Project logo:

Priority logo:

Project No: **INCO – CT – 2004 – 509205**
Project acronym: **VBPC – RES**
Project title: **Virtual Balkan Power Centre for Advance of Renewable Energy Sources in Western Balkans**

Instrument: Coordination Action

Thematic priority:
International Cooperation (INCO)

D16: Educational Learning Material for Students on RES

Due date of deliverable: 30. November 2006
Actual submission date: 31. December 2006

Start date of the project: 1.1.2005 Duration: 36 months

Organization name:
University of Ljubljana

Revision:

Project co-founded by the European Commission within the Sixth Framework Programme (2002 – 2006)

Dissemination level

PU	Public

Renewable Energy Sources Technology, Economics and Policy (RESTEP) Curriculum

1 Introduction

In the energy-hungry society of today, sustainable development and environment conservation are the prime goals that need to be met. Common actions need to be taken to limit the greenhouse gas emissions exhausted by the fossil fuelled power plants, and renewable energy sources (RES) are rapidly becoming the key instrument to achieve this goal. To achieve this, intensified development of RES technology as well as RES policy need to be enacted.

Beside the engineers, policy makers and the potential investors, the general public needs to become more aware of the importance of the RES and especially their impact in electricity production. One of the key fields to ensure systematic awareness building on RES is through the teaching of students on undergraduate and graduate levels. They are uniquely poised to take over important positions in the technological and policy development early on, and to contribute important influence as the future opinion leaders. For this reason, in the VBPC-RES project we collected educational material to aid teachers in preparation of a higher-education curriculum to facilitate teaching of various aspects of electricity production from renewable energy sources.

2 Purpose of the project

The aim of the project “Virtual Balkan Power Centre for Advance of Renewable Energy Sources in Western Balkans – VBPC-RES“, organized under the auspices of EC, DG INCO, 6th Framework Program, is to increase awareness concerning the advantages offered by RES technologies. The project consortium consists mainly of partners from Western Balkans (WB) and from EU member countries, which are located in the Balkan area or near to it. The proceedings of the project focus on transferring the experience gained by countries with a high penetration of renewable energy sources to the Western Balkans countries. The awareness building is related to many factors such as: examination of different RES technologies, choosing the appropriate technology for particular sites, doing specific economic calculation to determine the investment efficiency, analyzing the connection possibilities to the electrical network, integration into the power market, etc. While the emphasis was on electricity production, other issues concerning the use of RES technologies were also mentioned, such as heating, cooling and wastewater treatment.

It should be mentioned that WB region is rich on renewable energy sources. Hydro energy and wood contribute significantly at present energy balances of WB countries, but experiences with modern RES technologies are limited. Due to the massive reconstruction of industry across the WB region, a space is widely opened to new sustainable energy options.

The partners of the VBPC-RES project consortium have great experience in either technology, policy or information dissemination. Within the project, several knowledge-gathering workshops were organized to harmonize the knowledge within the consortium, referring to a broad palette of issues about RES to be analyzed, mainly economic, social and technological. The higher education materials gathered are based on the experience and the and knowledge of the project partners.

3 Aim of the curriculum

The higher educational material gathered in the form of PowerPoint presentations and should contribute towards building of a curriculum on Renewable Energy Sources Technology, Economics and Policy (RESTEP). The curriculum for RESTEP should build on the existing higher education curricula. The contributing material was gathered during the course of the project and tested on two VBPC Summer Schools. It covers the current state of the art of RES technology and policy measures, and should give the students a fair amount of skills for economic evaluation of investment in RES projects. The emphasis is on electricity production, where each energy source, combined with technology, is treated as a Technology-Source Combination (TSC).

The courses were developed such that to include the main renewable energy sources as well as some distributed generation technologies. Specific characteristics were identified for each RES technology and included into the presentation so that to emphasize their particular advantages. The information presented by the lecturers were based on the current state of the art RES technology and policy measures, and it was structured in such a manner so that the students were given a fair amount of skills for economic evaluation of investment in RES projects.

The contents of the higher educational material were tested during the two Summer Schools organized within the VBPC-RES project. The Summer Schools were held at University “Politehnica” of Bucharest, Romania, in 2005, and in Fojnica, Bosnia and Herzegovina, in 2006. The main objectives of summer schools was to disseminate the knowledge and latest research achievements and practical experiences on RES to students, to enhance cooperation in the region by establishing networks of students and to test developed educational learning materials, providing independent students’ feedback. The two summer schools reached their objectives in the sense that the attending students increased their interest for RES technologies and showed a satisfaction concerning their improved skills at the end of the courses.

4 Curriculum Contents

The learning materials that would contribute towards RESTEP Curriculum comprise modules covering different aspects of a single TSC, as well as some general, cross-cutting modules not focusing on any single TSC. The RESTEP Curriculum should cover the following issues **for each TSC**:

- Physical principles
- Technology description;
- Economics of the TSC;
- Environmental influences;
- Regulatory framework;
- Best practice projects at the international level, in particular in the European Union;
- Case study: regional potentials and developed projects;
- References.

In the RESTEP Curriculum, the following **TSC modules** should cover:

- Photovoltaics, including electricity, heating and cooling;
- Wind Energy;
- Biomass: wood chips, pellets, forest residues, animal waste;
- Hydro Power: focus on small hydro;
- Geothermal Energy, including electricity and hot water;

In addition to the TSC modules, **General modules** should include:

- Comparison of Different TSCs
    - Focus on benefits and drawbacks of TSCs with examples
    - Forecasted development in the future
- Potentials of Various RES – state of the art in EU and in WB Countries
- Overview of RES-related Policies in EU and WB countries;
- Impact of RES on Power System Operation;
- Implementation of RES projects:
    - Technical and non-technical aspects;
    - Project preparation, management, decision making processes at project level;
    - Planning and organization of RES systems;
    - EU best practice at project implementation;
    - Barriers and country specifics.

The higher education materials gathered in the course of VBPC-RES project have already been used as the basis for improvement of the pertaining teaching curricula and introduced into the education process at University of Tuzla, University of Zagreb, University of Ljubljana and University “Politehnica” of Bucharest. In the latter, at the Faculty of Power Engineering, there are some new courses introduced for undergraduate students such as “Distributed generation”, in the 2nd year, “Renewable energy sources”, in the 4th year, as well as for master students such as “Sustainable development”, in the 1st year. All concerned partners find the collected materials as a sound base to further develop their courses.

VIRTUAL BALKAN POWER CENTRE

Renewable Energy Sources Technology, Economics and Policy Curriculum

RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

Technology-Source Combination module

GEOTHERMAL ENERGY

Authors: Dr. C. Karytsas, D. Mendrinos, and K. Karras

Centre for Renewable Energy Sources

July 2006

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Contract: INCO-CT-2004-509205

Geothermal energy : The Reliable Renewable

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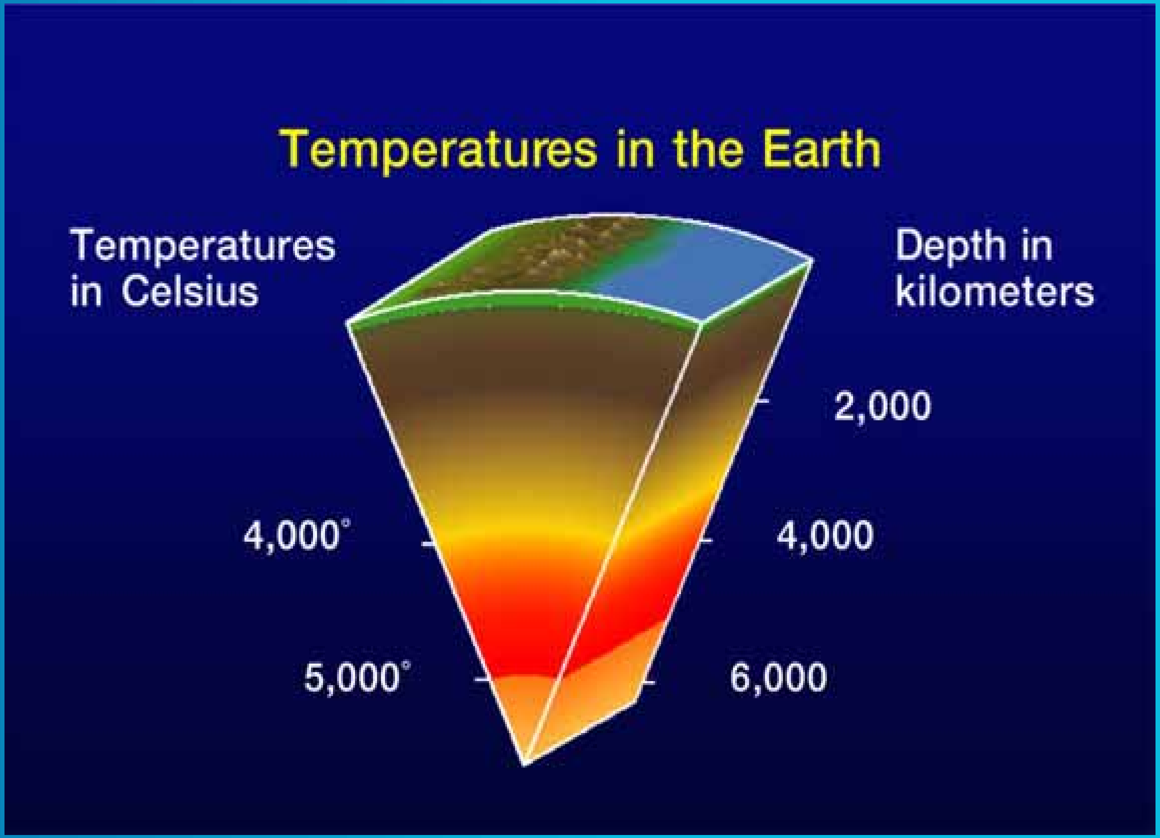
Geothermal Energy is the Heat of the Earth interior



Geothermal Energy forms

- High Enthalpy:
  - Ground rocks & water heat of temperatures > 150 ºC
- Low Enthalpy:
  - Ground rocks & water heat with temperature 25-150 ºC
- Shallow geothermal energy:
  - Rocks and water of low depths with temperature < 25 ºC

Geothermal Power stations

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Power production Technology

Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

Drilling rig view

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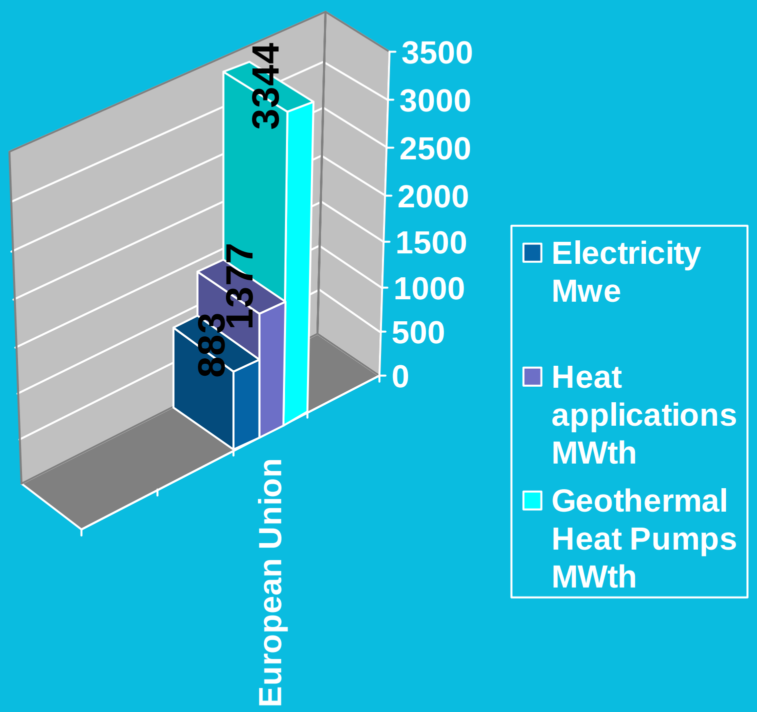
Geothermal Energy applications in the E.U.

- Electricity Production
- Heat utilization
- Geothermal Heat Pumps



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Geothermal Powerstation view

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High-enthalpy (temperature) drilling

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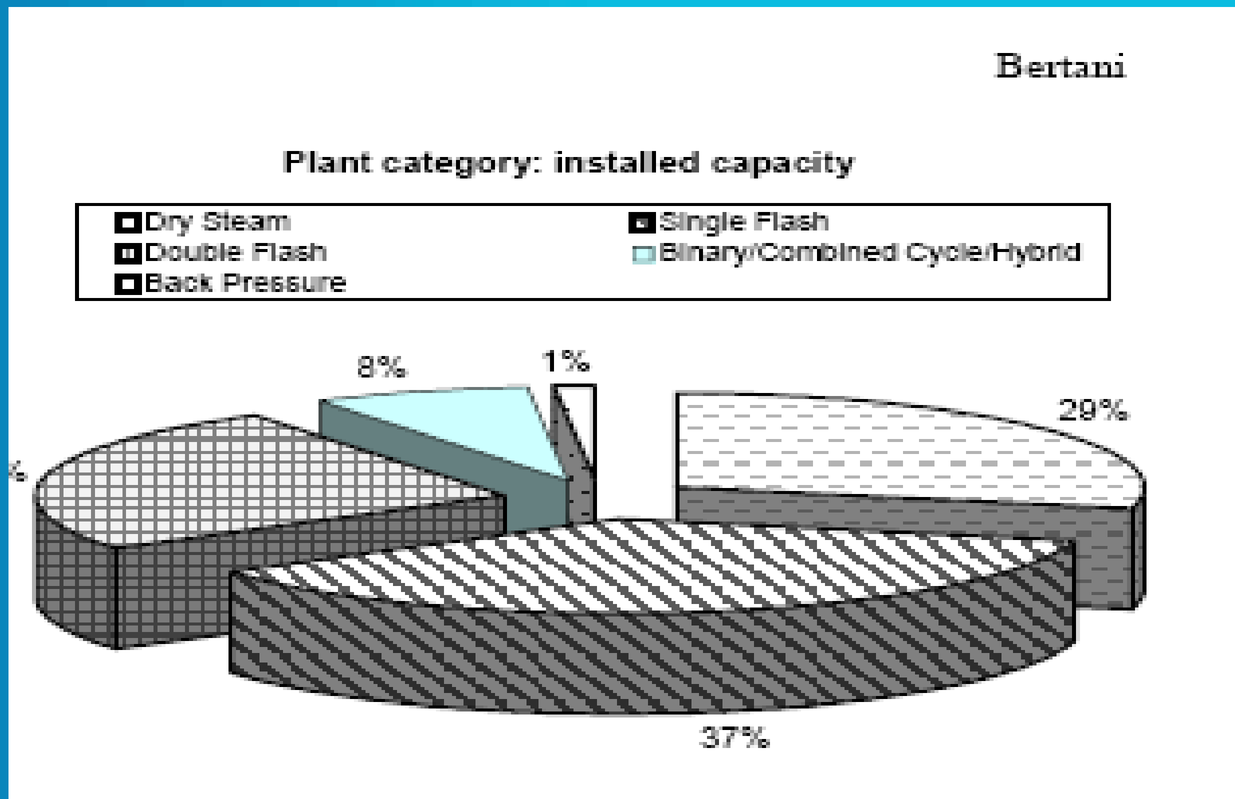
From Bertani 2005

Table 1: Installed Capacity and Energy Generation.

