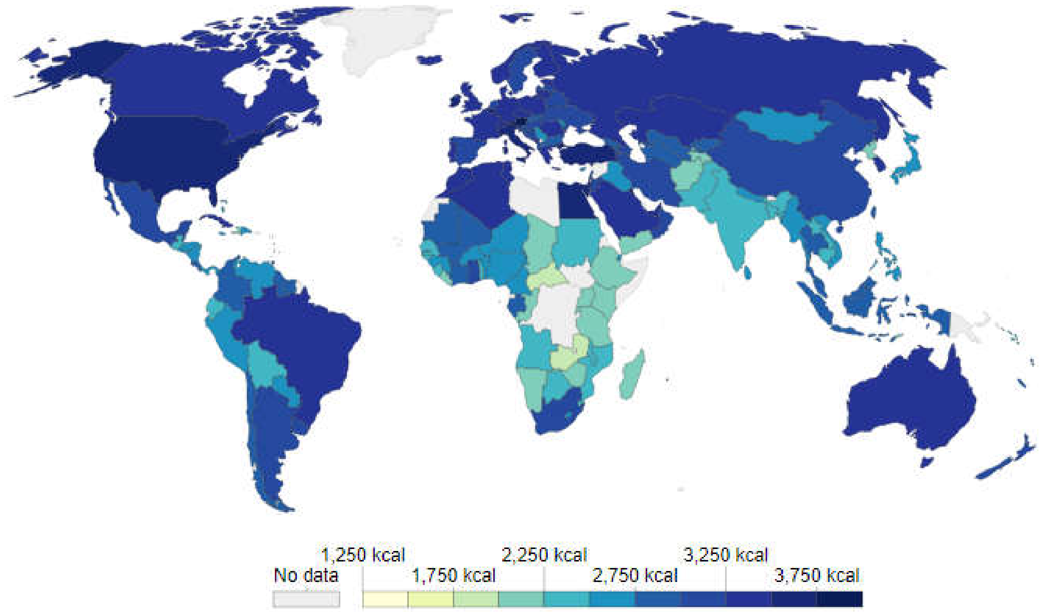


Food

The recommended Caloric supply ranges:
from 1000 kcal/d for an infant
to 3200 kcal/d for an active male

"The *2015-2020 Dietary Guidelines for Americans*"

Caloric supply, 2013 (kcal/c/d)



Source: Daily caloric supply per capita long-term - FAO (2017)

Food items have been grouped in six categories:

1. cereals and starchy roots (including rice, wheat, maize, potatoes)
2. vegetables and fruits
3. animal products (meat, fish, eggs, milk, animal fats)
4. sugar and sweeteners
5. oil crops and vegetable oils
6. alcoholic beverages

According to FAO in 2003, these foods accounted for 98% of the total food consumption in weight and the total caloric supply

Food

Mean food consumption in Germany (g/c/d) and (kg/c/y)

	gr/d	kg/y
Bread	160	58
Cereals and cereal products	73	27
Potatoes and potato products	84	31
Vegetables, mushrooms and pulses	234	85
Fruit and fruit products	253	92
Milk, dairy products and cheese	248	90
Meat, meat products and sausages	110	40
Fish, fish products and seafood	25	9
Eggs	15	5
Fats and oils	33	12
Soups	52	19
Sauces and spicy ingredients	40	15
Sweets	68	25
Water	1129	412
Coffee and tea (black/green)	527	192
Soft drinks	166	60
Beer	148	54
Wine and sparkling wine	41	15

Source: T. Heuer, C. Krems, K. Moon, C. Brombach, and I. Hoffmann, Food consumption of adults in Germany: results of the German National Nutrition Survey II based on diet history interviews, Br J Nutr., 2015.

Arable land (ha/c)

Country	1961	2015
Denmark	0.61	0.41
Egypt	0.09	0.03
Ethiopia	0.49	0.15
Germany	0.17	0.15
Greece	0.33	0.21
Switzerland	0.07	0.05
Tanzania	0.50	0.25
World	**0.37**	**0.194**

Calculations for our island

120 t/y cereals
85 t/y vegetables
92 t/y fruits
90 t/y milk
40 t/y meat
12 t/y oil
15 t/y wine

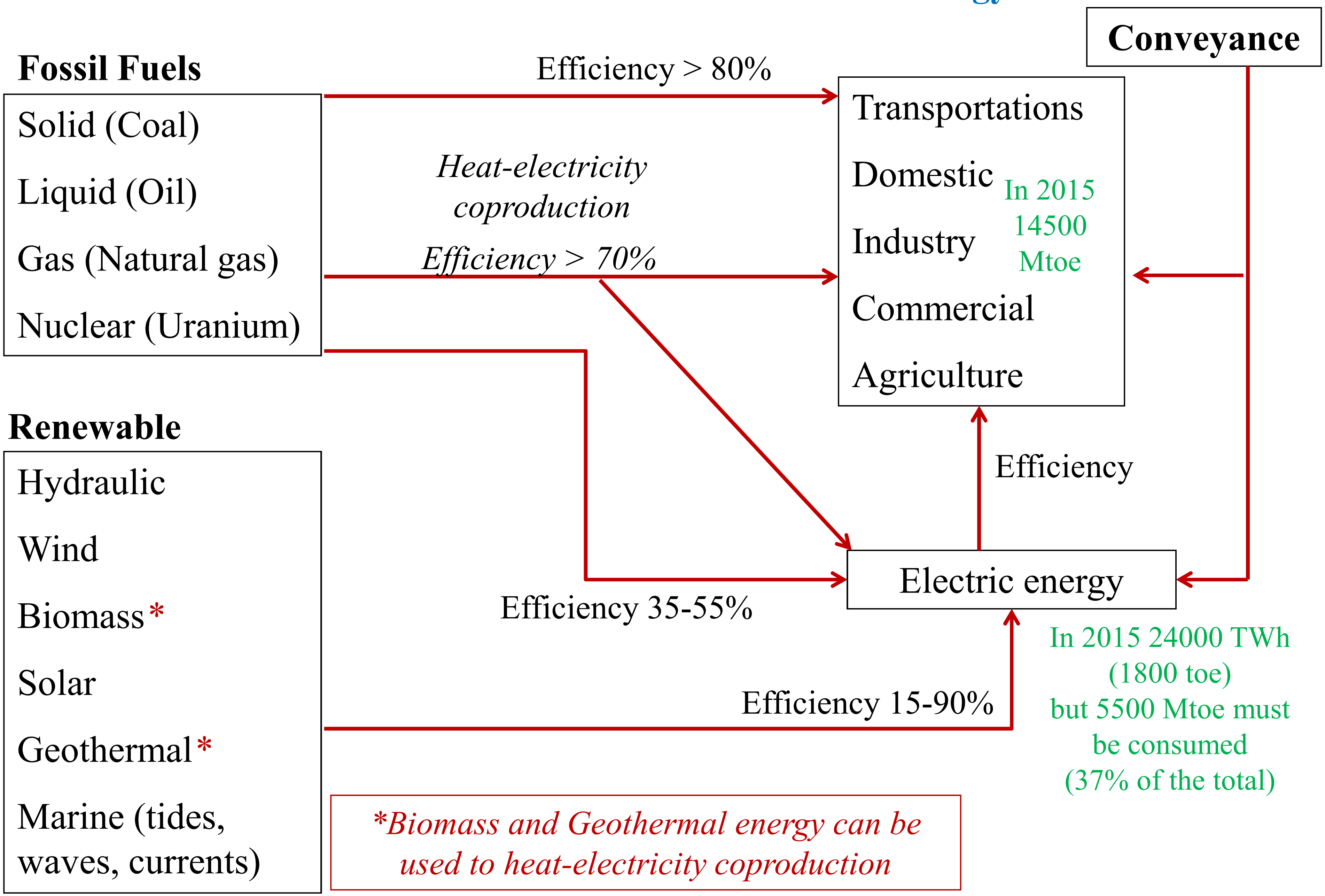
194 ha arable land

How to find energy?

Energy sources

To do what ?