Year	Installed Capacity [MW]	Electricity Generation [GWh/y]
1975	1 300	
1980	3 887	
1985	4 764	
1990	5 832	
1995	6 798	37 744
2000	7 974	49 261
2005	8 912	56 798

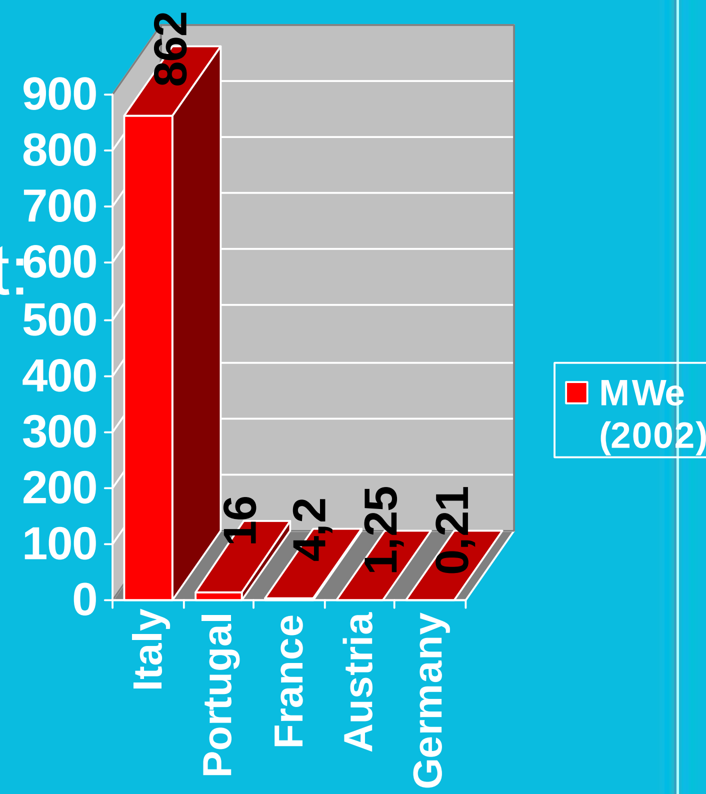

Bertani
Plant category: installed capacity
Dry Steam
Single Flash
Double Flash
Binary/Combined Cycle/Hybrid
Back Pressure
8%
1%
29%
37%

Electricity Production

- Capital cost:
  800 – 1600 € / kW(e)

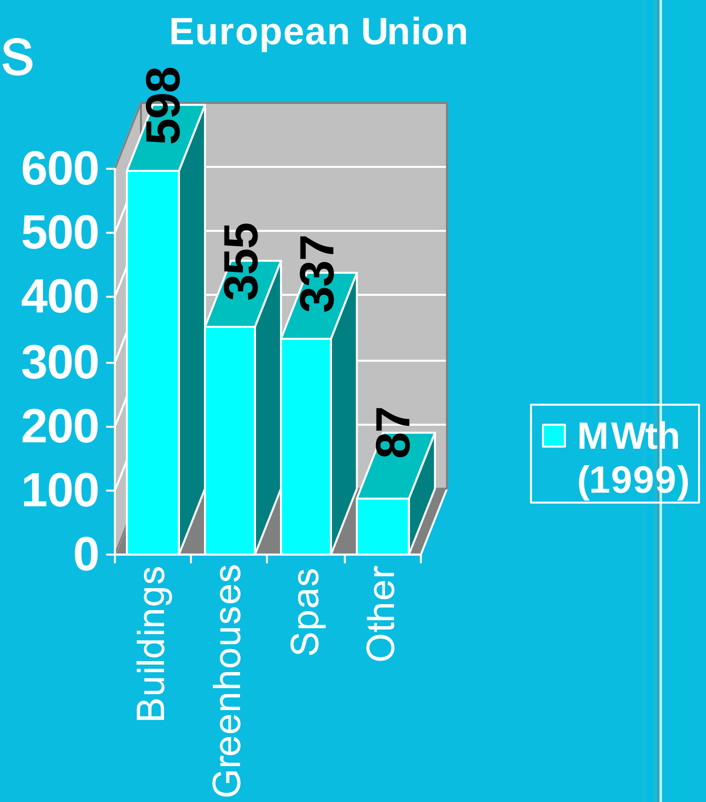
- Operation and Maintenance cost:
  2 – 3 %

- Energy cost:
  0,03 – 0,09 € / kWh(e)



Thermal applications (I)

- Buildings heating
- Heating of Greenhouses and soils
- Spas
- Other applications



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Thermal applications (II)

- Capital cost:
  200 – 1400 € / kW(th)

- Operation and Maintenance cost:
  2 – 3 %

- Energy cost:
  0,005 – 0,035 € / kWh(th)

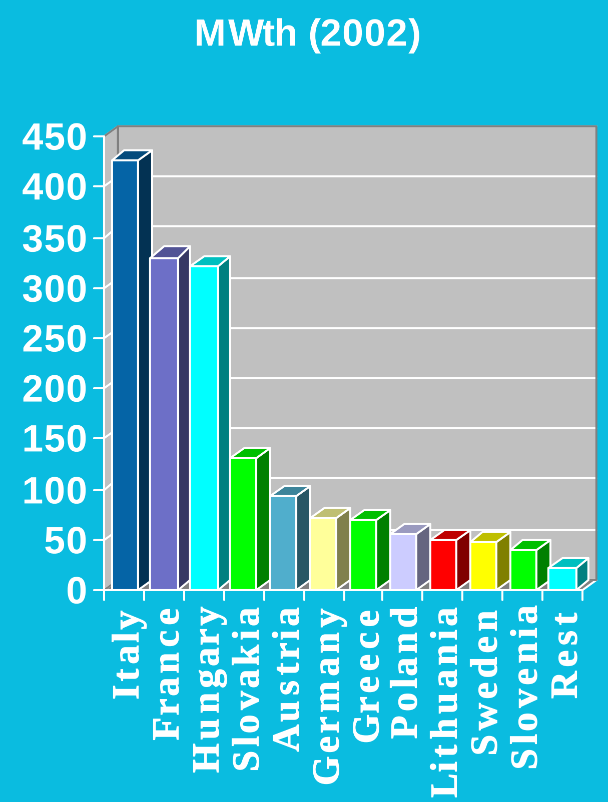

Table 3. Summary of the various worldwide direct-use categories, 1995-2005

	Capacity, MWt			Utilization TJ/yr			Capacity Factor		
	2005	2000	1995	2005	2000	1995	2005	2000	1995
Geothermal heat pumps	15,723	5,275	1,854	86,673	23,275	14,617	0.17	0.14	0.25
Space heating	4,158	3,263	2,579	52,868	42,926	38,230	0.40	0.42	0.47
Greenhouse heating	1,348	1,246	1,085	19,607	17,864	15,742	0.46	0.45	0.46
Aquaculture pond heating	616	605	1,097	10,969	11,733	13,493	0.56	0.61	0.39
Agricultural drying	157	74	67	2,013	1,038	1,124	0.41	0.44	0.53
Industrial uses	489	474	544	11,068	10,220	10,120	0.72	0.68	0.59
Bathing and swimming	4,911	3,957	1,085	75,289	79,546	15,742	0.49	0.64	0.46
Cooling/snow melting	338	114	115	1,885	1,063	1,124	0.18	0.30	0.31
Others	86	137	238	1,045	3,034	2,249	0.39	0.70	0.30
Total	27,825	15,145	8,664	261,418	190,699	112,441	0.30	0.40	0.41

From Lund et al. 2005

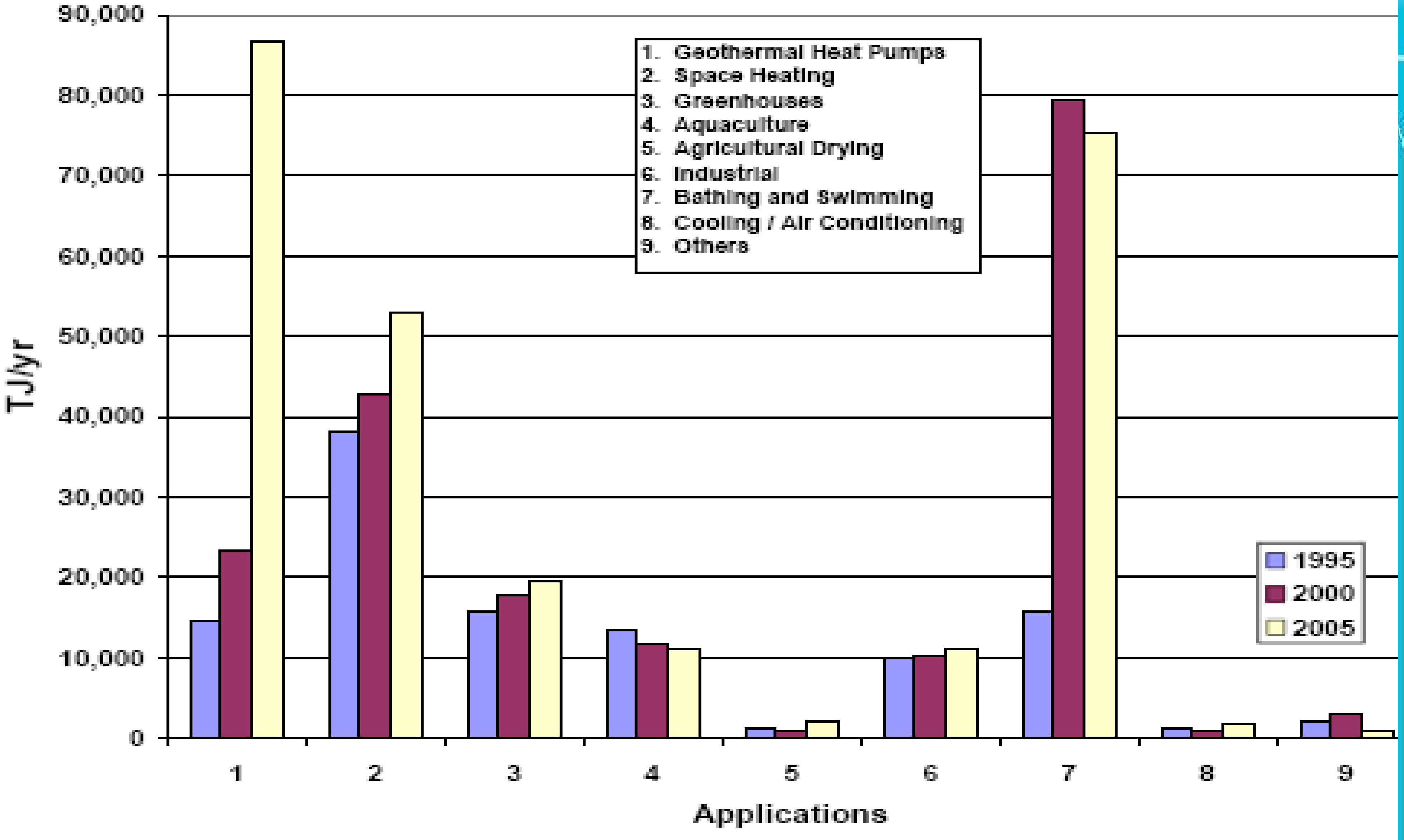

Figure 1: Comparison of worldwide energy use in TJ/yr for 1995, 2000 and 2005.