Energy needs



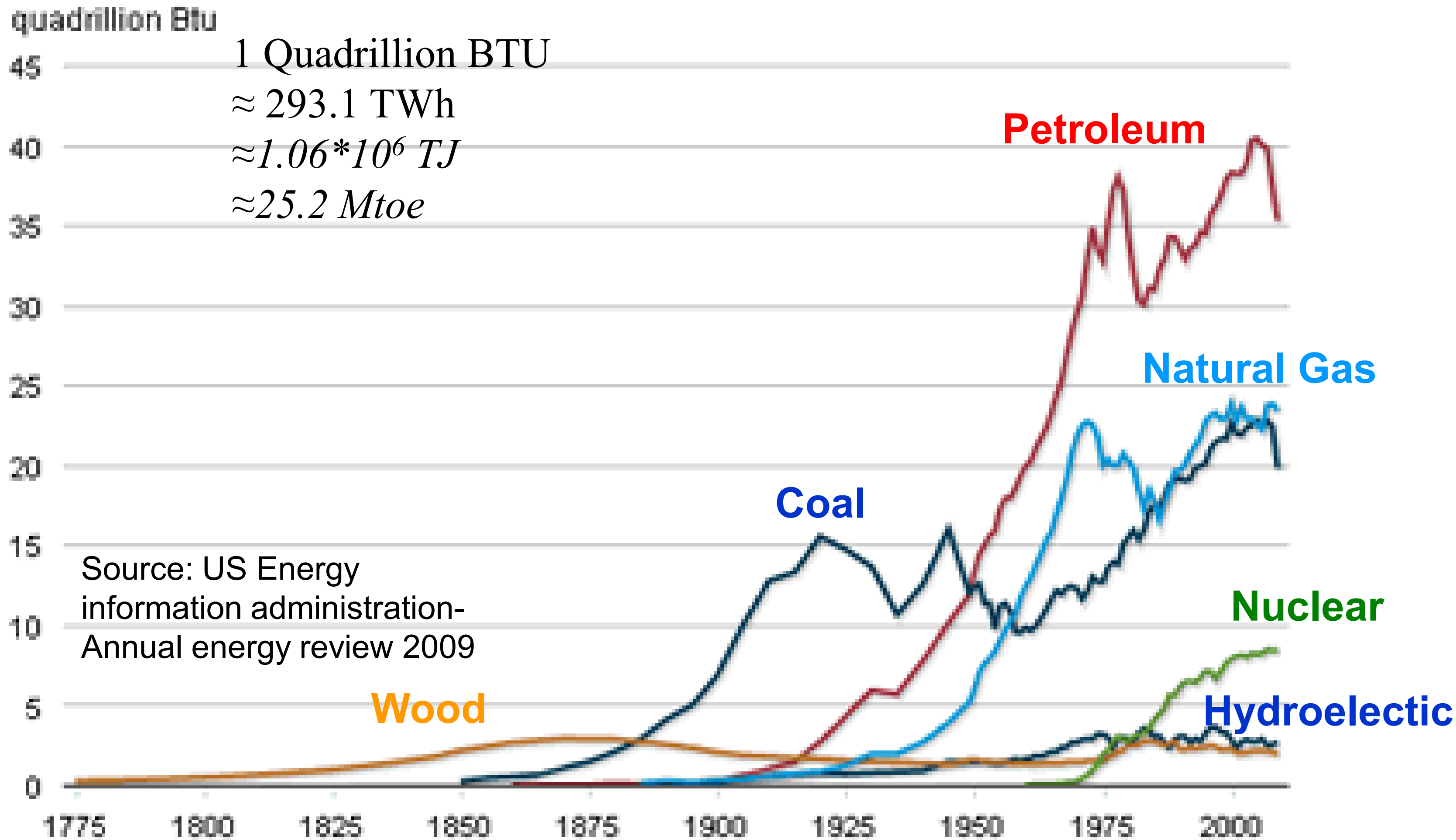
Human evolution and energy

Milestones of energy use through history

Time (approximately)	Era	Inventions	Fuels
100th mill. BC	Palaeolithic	Control of Fire	Wood
10th mill. BC	Neolithic revolution	Agriculture, Animal domestication, Sailing	Wind
5th mill. BC	Urban revolution		
1th mill. BC	Iron age	Charcoal production	Charcoal
5th cent. BC		Pumping devices, Water mills	Water
7th cent. AD		Wind mills	Wind
18th cent.	Industrial revolution	Internal combustion engine	Coal
19th cent.	Scientific revolution	Steam engine	Petroleum, Natural Gas
20th cent.		Electricity, Nuclear Energy	Water, Nuclear fuels, Geothermic, Solar, Marine

Human evolution and energy

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



Energy characteristics

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

Energy characteristics

Capacity factor (CF)

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

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 with reservoir the energy produced depended on the river flows of long time periods (years). The installed power is designed considering the scope of the plant. The CF of a year can be scheduled taking into account the desired operation hours and the active power used.

The calorific value of fossil fuels

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 heat 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%)

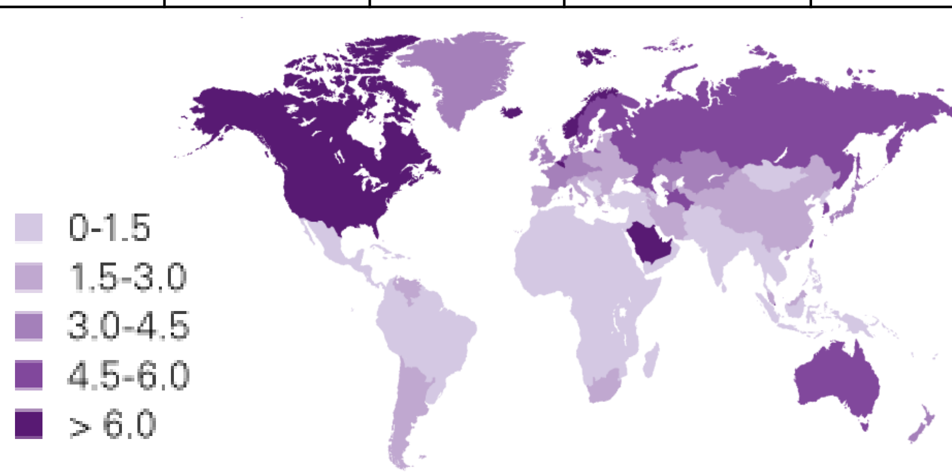
Fuel	Colorific value	Quantity
Anthracite	33 (MJ/kg)	1.27 tn
Lignite	15 (MJ/kg)	2.80 tn
Wood	14 (MJ/kg)	3.00 tn
Diesel fuel	45 (MJ/kg)	0.93 tn
Petroleum	43 (MJ/kg)	0.98 tn
Natural gas	43 (MJ/m^3)	977 m^3
Gas oil	38 (MJ/lt)	1105 lt
Uranium 235	80 (TJ/kg)	0.532 gr

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*

The calorific value of fossil fuels

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

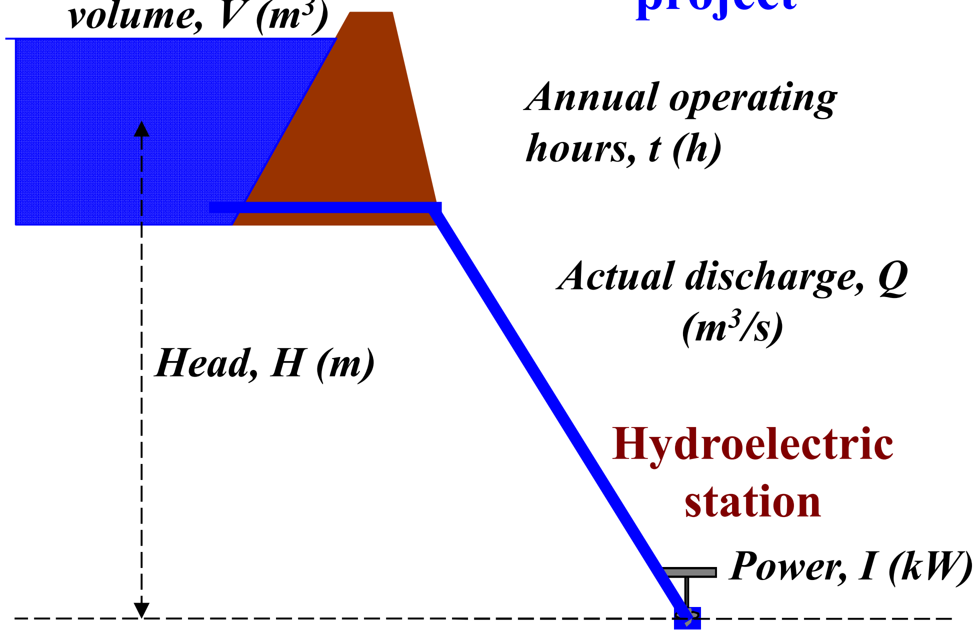
The total primary energy corresponds to the combustion of the following quantities:

1910 tn of anthracite
4200 tn of lignite
4500 tn of wood

1400 tn (10300 barrels) of diesel
1.46 Mm^3 (1000 tn LNG) of natural gas
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.

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

I (kW) = g * n* H (m) * Q (m^3/s)

E (kWh) = I (kW) * t (hr)

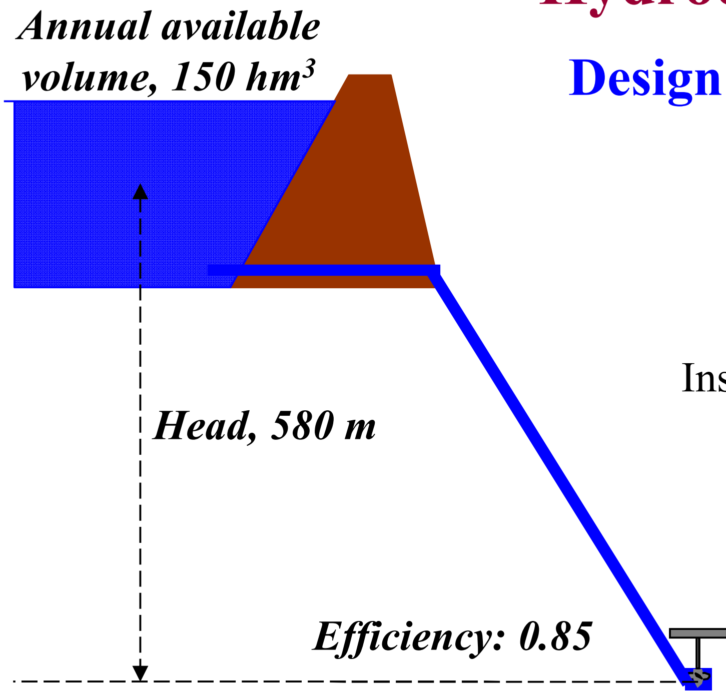
Example (using Plastiras' data)

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 (m^3/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 m³/s=17.280 m³/hr**

Installed Power=9.81*4.8 m³/s*580 m*0.85 ≈**23000 kW=23 MW**

Annual operating hours=
150.000.000 m³/(17.280 m³/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 m³/s=100.080 m³/hr**