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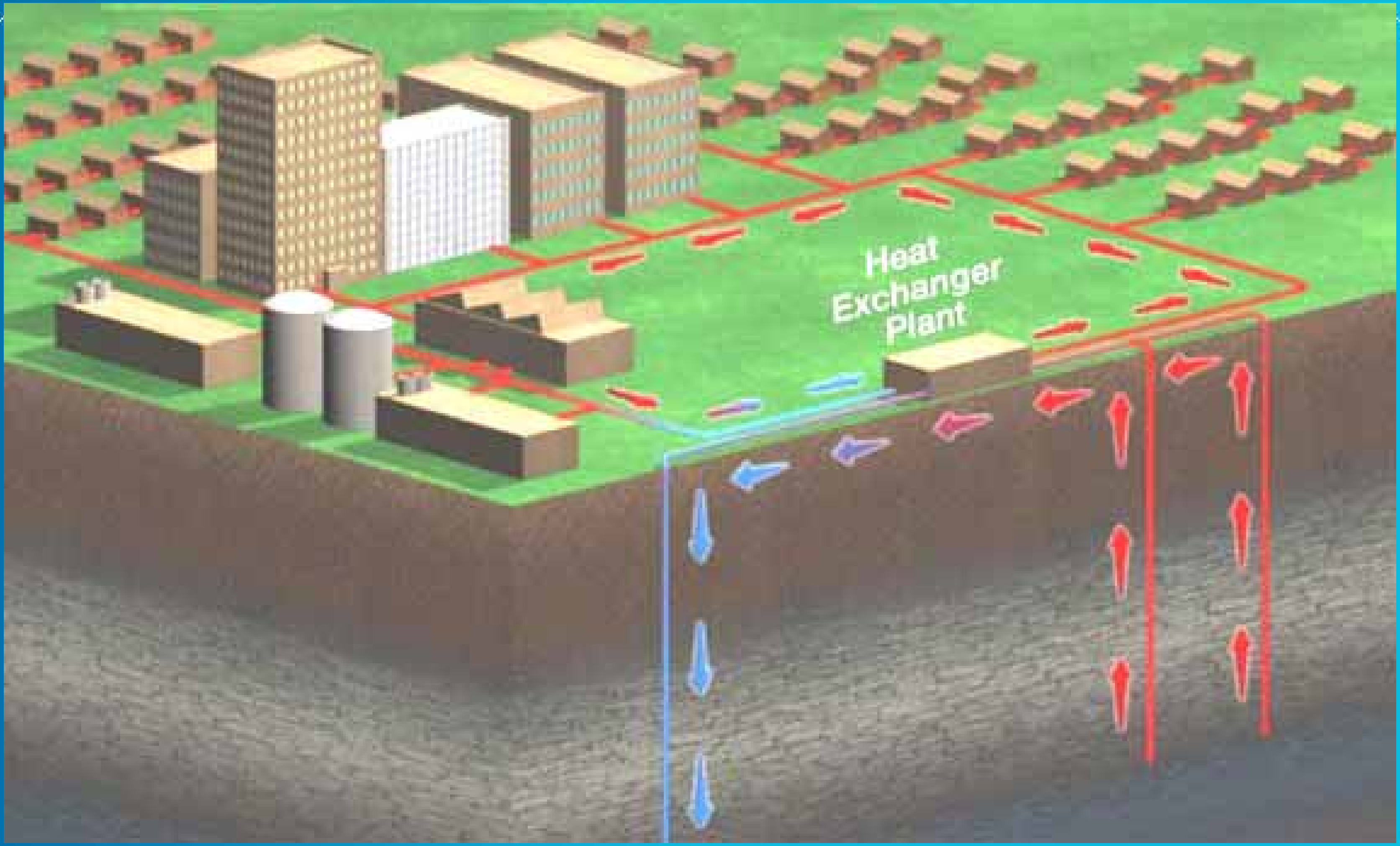
District-Heating



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Traianoupolis-spas system specifications

- Borehole ~60m^3/h, 52°C
- Heat exchanger
- Re-injection at 37°C
- Power 1 MWth
- Underground PP piping
- 4 buildings of 11 rooms
- Spas buillding
- Floor system 40⇒30 °C
- Hot water pre-heating

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Traianoupolis-spas hotel heating

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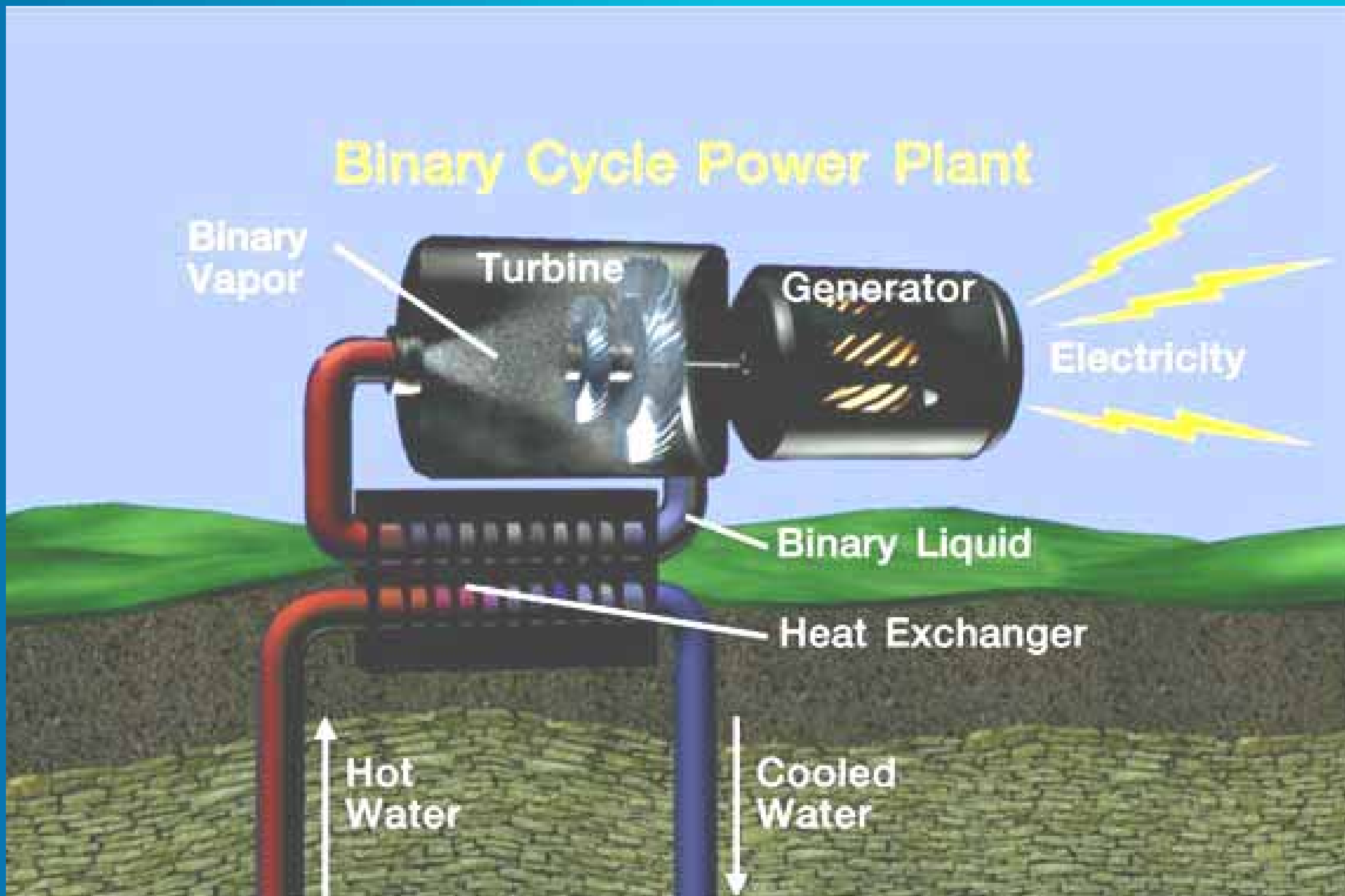
Power-production by use of an Organic substance or Ammonia



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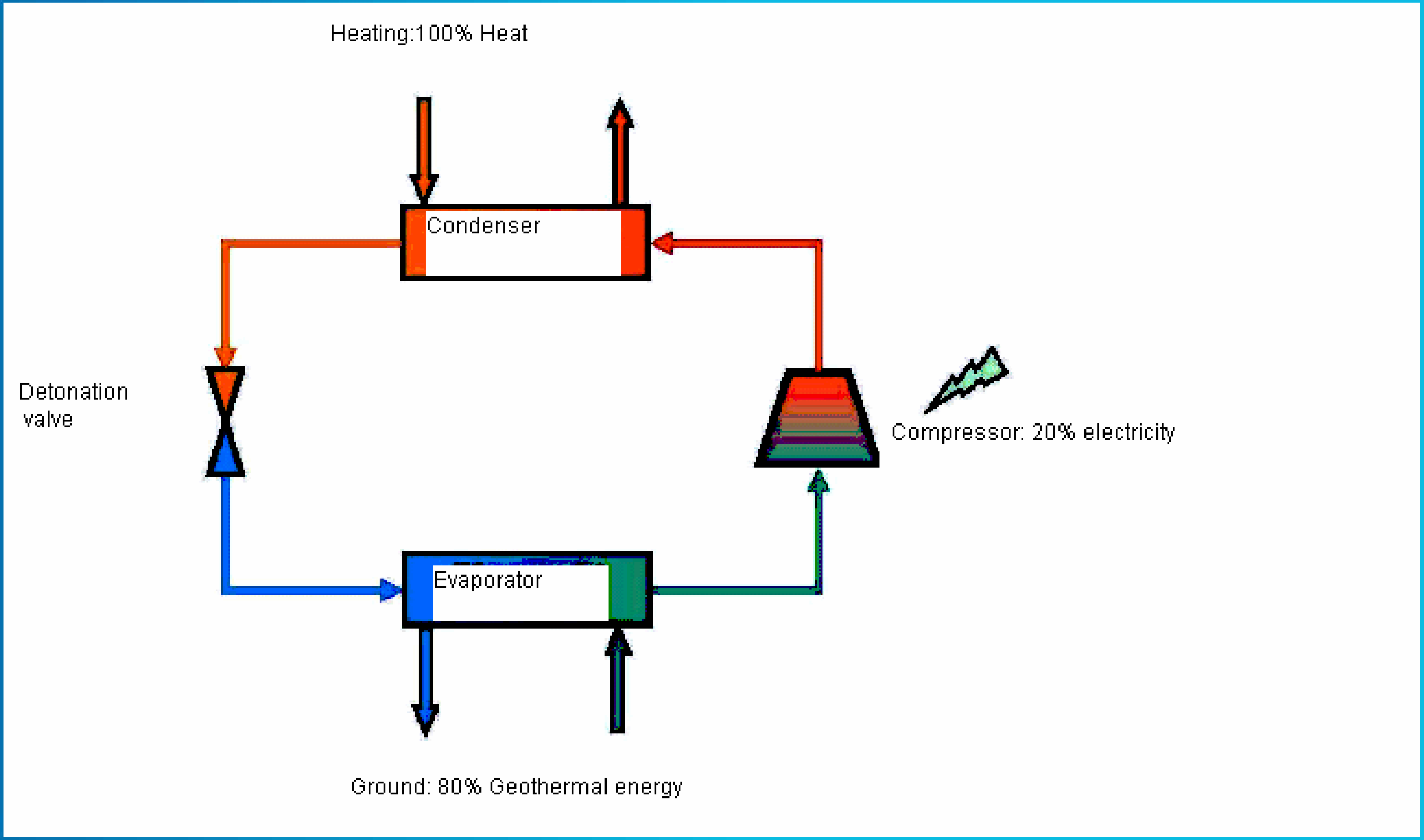
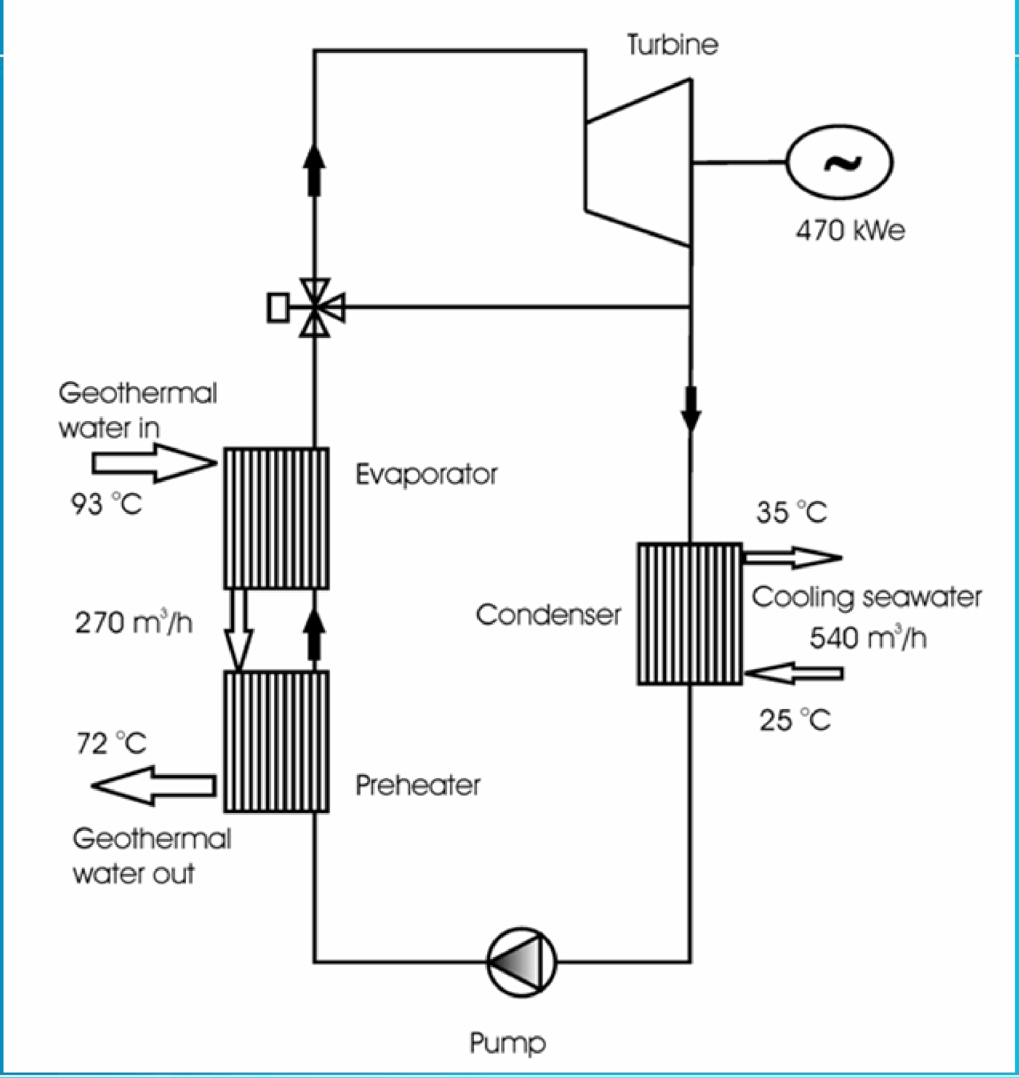
Operation principle



Operation principle



Kimolos desalination unit

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Heating of Greenhouses

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Fish farming

SPA's

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Drilling-rig view

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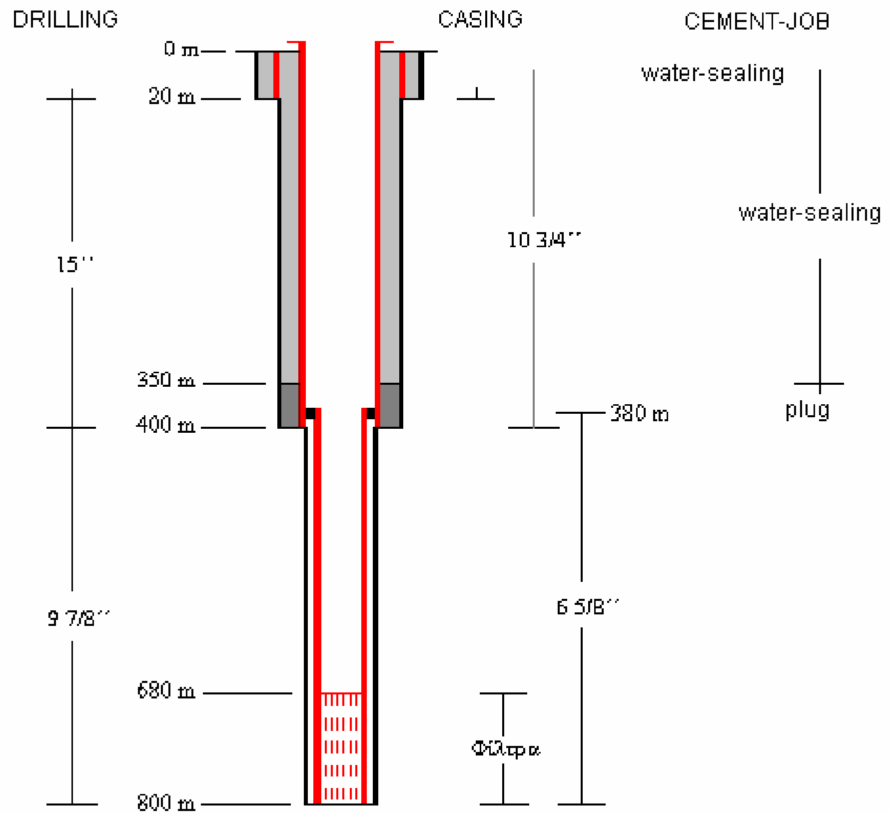
Borehole section



GEOTHERMAL BORE-HOLE OF SALONICA AIRPORT "MACEDONIA"

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Submerged pump placement in a low temperature well in Langadas

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Langadas Geothermal Cascade Utilization System

- 90 m³/h water at 22-40 °C
- 3 boreholes 8" of 100-200 m
- 2.2 km water transportation pipe
- Water Tanks
- 8 Water-source Heat Pumps
- Building entering temp. 45 °C
- Low temperature heating system
- Automations (Inverter)

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Geothermal Heat Pumps (I)

- Shallow Geothermal energy (t < 25 ºC):
  - Heating & cooling
    with water-cooled heat pumps

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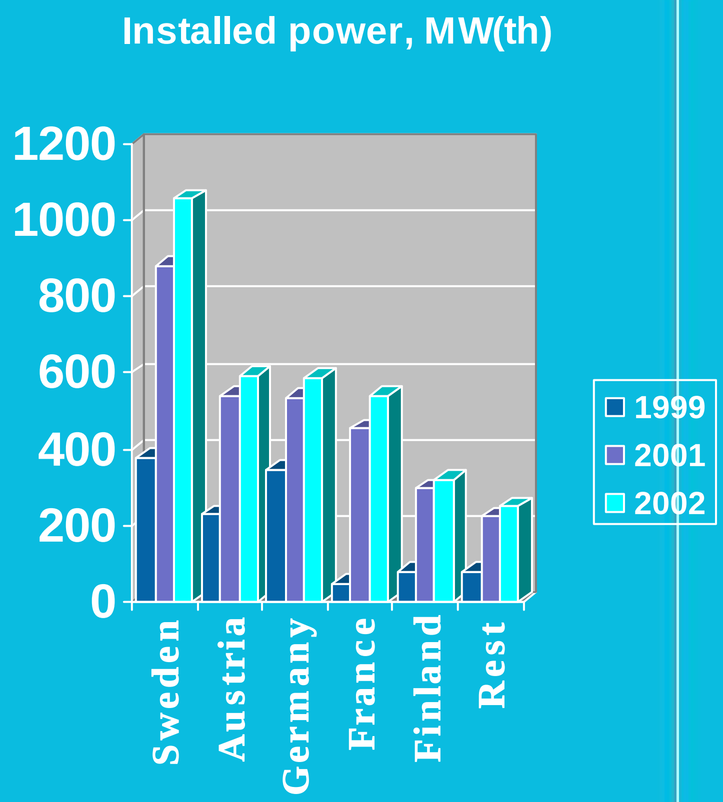
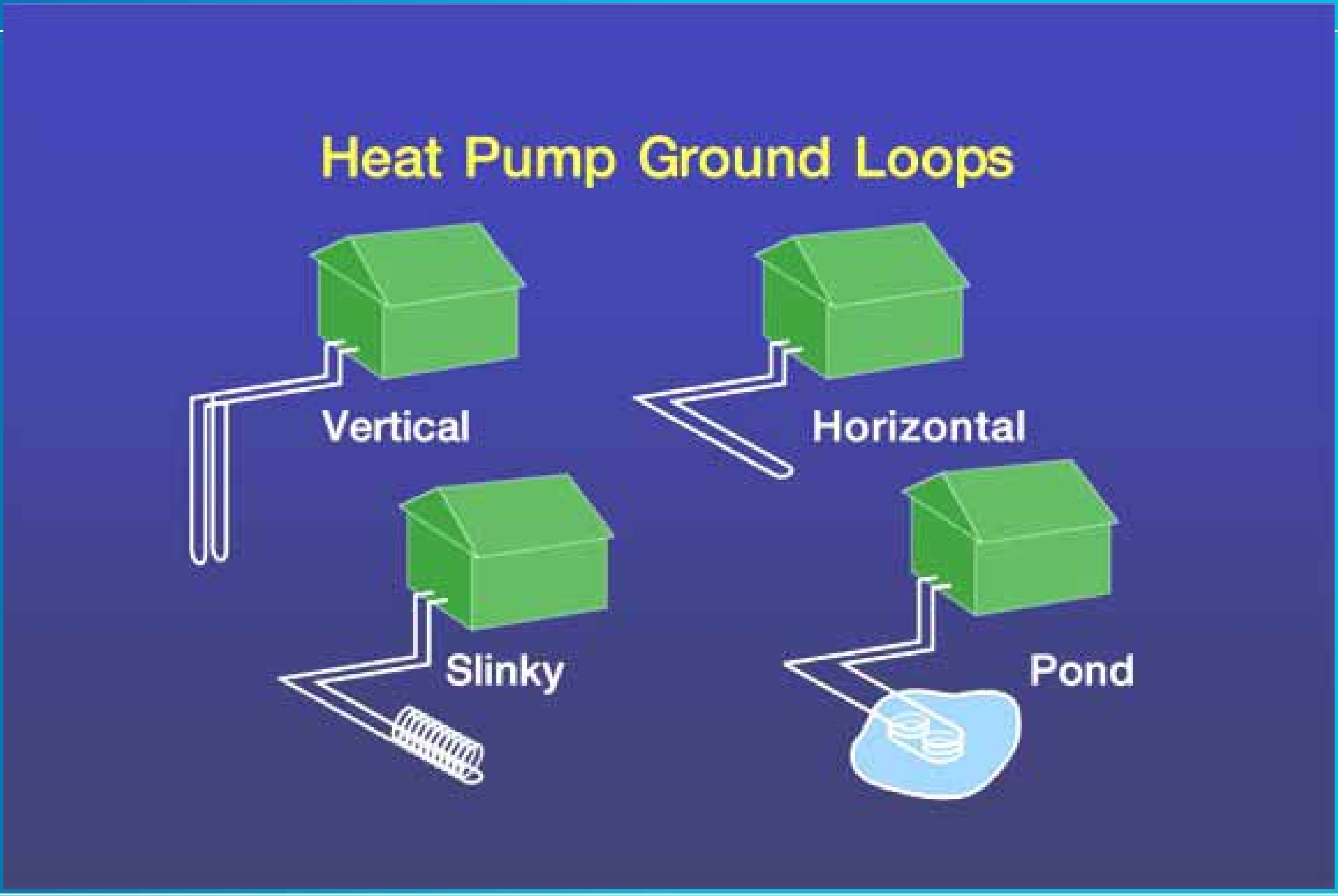
Geothermal Heat Pumps (II)

- Capital cost:
  600 – 1800 € / kW(th)
- Energy cost (Electricity & maintenance):
  0,012 – 0,024 € / kWh(th)
- Energy cost (Including capital with money cost 5% for 20 years):
  0,030 – 0,048 € / kWh(th)



Underground heat pumps arrangement



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Horizontal Earth Heat Exchanger (HEHE) Technology

Borehole Heat Exchanger (BHE) Technology

Underground Heat exchanger Technology

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Pylaia Town-Hall system specifications

- 21 6’’ boreholes
- 80 m deep
- U-tube , Φ 40
- 10 Water-source HPs
- 155 kWth & 215 kWC
- Fan-coils
- Central AHU

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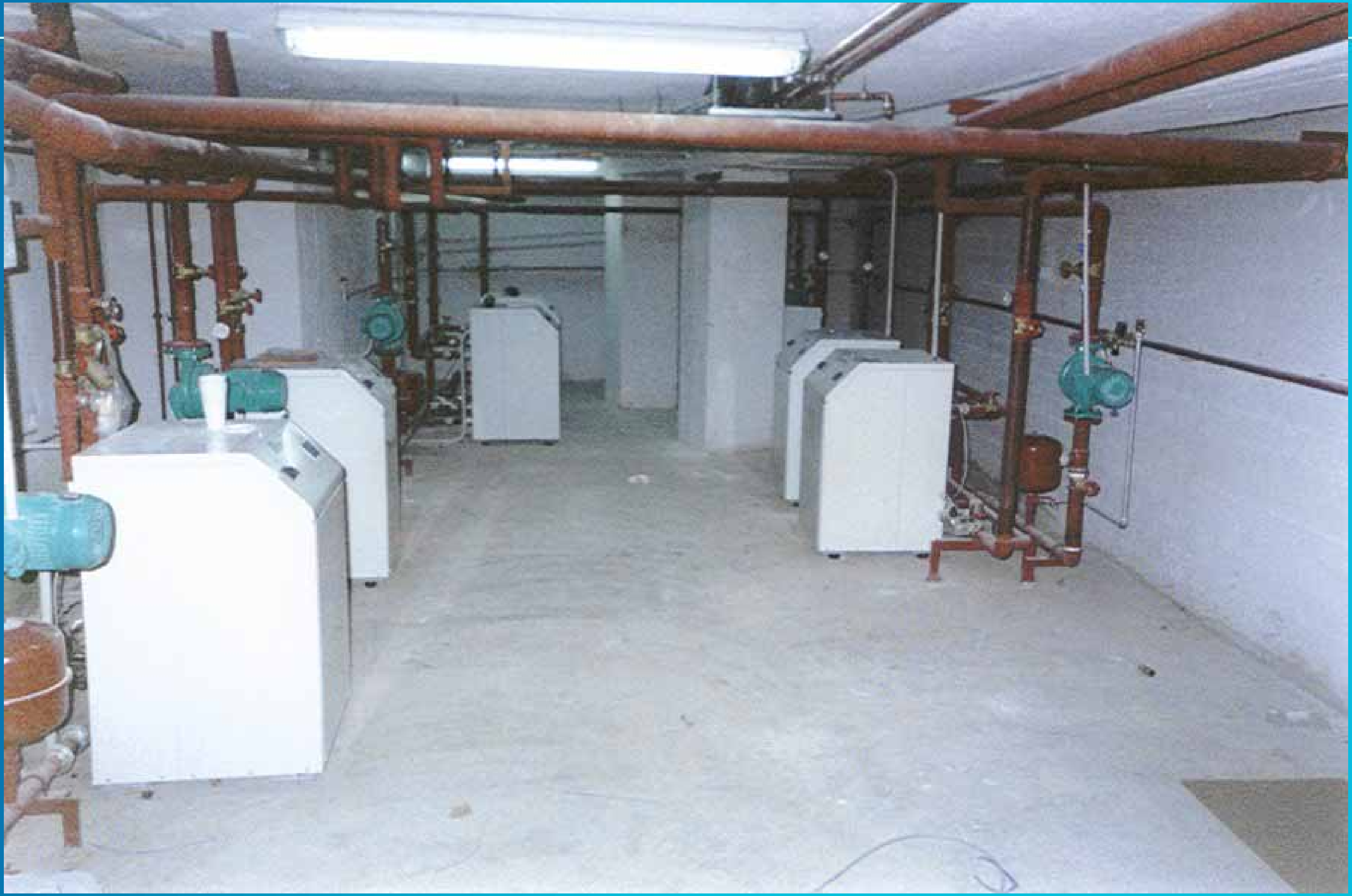
Heat Pumps in Pylaia Townhall