Installed Power=9.81*27.8 m³/s*580 m*0.85 ≈**134.300 kW=134.3 MW**

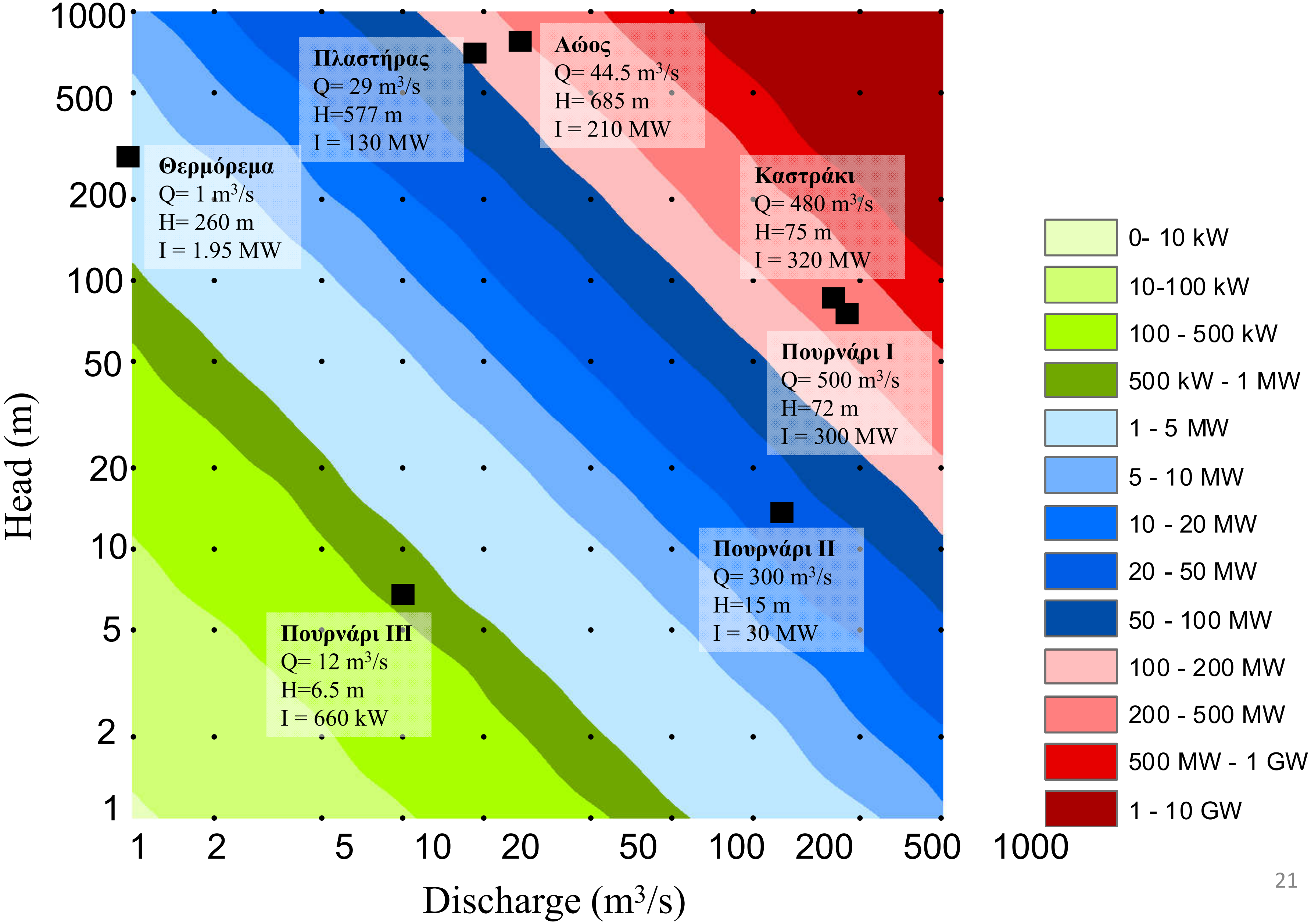
Annual operating hours=
150.000.000 m³/(100.080 m³/hr)**≈1500 hr per year**

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

Hydroelectric power plants

Head-Discharge-Power of hydroelectric projects in Greece

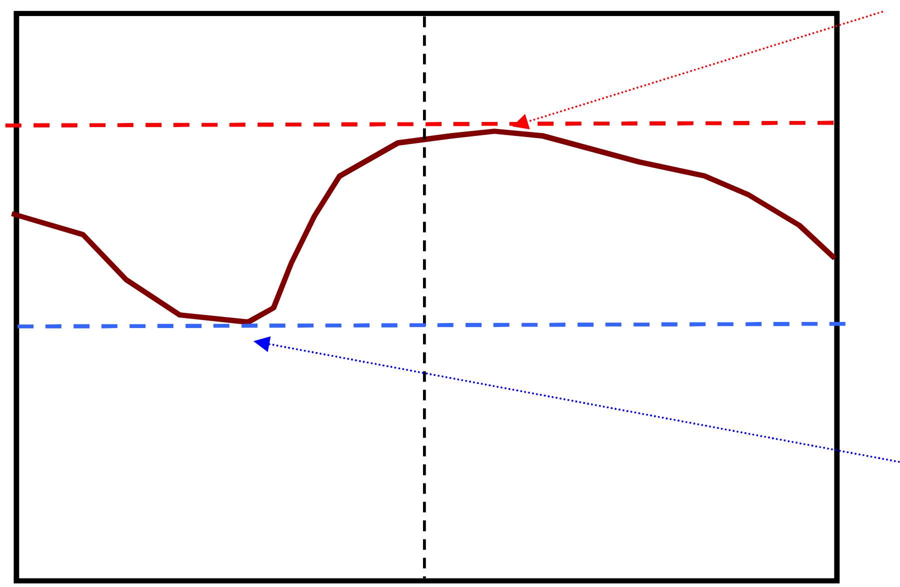
Theoretical power



Electric energy management

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

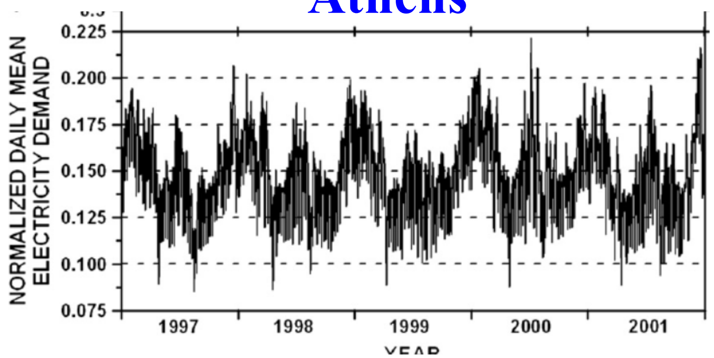
- The grid must be fed with the same amount of energy that is consumed, thus the electric energy production must be continuously reformed
- The time span for alteration of energy production, is different for various power plant. This time is several hours for the thermal stations (coal and natural gas)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

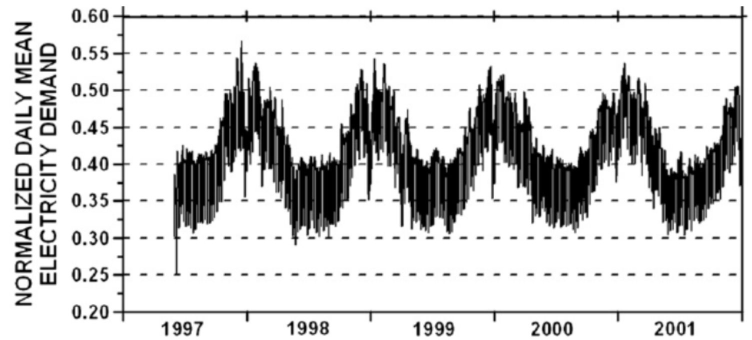


The electric energy demand peaks

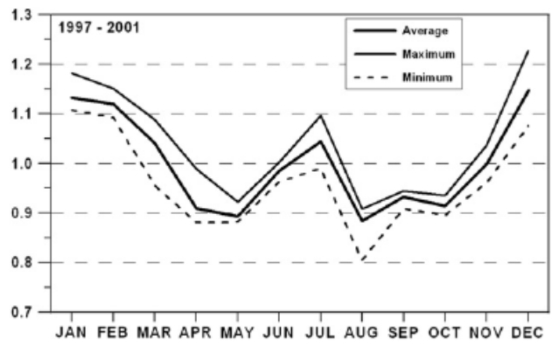
Athens | London

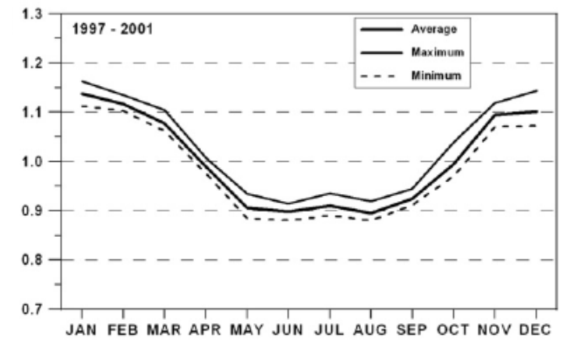
Fluctuation of daily electricity demand (1997-2001)



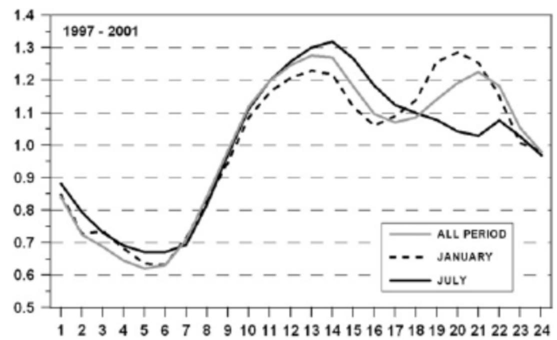


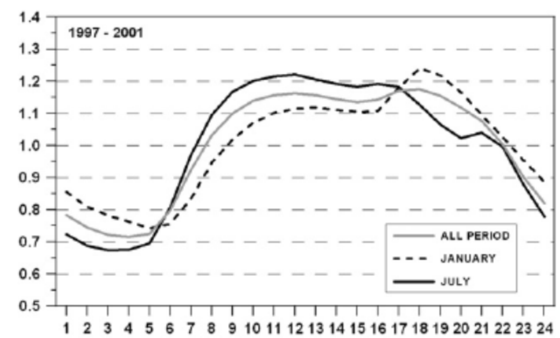
Fluctuation of mean monthly electricity demand (1997-2001)





Fluctuation of mean hourly electricity demand (1997-2001)