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NTUA Building

- Borehole of 280 m, 35 m^3/h, 22 °C ⇒ 80 % energy
- 13 VEHEs 8½", 90 m deep, U-TUBE ⇒ 20 % energy
- 2 Water-source HPs
- 526 kWth & 461 kWC
- COP = 3,3 – 3,5

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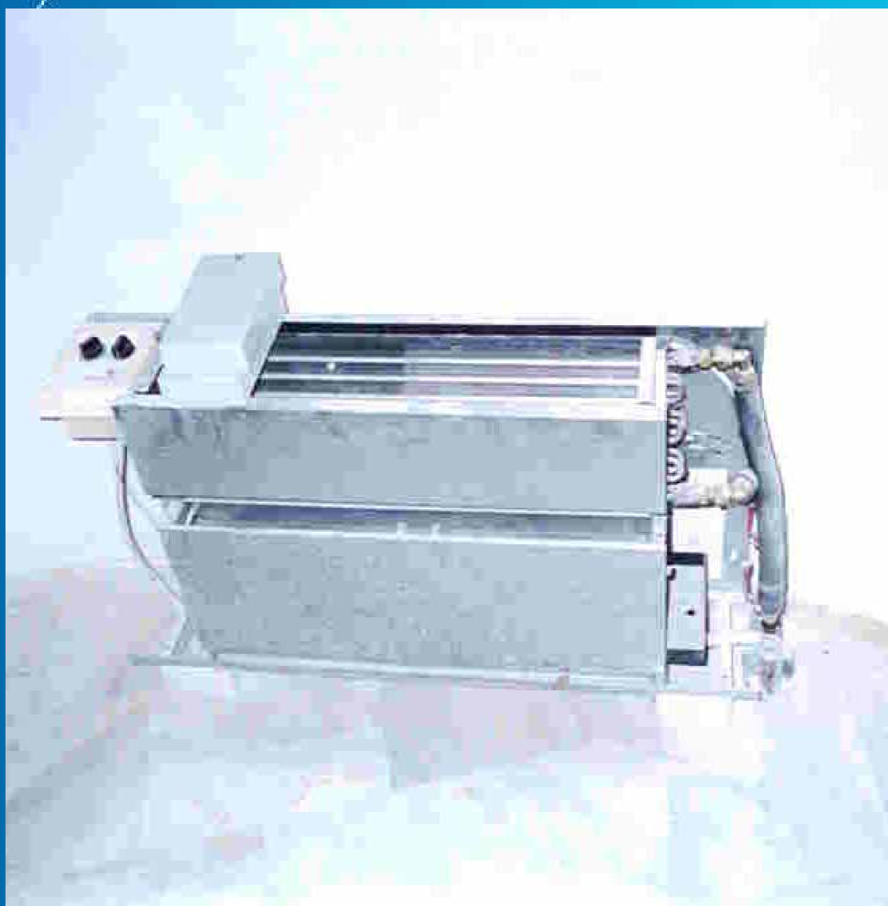
Fan-coil in Pylaia Townhall



European Public-law Centre

- Borehole 24 °C
- Heat Exchanger
- 2 Water-source HPs
- 70 kWth & 100 kWth
- Fan-coils
- 2 Central AHU
- Solar Collectors
- COP = 3,91 & 4,3

Geothermal ORC & MED in Milos Isl.

- 8 Boreholes 70 – 185 m
- Total 550 m³/h
- Wellhead Temps. 55 – 100 °C
- 20.000 – 55.000 ppm
- 75 m³/h GEOTHERMAL MED Unit
- ORC 600 kWe

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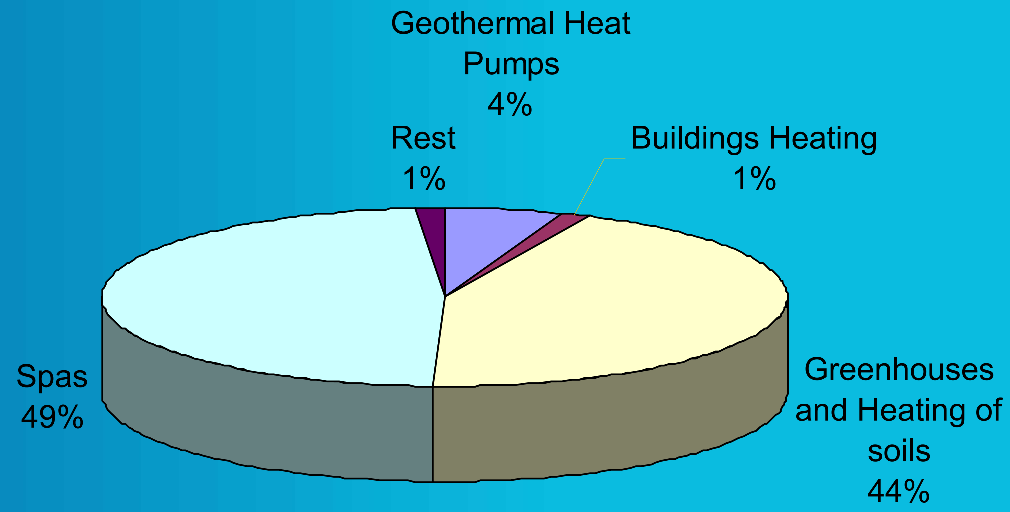
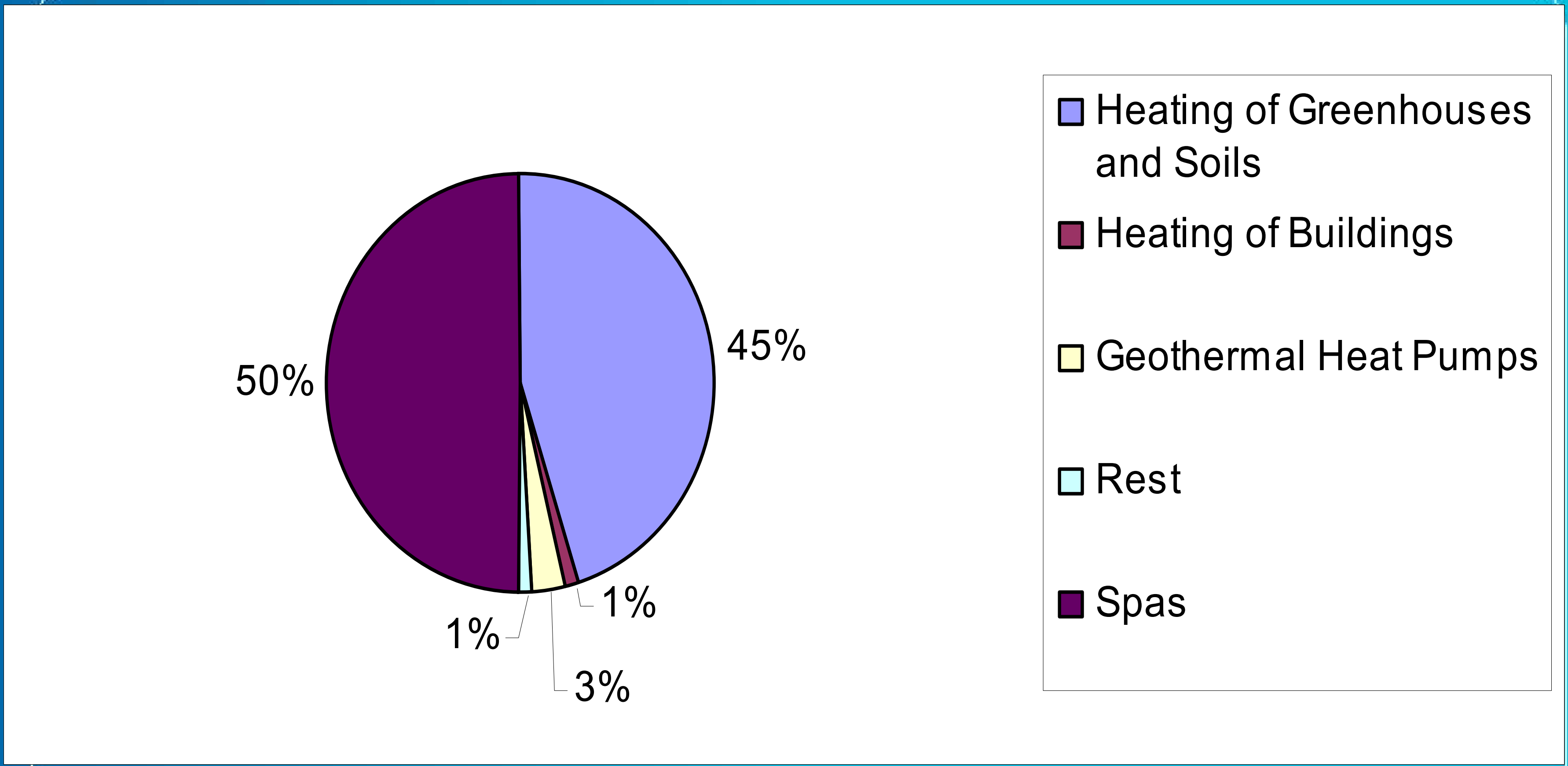
Geothermal Energy applications in Greece (2005): 74 MW



Geothermal Energy applications in Greece (2001): 71 MW



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Renewable Energy Sources Technology, Economics and Policy Curriculum

Technology-Source Combination module

Wind Energy

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Aim of lecture

- To give a general and comprehensive overview of techno-economic and environmental characteristics of wind energy use
- Why?
  - Rapid increase in installed capacities world wide
  - Strong technology development
  - Specificities related to the operation and control
  - Economic feasibility
  - Strong interest of investors and good potentials for exploitation in Croatia
  - Benefits from wind energy use

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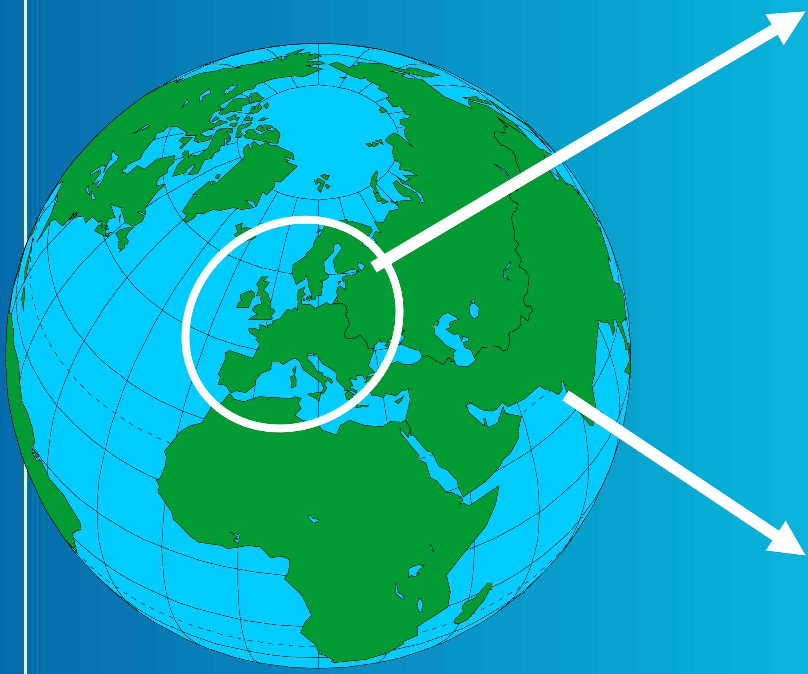
Content of lecture

- Introduction to wind energy use
- Physical principals of wind energy use
- Technology for wind energy use
- Economics of wind energy use
- Environmental impacts
- Implementation of wind power projects
- Conclusion: Benefits from wind energy use

Introduction

- Wind energy potentials
- Wind energy status
  - in the world
  - in Europe
  - in Croatia
- Regulatory framework to support wind energy use

Wind energy potentials



Europe

	TWh/year
onshore	500
offshore	2000
consumption [1]	3000

World

	TWh/year
potential [2]	25.000
consumption [1]	20.000

1) approx. current level
2) no offshore !