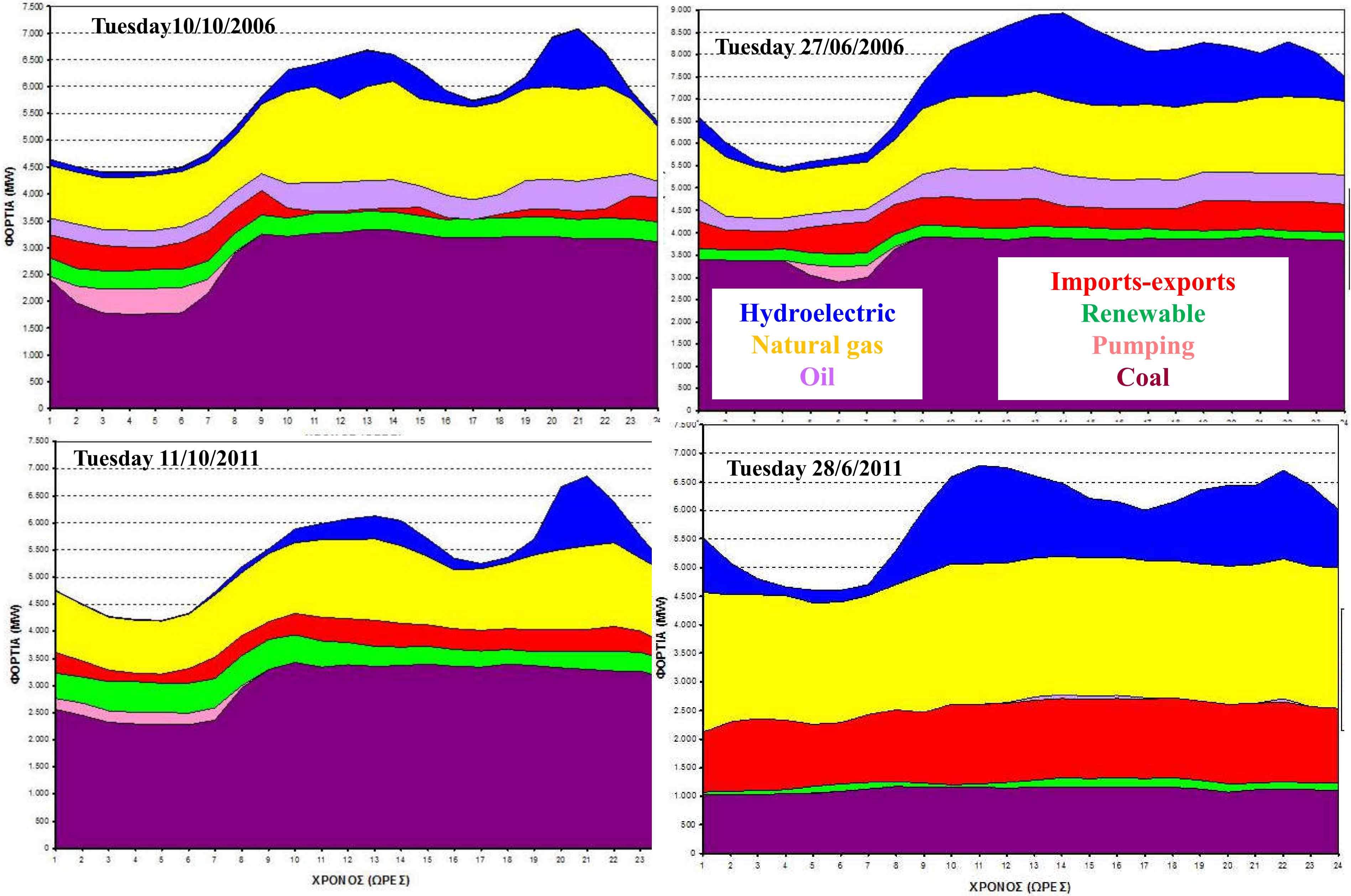


In Greece, the mean annual electricity demand of about 55 TWh could be produced by power plants with an installed power of 6.3 GW considering continuous operation (CF=1). The peak hourly demands had reached the 11 GWh (during hot noon summer hours). During these peaks the total installed power of the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

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

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?

The need for synchronization of production to demand in the electrical grids that use various energy resources, points to **three important parameters** that characterize each power plant:

1. Control and predictability of energy production

In thermal power plants the energy production is totally controlled (considering availability of the fuel and operational readiness)

In controllable renewable energy resources (biomass, geothermal) energy production is totally controlled or can be reliably predicted (tide).

In uncontrollable renewable energy resources that exploit natural processes (wind speed, solar radiation, water flow, waves) the energy production has poor predictability.

The predictability and reliability of hydro power are much greater when is stored in hydroelectric reservoirs

2. Time required to adjust the energy production

This time ranges from several hours (or even days) for the coal and nuclear stations, a few hours for natural gas thermal stations to a few minutes for hydroelectric stations. Peak loads are covered mainly by hydroelectric stations and base load mainly by coal and nuclear stations.

3. Ability to store energy for later use

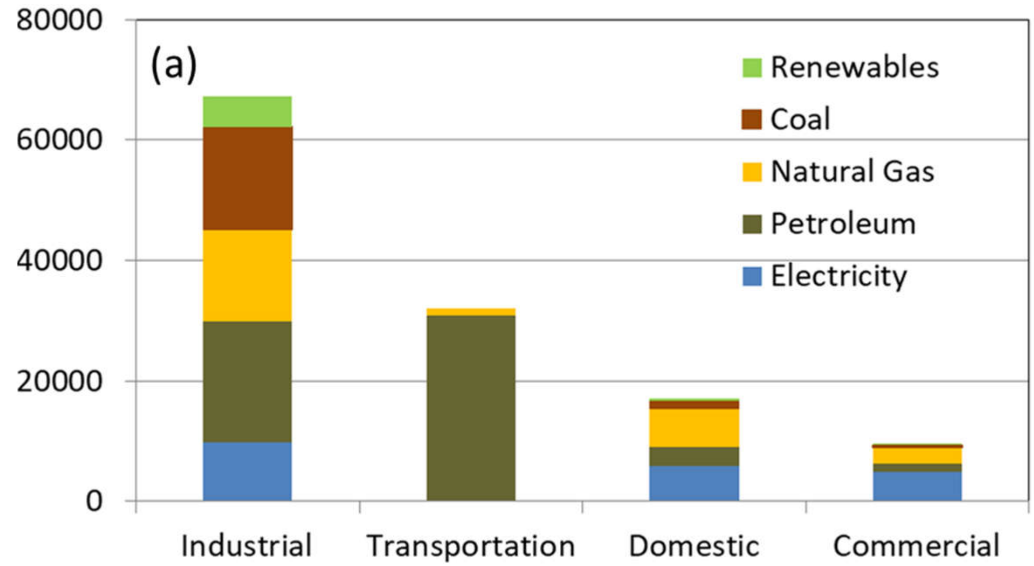
In fossil and nuclear fuels the energy is stored inside the material and the total amount is measurable and expressed by local and global reserves.

In renewable resources, opportunity of storage is only offered by hydropower (using reservoirs) and biomass. Additionally, on geothermal fields the total "stored" energy can be estimated, while tidal energy is reliably predicted.

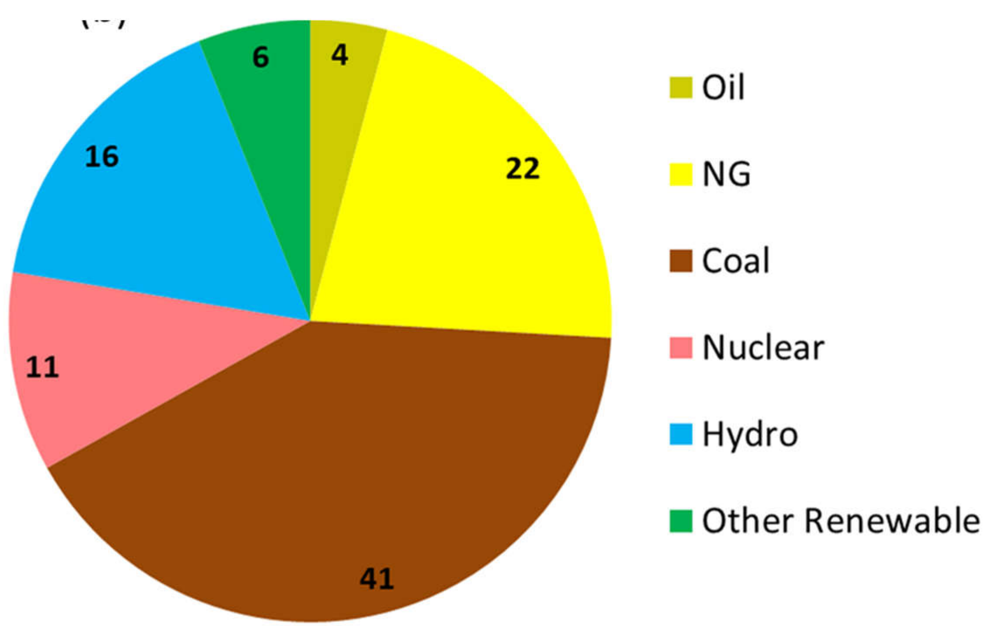
The other renewable energy sources could be stored through pumped storage hydro schemes or, in smaller scale systems, in batteries, a sector that today is under extensive research and development.

What are the energy recourses?

Energy produced (TWh) by fuel and sector (2016)

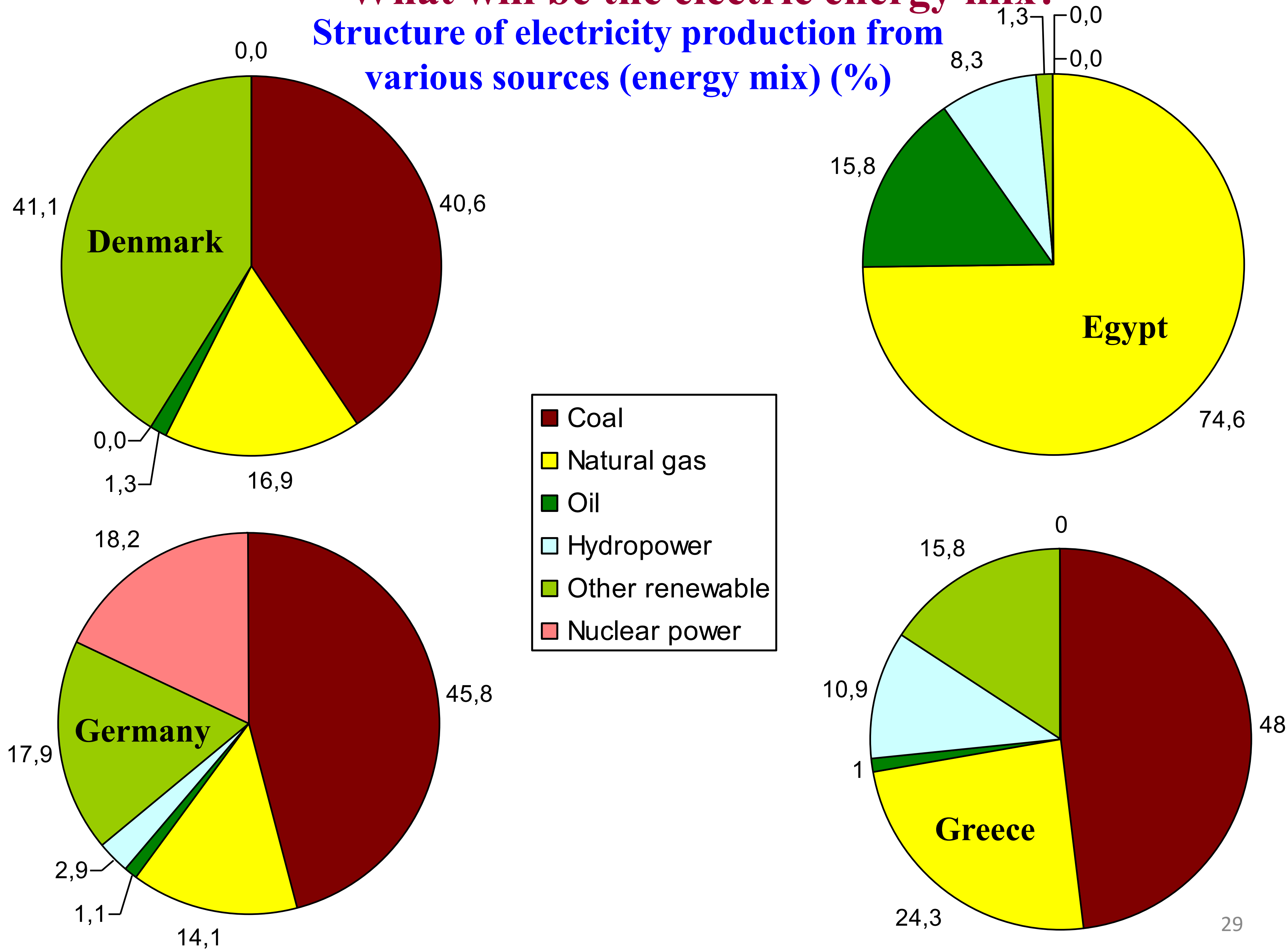


World electric energy mix (2016)



What will be the electric energy mix?

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



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 *1000 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 4050 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?

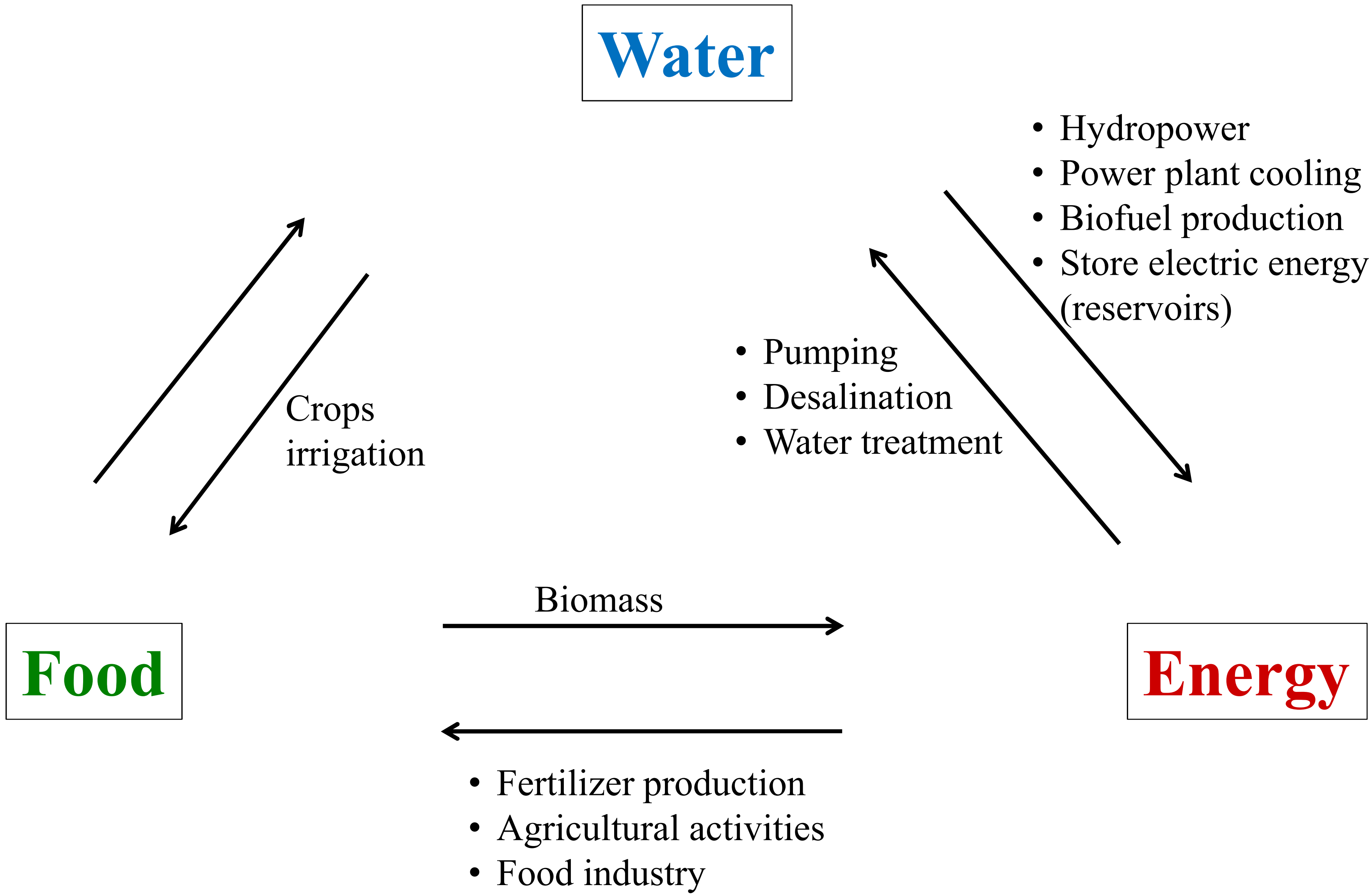
Some ideas and calculations for our island

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 5 to 7 GWh/y
- Photovoltaic panels of with installed power of 2 MW (panels area about 1.4 ha), could produce 3 to 4 GWh/y
- Biomass installation. 3000 tn wood retails contain 1000 toe of thermal energy and could produce 4.4 MWh of electric energy
- A geothermal field can be used a 1 MW installation could produce 6 to 8 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

Water-Food-Energy interlinkages



Water-Food-Energy interlinkages

Mediterranean diet: Bread, olive oil and wine

Cereals, olive trees and vines in our island. The characteristics are indicative for Greece

	Consum-ption (kg/c/year)	Production (tn/ha)	Water required (m^3/ha)	Biomass produced (tn/ha)	Calorific value (MJ/kg)
Maize (corn)	150	10	8000	2,2	18
Wheat	150	3,5	4000	10	19
Olive oil	15	3		1,6	20
Wine	25	8	5000	0,3	19

Water

	Total water required (m^3)
Maize (corn)	120000
Wheat	171429
Olive oil	0
Wine	15625

Food

	Land Required (ha) for 1000 people
Maize (corn)	15
Wheat	43
Olive oil	5
Wine	3

Energy

	Residuals (tn)	Potential Energy (toe)
Maize (corn)	150	64,3
Wheat	94	42,7
Olive oil	8	3,8
Wine	0,9	0,4

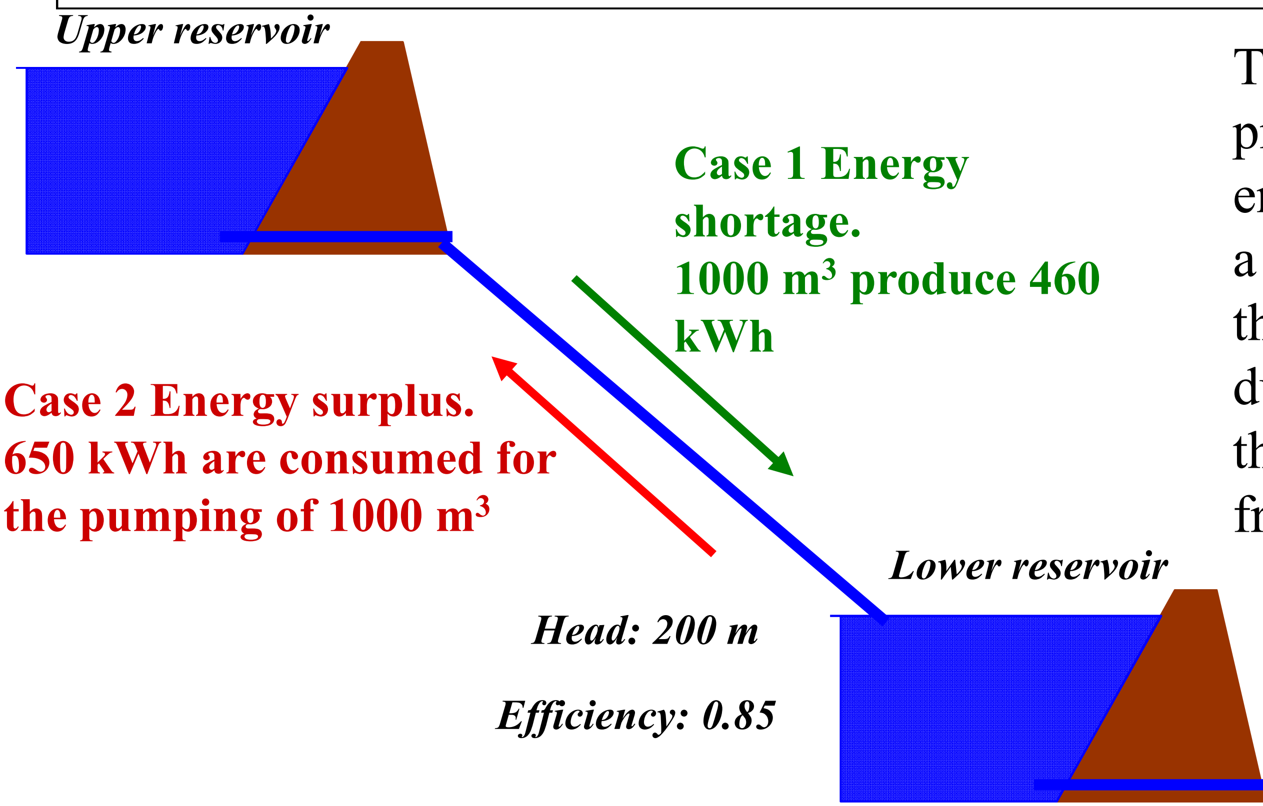
Water-energy cooperation

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

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 m^3/s**

The reality in our island: Astypalaia

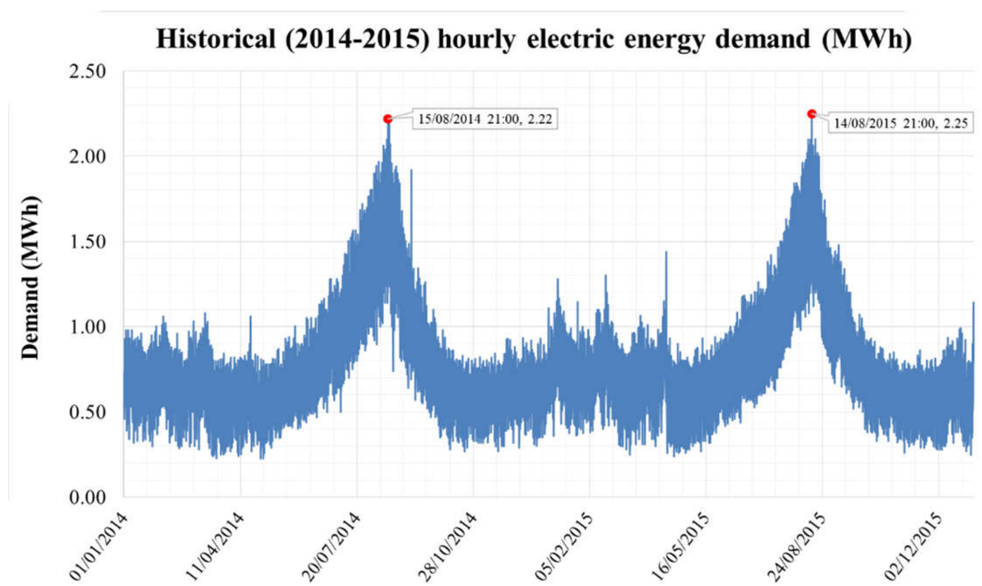
Water consumption
Domestic: 130 000 m^3/y (includes visitors)
Agricultural: 250 000 m^3/y (includes livestock)
Industrial: 4 000 m^3/y