Source: ALTENER

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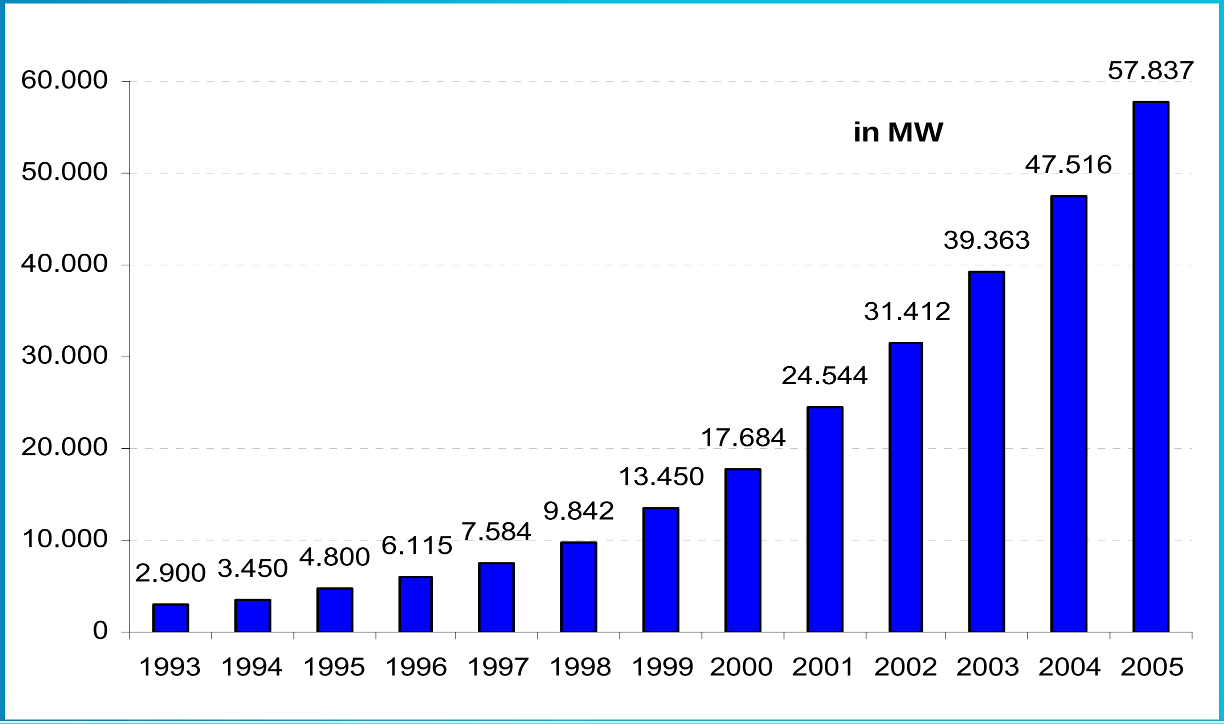
Status of wind energy use

- Installed world capacities have grown in time period 1993-2005 from 2,900 MW to 57,837 MW (annual average growth rate of 28.4%)



Status of wind energy use, II

- In 2005 installed capacity in the EU has reached 40,455.4 MW
- Wind energy origin electricity production in the EU was equal to 69.5 TWh in 2005 → a little over 2% of total EU electricity production
- The EU share in total world installed wind power capacities at the end of 2005 was equal to 70.6% and the share in market for generating equipment was equal to 60.3%
- Constant growth and development directed towards increase of wind turbine sizes, improved operation and control procedures and off-shore applications

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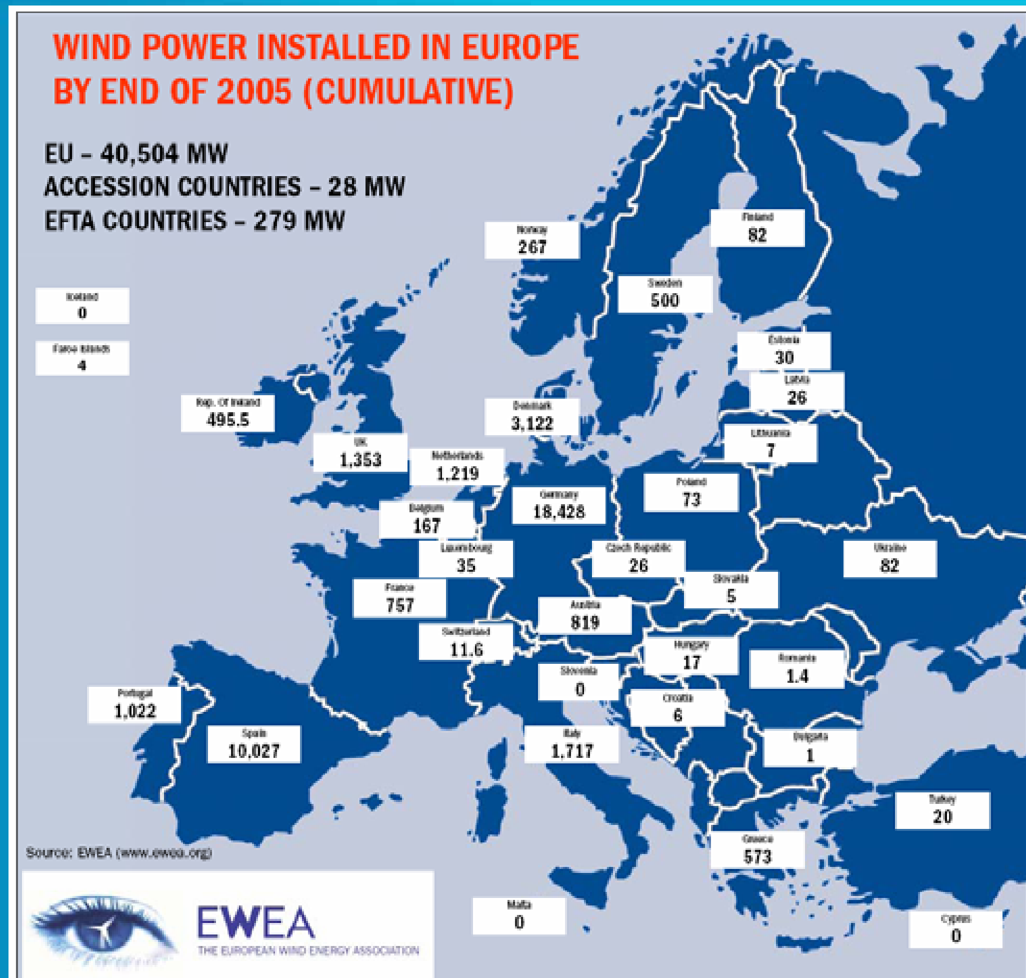
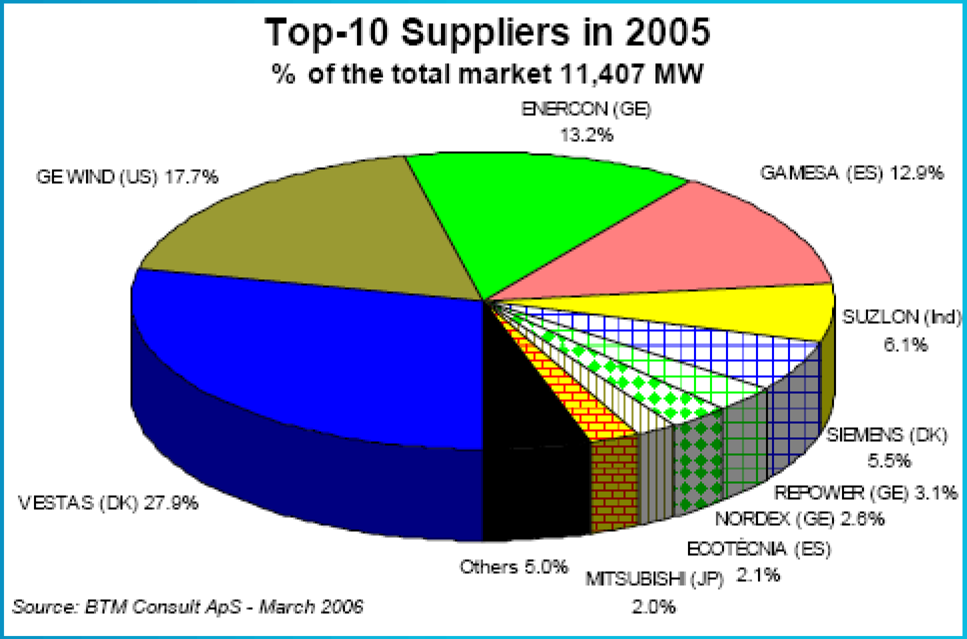
Status of wind energy use, III



Status of wind energy use, IV

- Market share (manufacturers) → trend is concentration



Wind energy status in Croatia

- Strong interest for wind energy use in Croatia
- National wind energy programme ENWIND established in 1998 → assessment of potentials, wind mapping, proposals for pilot projects → 29 locations → 400 MW installed capacities and 800 GWh electricity production per year
- Update of ENWIND in 2003 → 104 locations → 1300 MW installed capacities and 3.000 GWh electricity production per year
- Currently only one wind power plant operating – 5.95 MW WPP Ravne on the island of Pag → private (foreign) investor and power purchase agreement with Croatian power utility
- Several projects in preparation → 11.2 MW WPP Trtar-Krtolin near Šibenik

Wind energy status in Croatia, II

- Development of domestic industry
  - Development of own 750 kW and 1 MW wind turbine in energy equipment production company Končar
  - Commissioning of the first 1MW wind turbine in 2006
  - Commissioning of the 14 1MW wind turbines in 2007 – WPP Pometeno Brdo
- Maintaining existing and creating new jobs!
- Apart from grid-connected facilities, possibilities exist for off-grid applications, especially see water desalinisation on the Adriatic islands, water pumping and irrigation systems → development of isolated areas

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Wind energy status in Croatia, III

- Main barriers and problems
  - Lack of complete regulatory framework in Croatia → tariff system for RES and CHP
    - prescribed purchase price for every RES type
    - differentiation according to the installed power
    - proposal: for WPP over 1 MW → 0,57 HRK/kWh (7,6 €cents/kWh)
  - Jurisdiction of different ministries → Ministry of Environmental Protection, Physical Planning and Construction has brought out the Ordinance which forbids the construction of WPP on the islands and in the area 1000 m away from coast line
  - Long and complicated administrative procedure and permit issuing
  - Negotiations with TSO

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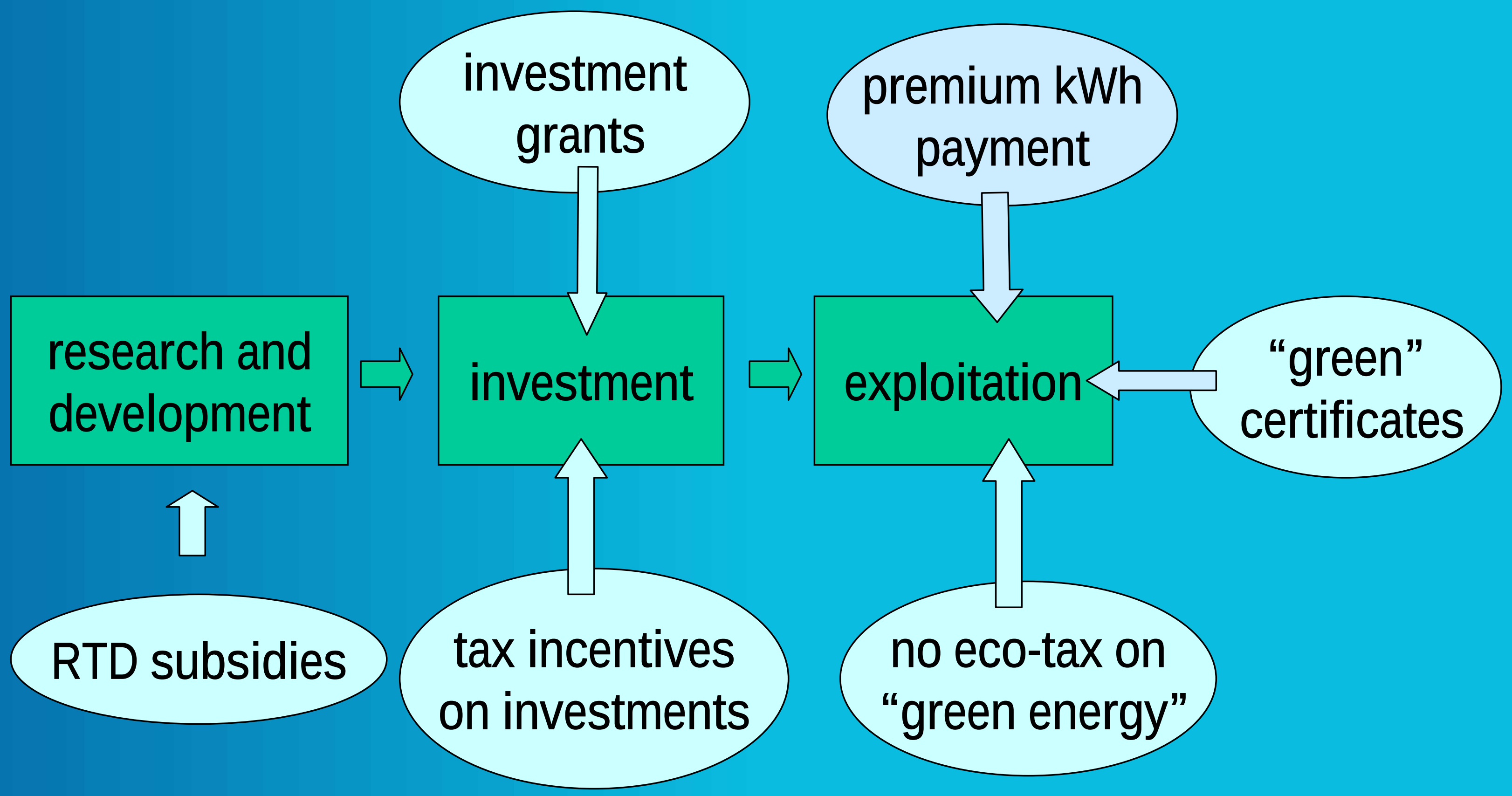
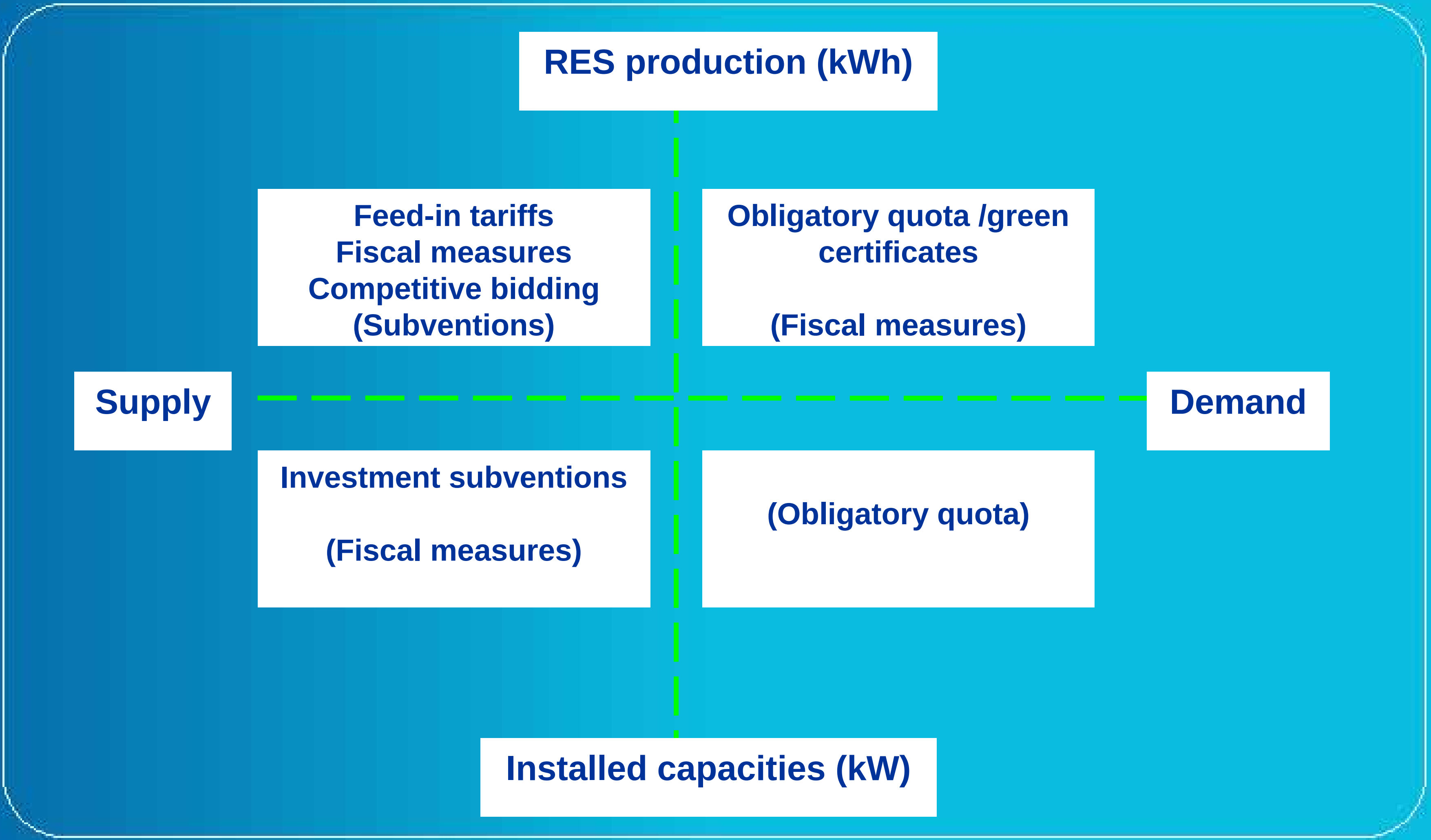
Regulatory framework