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 oil

Electric energy demand calculated from 2 years hourly data (2014-2015)

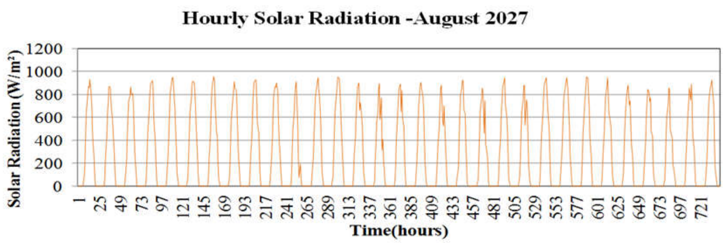
- Mean Annual: 6250 MWh
- Maximum Hourly: 2.2 MWh (14/8/2015 21.00)



Examining Astypalaia's energy recourses

Exploration of weather related renewables

Solar radiation



Photovoltaic panels

Power: 0.1 MW

Total area of panels: 754 m²

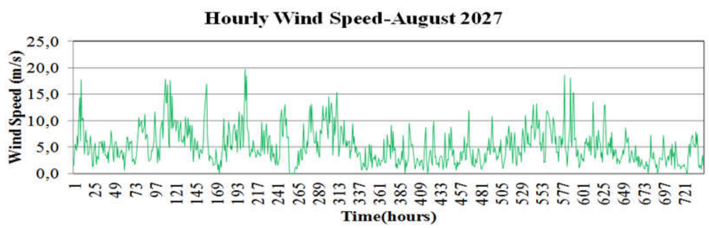
Total area of plant: 11000 m²

Panel efficiency: 13.4%

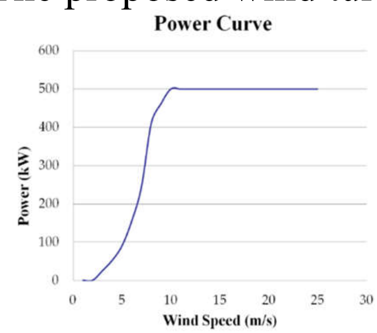
Expected electric energy per plant≈**162 MWh/y**

Capacity factor: **0.16**

Wind speed



The proposed wind turbine:



Power: 0.5 MW

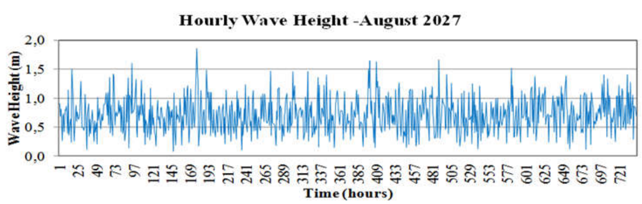
Height: 75 m

Diameter: 54 m

Expected electric energy per turbine≈**2233 MWh/y**

Capacity factor: 0.5

Marine



Overtopping Wave Energy Converters produce energy collecting the incoming waves through overtopping and wave run-up into deposit reservoirs, and using the water to feed a low head turbine.

A **0.3 MW** power machine is proposed:

Expected electric energy≈**835 MWh/y**

Capacity factor: **0.32**

Water

There is a dam located at Livadi area with the following features:
Height: 32 m, Reservoir volume: 875.000 m^3,
Watershed area: 8 km^2, Mean annual inflow: 480 000 m^3 (60 mm).

A turbine **of 0.08 MW** is proposed on the existing dam to produce≈**25 MWh/y**.

Examining Astypalaia's energy recourses

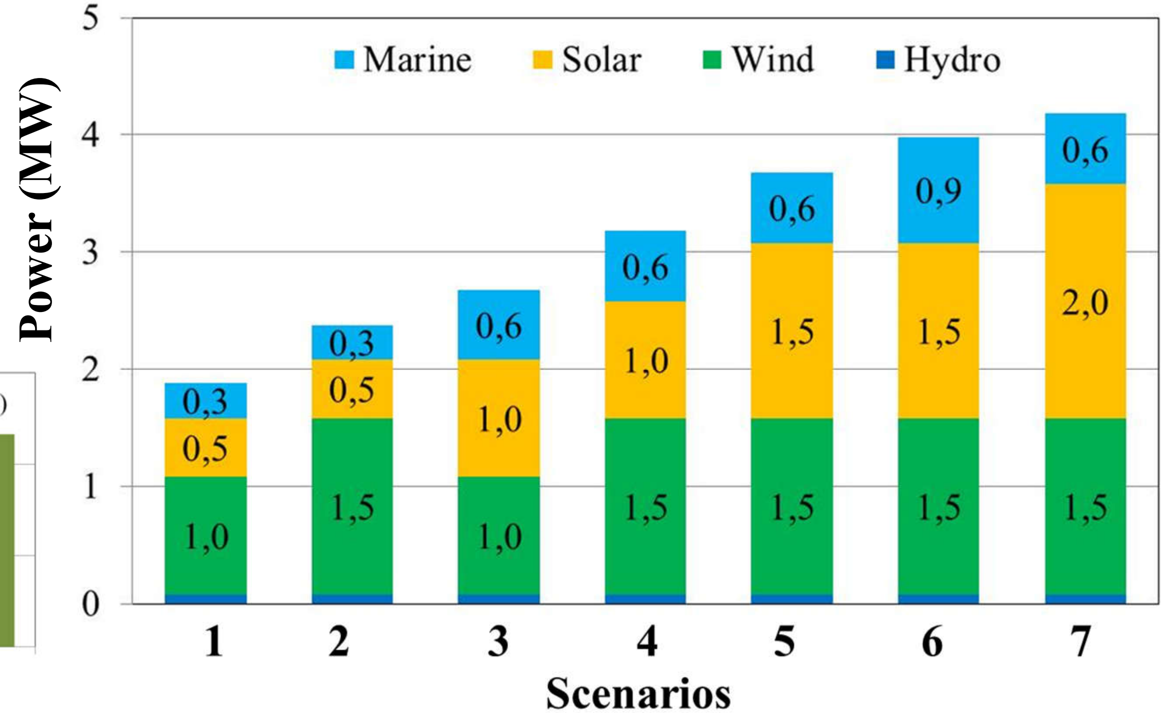
Simulation of electric energy system

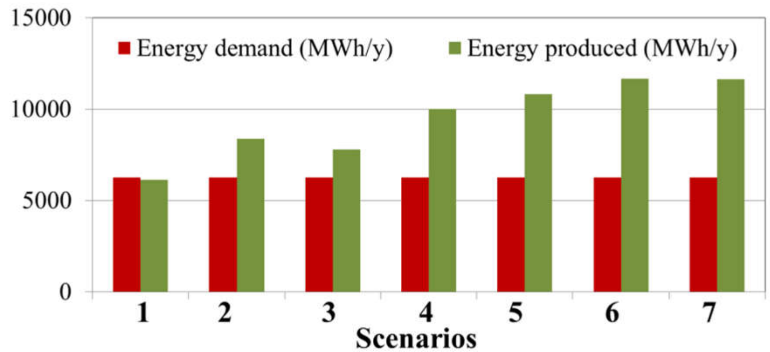
The energy system is simulated in hourly basis for a 100 years period.
Several combinations of renewable resources are examined.

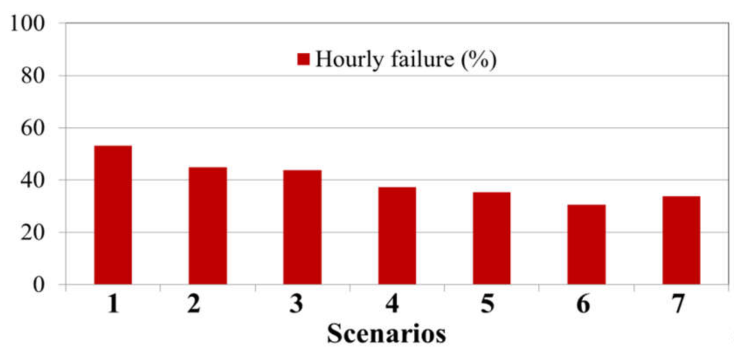
For each mix the following are calculated:

(a) probability of failure to satisfy the peak hourly energy demand,
(b) mean annual deficit of energy,
(c) mean annual surplus of energy

Energy mix analysis (wind, solar, marine, water)







The use of weather related renewable resources results in **high values** of probability of failure, mean annual deficit and mean annual surplus

Examining Astypalaia’s energy recourses

Adding controllable renewables

Geothermal

Astypalaia is located at the Volcanic Arc of southern Aegean Sea. Although no measurements have been implemented, we assume that there is an exploitable geothermal field with a minimum **power of 0.5 MW.** In Milos and Nisyros plants of 2 and 3 MW respectively have the potential to be installed.