Source: ALTENER

Regulatory framework, II



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Regulatory framework, III

Country	Green certificates	Feed-in tariffs	Fiscal measures	Investment subventions	Other
Austria	Active	Active			
Belgium	Planned	Active			
Czech		Active		Active	
Denmark	Planned	Active	Active		
Finland			Active	Active	Active
France		Active			Active
Greek		Active	Active	Active	Active
Ireland					Active
Italy	Active				
Hungary		Active		Active	Active
Netherlands	Active		Active		
Norway				Active	
Germany		Active	Active	Active	
Poland		Active		Active	Active
Portugal		Active			
Slovakia			Active	Active	
Slovenia		Active	Active		
Spain		Active			
Sweden	Planned	Active	Active	Active	Active
Switzerland		Planned		Planned	Planned
Great Britain	Active		Active		
Active system	Active		Planned system	Planned	

Regulatory framework, IV

- Feed-in tariffs – the most usual
  - Fixed tariff or
  - Market price cap
  - Importance of wind forecast:
    - obligation to communicate to the grid operator the power production they forecast each day
    - if the deviation in each of the scheduling intervals is more than 20% higher or lower than the forecast production → penalty!
  - Reactive power: penalty or bonus

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Physical principles of wind energy use

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Content of lectures

- Wind characteristics
  - Time and space variability
- Wind statistics
  - Measure – correlate – predict
  - Wind atlas
- Wind energy production
  - Use of wind statistics
  - Power curve
  - Energy production
- Further reading

Wind characteristics

- Wind is movement of air masses
  - caused by pressure differences (resulting from temperature differences)
  - influenced by rotation of the earth and terrain features

- Wind is converted solar energy (1 ~ 2 % of solar energy input)

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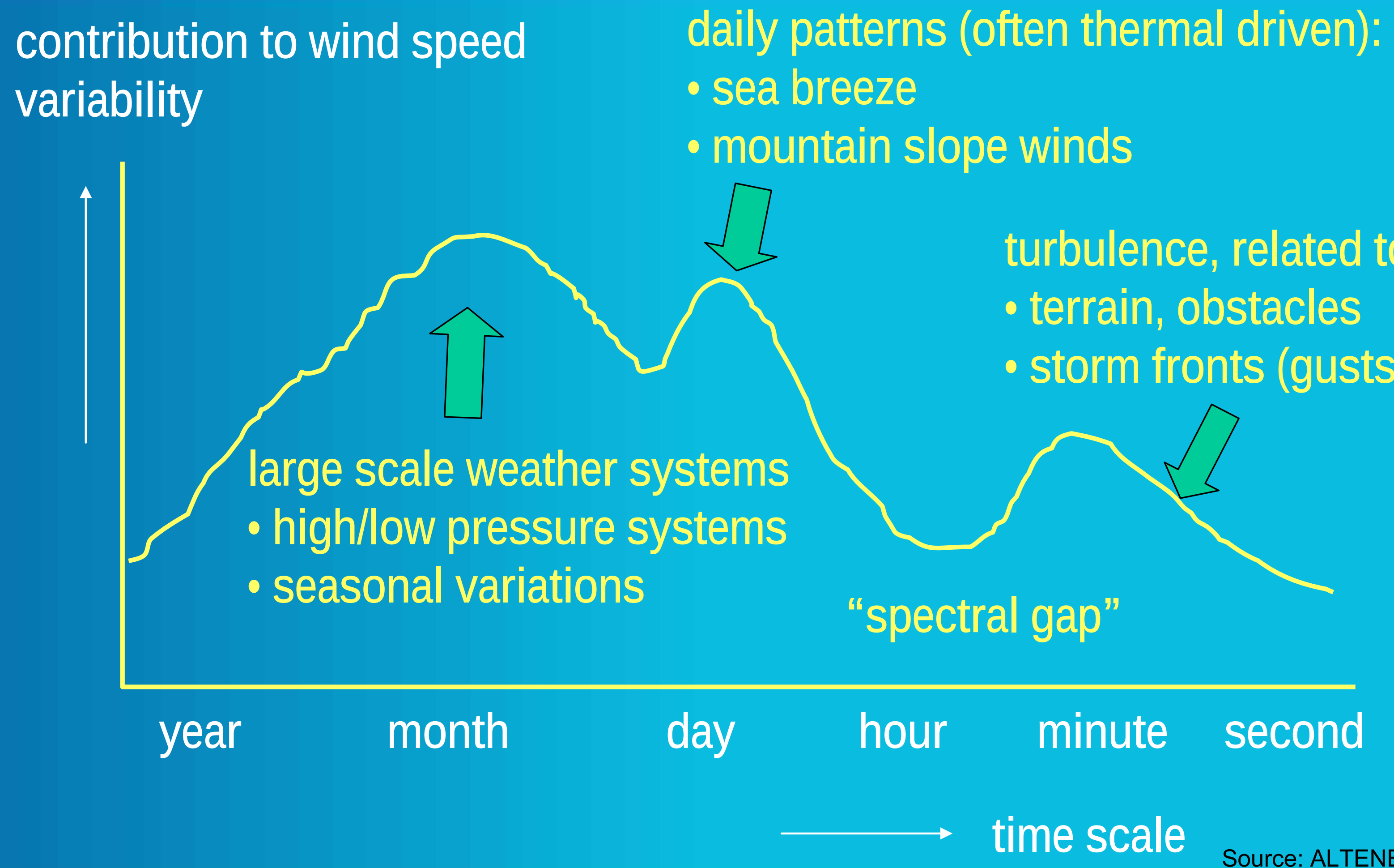
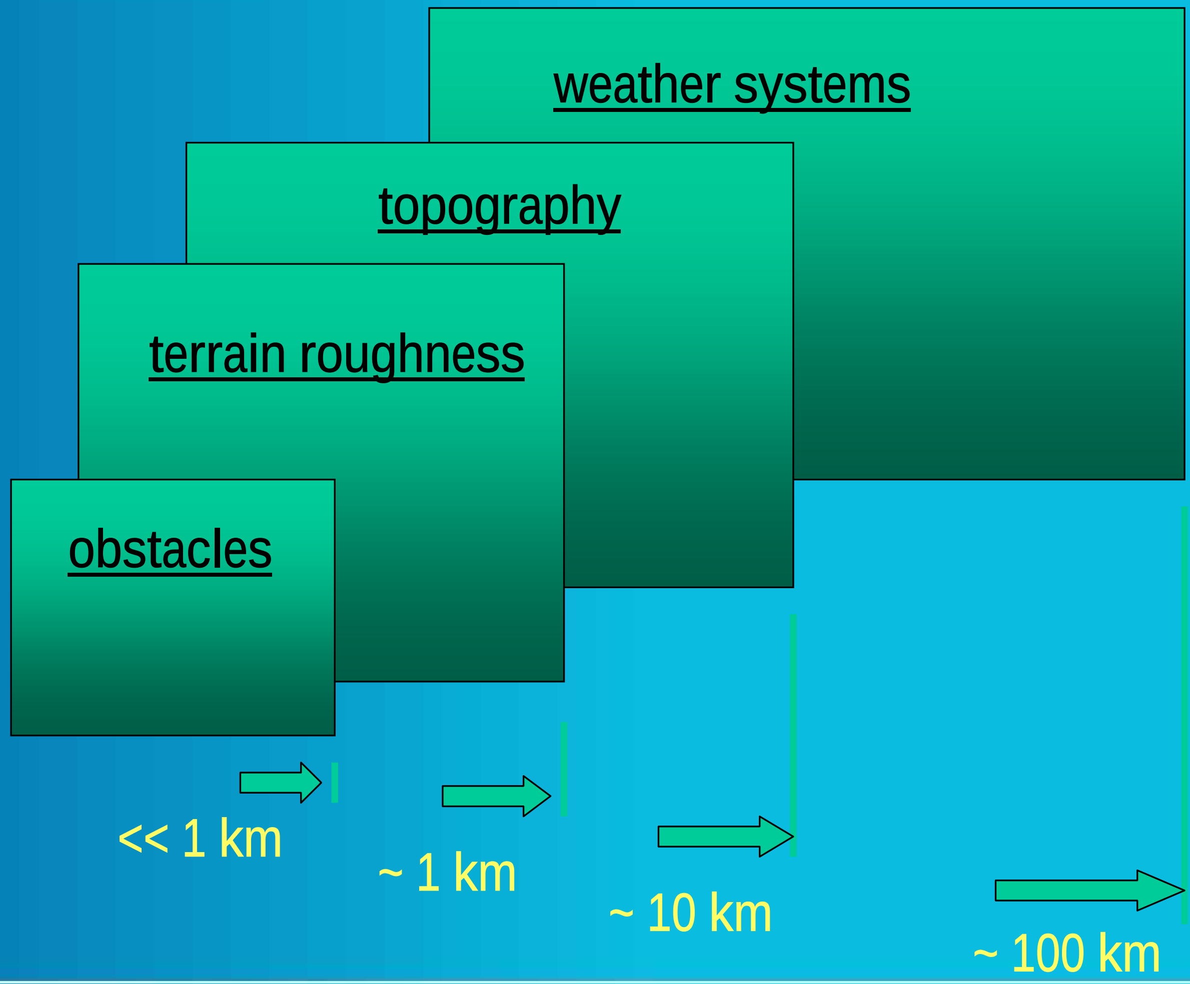
Variability of wind in time



Source: ALTENER

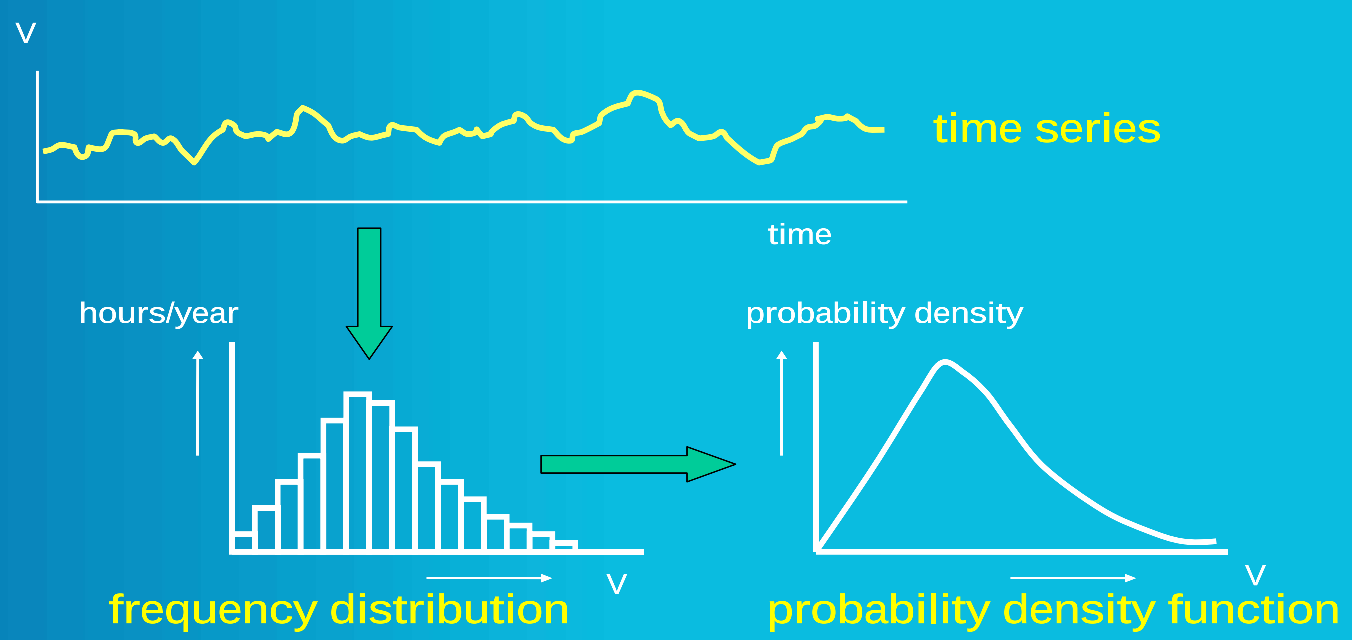
Variability of wind in space



Source: ALTENER

Wind – intermittent energy source

- Long-term distribution of observed wind speeds conforms well to the Weibull probability density function
- Development of wind prediction tools!
  - System reliability and to to avoid costs of deviations