Biomass

Biomass may refer to
(i) food crops, (ii) energy crops (iii) various types of organic waste from agriculture processes, e.g. manure and crop-residues

Exploitation of **existing** 50 ha that produce 100 t/y agricultural residues with a mean calorific value 18.5 MJ/kg
Expected electric energy≈**190 MWh/y**

Exploitation of **cultivated** energy crops.
100 ha produce 1000 t/y with calorific value 18 MJ/kg
Expected electric energy per 100 ha≈**1750 MWh/y**

Biomass Power Station of **1 MW** is proposed considering efficiency of 0.35

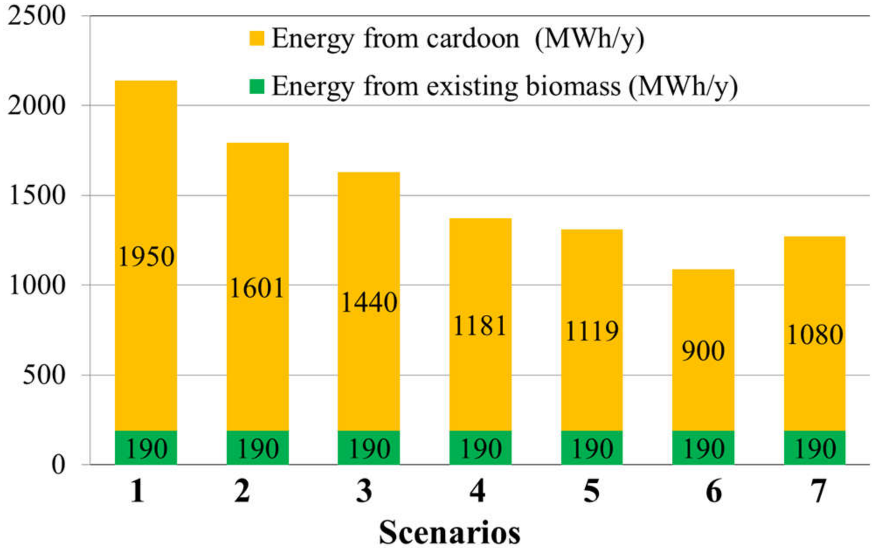
Controllable renewables (biomass, geothermal) are added to provide

- installed power (2.6 MW) in order to satisfy the peak hourly deficit,
- additional energy to cover the annual deficits (1-2 GWh) and
- management of surplus energy (2-6 GWh)

Examining Astypalaia's energy recourses

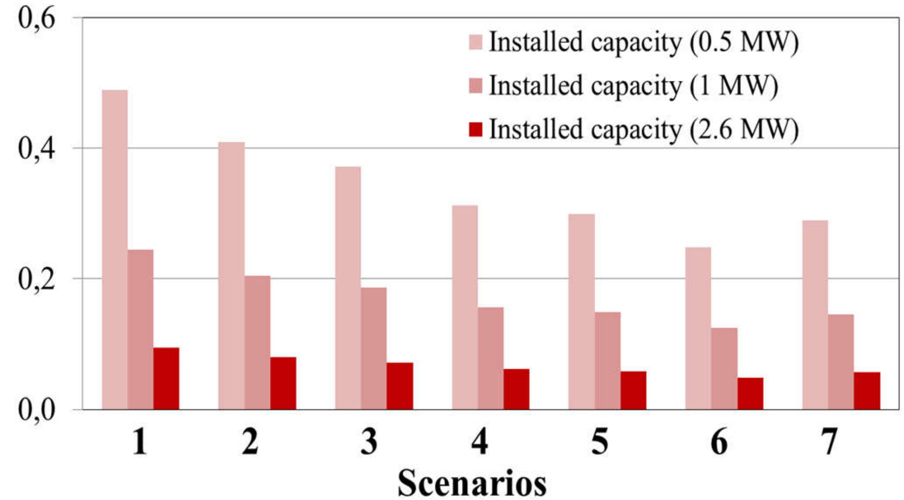
Simulation of electric energy system

Biomass



In all scenarios there is a requirement for cultivation of energy plants. The necessary cultivation area is about 50-110 ha.

Geothermal



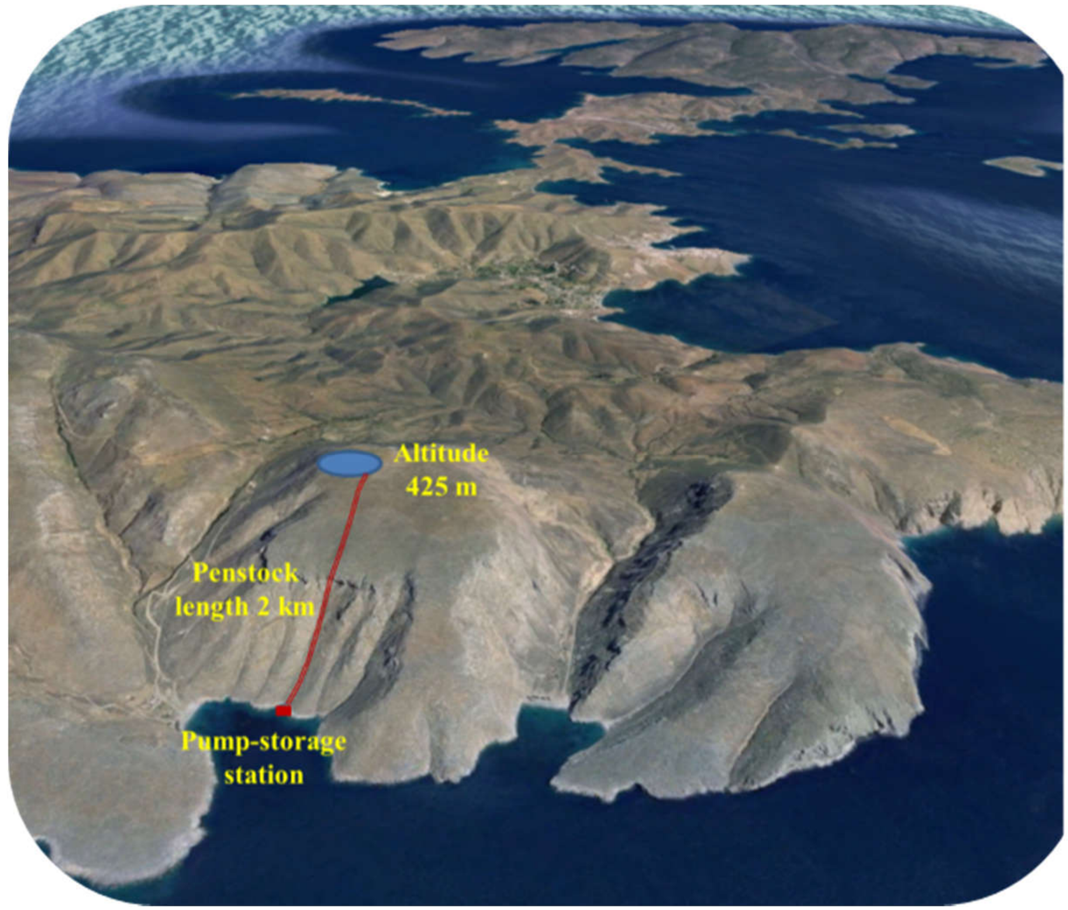
In case that a geothermal field (capable of electric energy production) exists, it will operate with a small capacity factor.

The use of controllable renewable resources could satisfy the peak hourly and the annual deficit, but the amount of surplus energy is still a significant factor.

Examining Astypalaia's energy recourses

Sea water pumped-storage system

A pumped-storage system, that uses sea water to store energy, is considered. The available net head is 400 m and the efficiency of pumped-storage cycle is 75%. The reservoir volume and the installed power of hydro-turbine will be decided after optimization.



The use of pumped-storage is a convenient way to store electric energy surplus from other resources. The existence of a reservoir also contributes to the satisfaction of peak deficits.

Examining Astypalaia's energy recourses

Towards an energy mix

1. Start with the energy mix with weather related resources

Solar: 0.5 MW **Wind: 1 MW**

Marine: 0.6 MW **Hydro: 0.08 MW**

2. Simulation results

Probability of failure: 47.5%

Annual surplus: 2464 MWh

Annual deficit: 1758 MWh

3. Considering a pumped-storage scheme

The pumped-storage system was simulated to calculate the energy production for various upper reservoir volumes and hydro turbines installed.

A scheme of **1 MW hydro-turbine** and a 0.5 hm^3 upper reservoir volume will produce 1245 MW/y (70% of the surplus) but there will still be a deficit of 513 MWh/y

4. Add **Biomass: 1.6 MW**

Existing biomass: 190 MWh/y

Energy plant cultivations required: 18 ha

Total installed power: 4.8 MW

Theoretically, the energy demand of the island could be satisfied using only renewable resources, but financial, environmental and sociological factors must thoroughly be examined.

Examining Astypalaia’s energy recourses

Comparison

Using only renewables

- **2 wind turbines** of **75 m** height,
- **3800 m² of photovoltaic panels**,
- **2 wave converter** installations,
- **a small hydro turbine** on the existing dam,
- a **biomass installation** that must be fed with **180 t/y** of cultivated biomass,
- a pumped-storage system that includes a **reservoir with a 0.5 hm³** volume, a **2 km penstock** and a hydro turbine installation.

The total installed power of the system will be **4.8 MW and the total cost will be much more than 10 M€.**

Using thermal station

The energy demand (peak and annual) of the island could be easily covered by a common **thermal station with installed power less than 3 MW.**

The quantity of fossil fuel that must be burned to cover the annual electric energy demand is estimated to be about **1300 toe** per year.

In case that the fuel is oil, the estimated annual cost is about **0.5 M€.**

Let’s imagine that on the island there is a small **coal deposit** with the **volume of a small hill (200X200X50 m)**. In that case the specific deposit would feed the thermal station for about **1000 years**.

Examining Astypalaia’s energy recourses

Discussion

The common advantage of **renewable energy resources** is the **free and renewable fuel**.

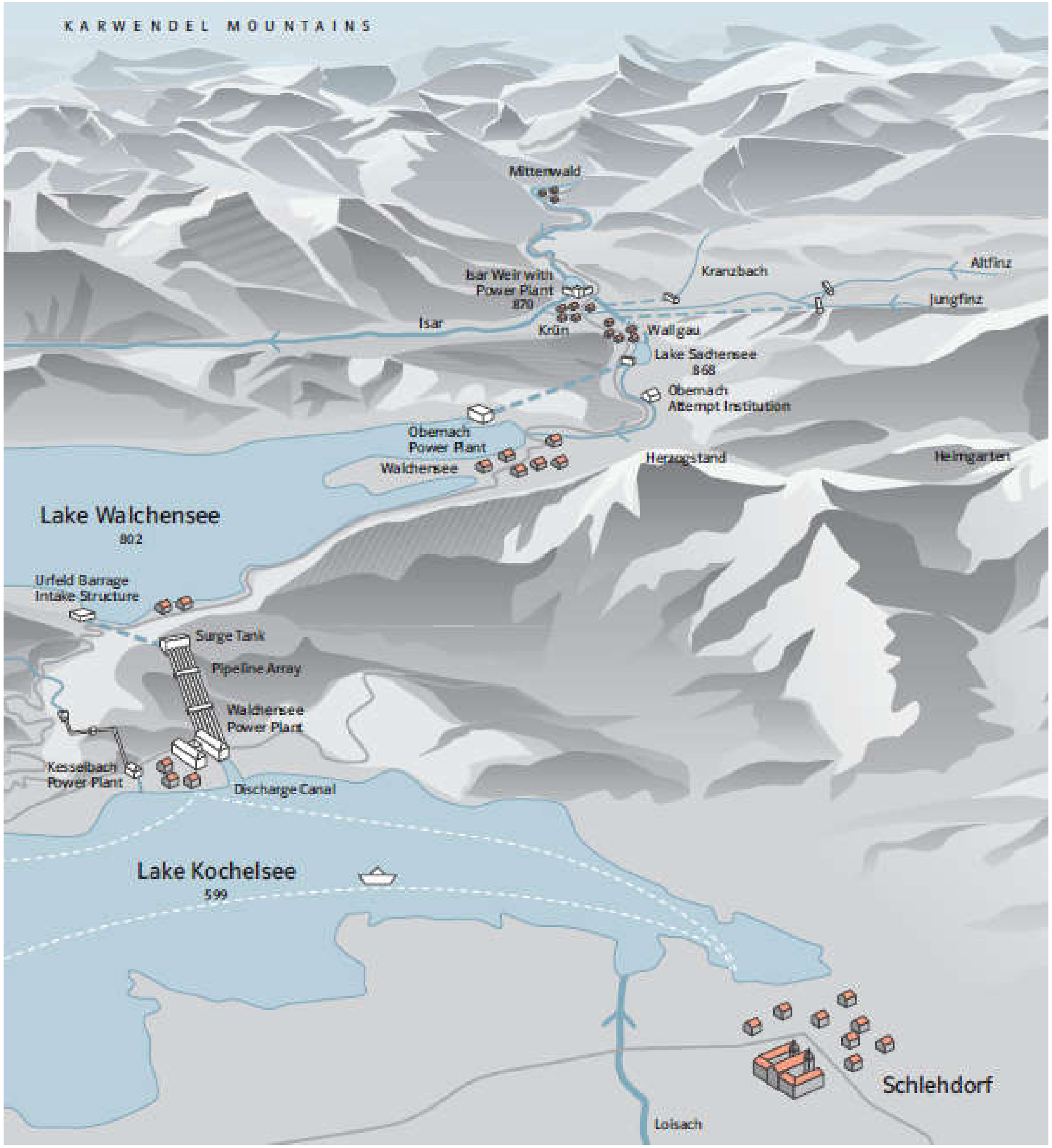
The energy production of **weather related resources** (wind, solar, marine, hydro) is completely **uncontrollable** and does not synchronize with demand. In the case of hydro energy, the use of reservoirs can control the production but also store the energy of other resources through pump-storage schemes.

The other two controllable resources **(biomass, geothermal)** are subject **to regulation** and therefore, capable of satisfying the peak electric energy demand.
In the case of biomass, the fuel must be collected and transported before its use
In the case of geothermal the necessary high enthalpy geothermal fields are located at few places in the world.

The decision of the energy mix must be taken after consideration of financial, environmental and sociological issues. The examined solutions have high demand of financial and organisational resources and therefore it is reasonable that thermal stations that are fed with oil, are broadly used on non-connected islands

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

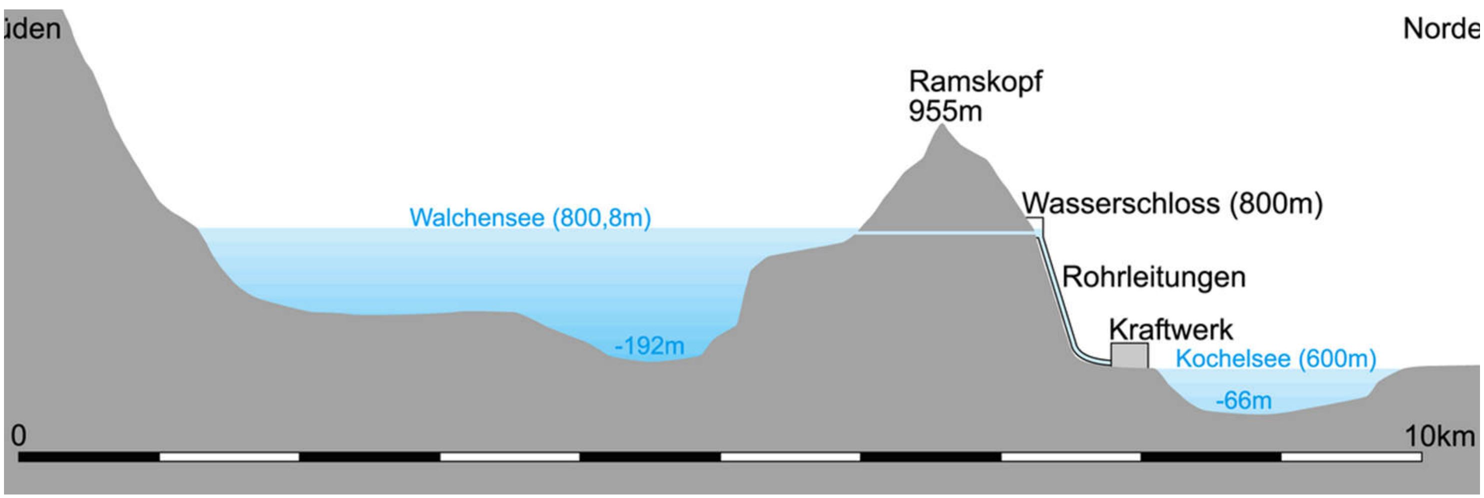
Technical data (from leaflet)

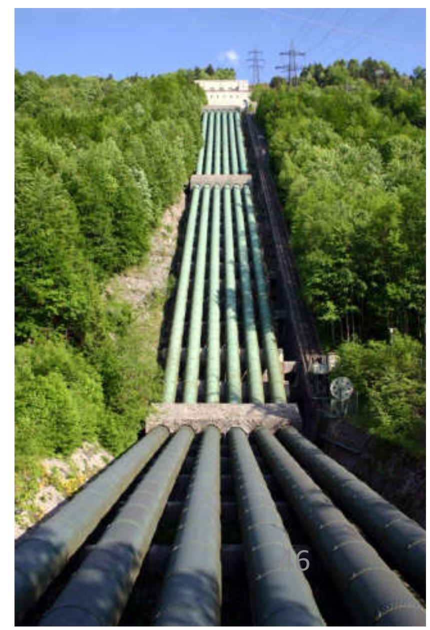
Installed capacity: **124 MW**
Annual energy production: **300 GWh**
Drop (head): **200 m**
Discharge: **84 m³/s**

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 m^3/s*200 m****n***
=>***n (efficiency)=0.75***





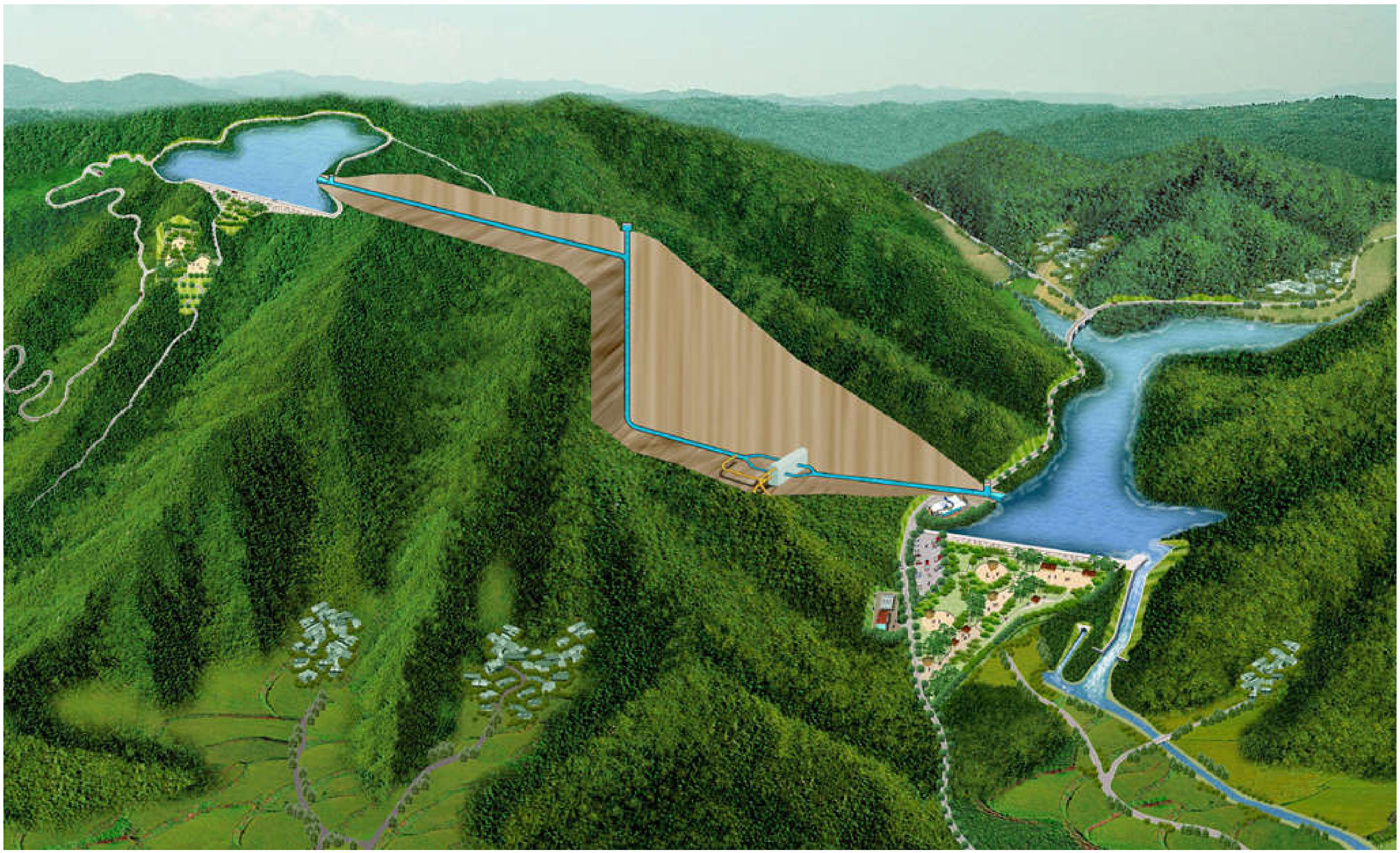
Electric energy management

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



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*