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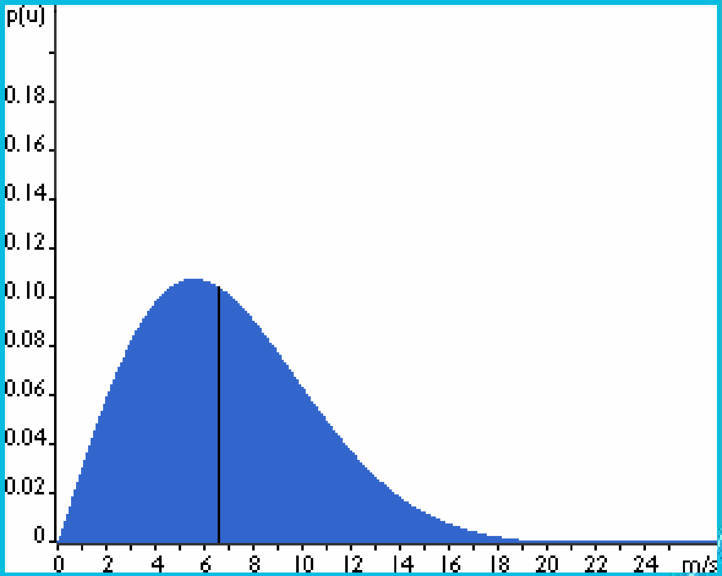
Mathematical modeling of wind speeds

- Long-term distribution of observed wind speeds conforms well to the Weibull probability density function
- The Weibull probability density function expresses the probability p(x) to have a wind speed x during the year, as follows

$$p(x) = \frac{k}{c}\left(\frac{x}{c}\right)^{k-1} e^{-\left(\frac{x}{c}\right)^{k}}$$

- valid for k >1, x ≥ 0, and c > 0



Wind statistics

- How to obtain wind data?

	problem:	solution:	
use existing data from other site	other site not representative	use of correction methods (terrain, obstacles)	Windatlas correction methods
perform local measurements	not possible to measure long enough to obtain long term statistics	correlate with other site which has reliable long term statistics	"Measure Correlate Predict"

two basic options

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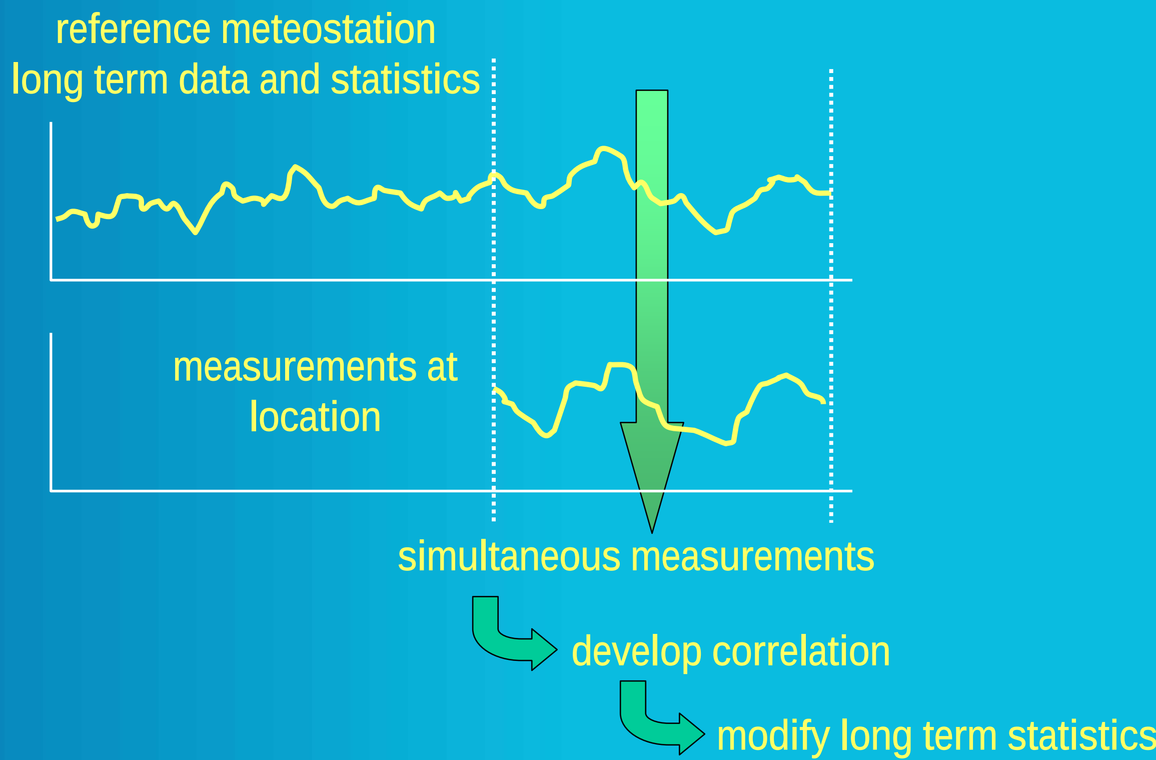
Wind statistics, II

- Measure – correlate – predict



Source: ALTENER

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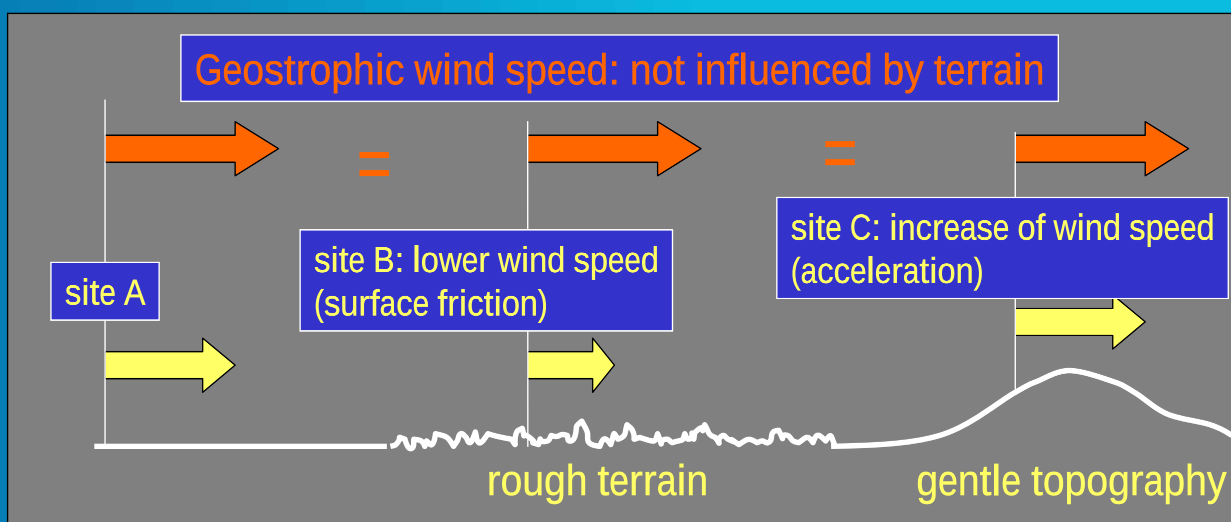
Wind statistics, III

➢ Wind atlas methods

key concept for correction:

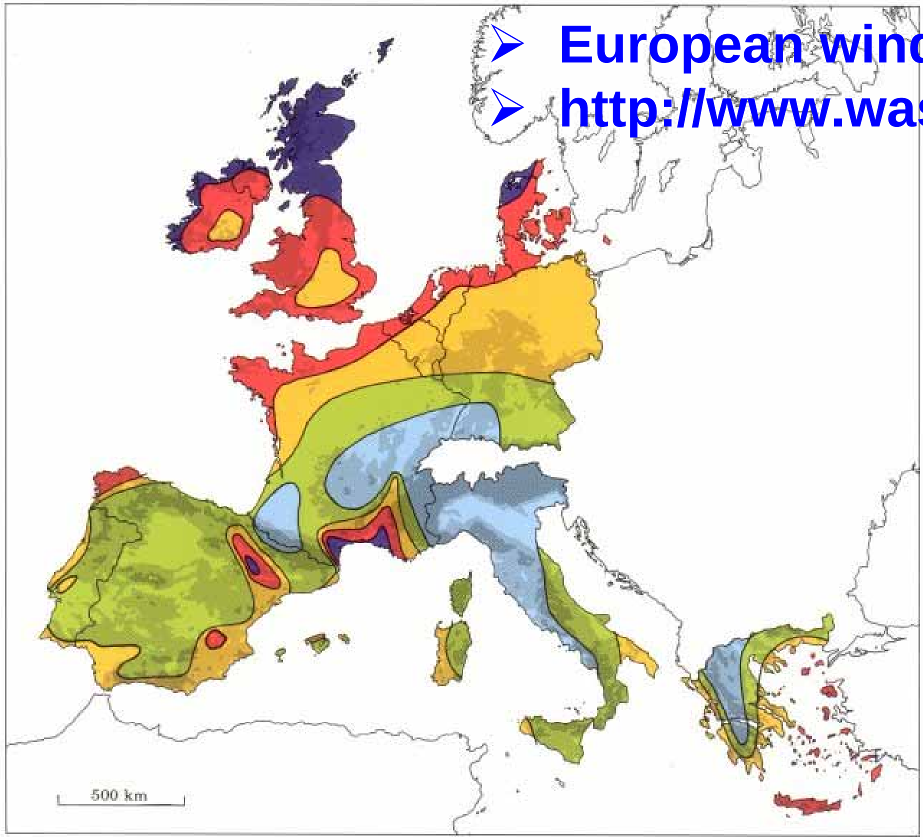
- IF sites A, B and C are close enough, they have the same macroscale wind climate
- corrections can be made for micro/meso scale effects assuming constant Geostrophic wind speed



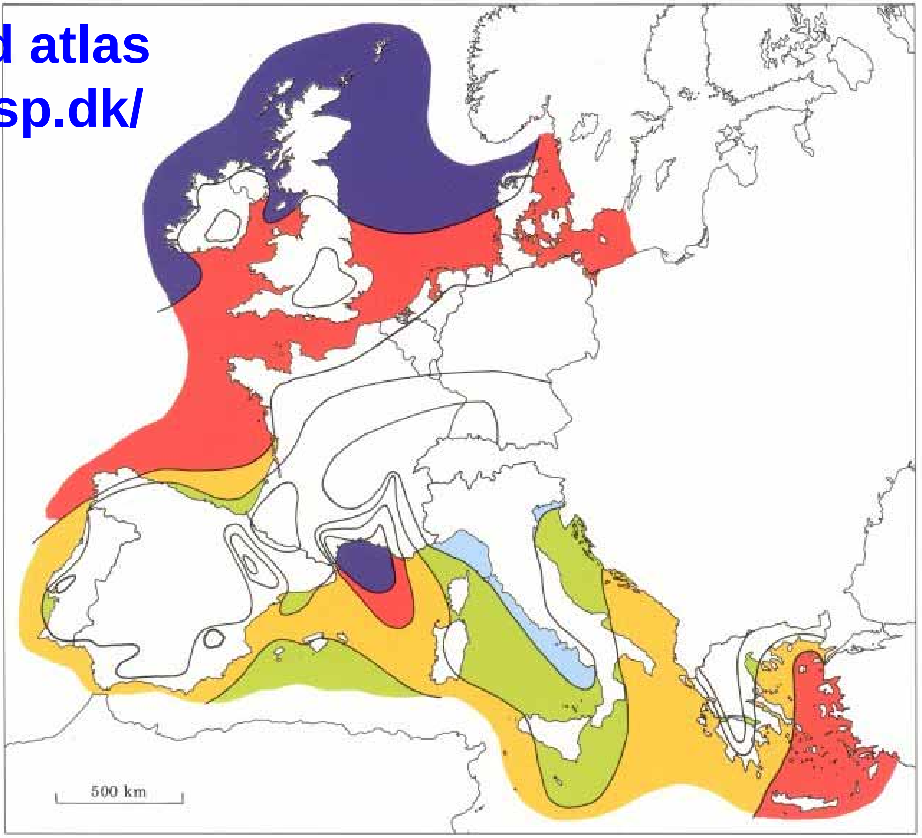
Source: ALTENER

Wind statistics, IV

- **European wind atlas**
- **http://www.wasp.dk/**



Wind resources[1] at 50 metres above ground level for five different topographic conditions	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400



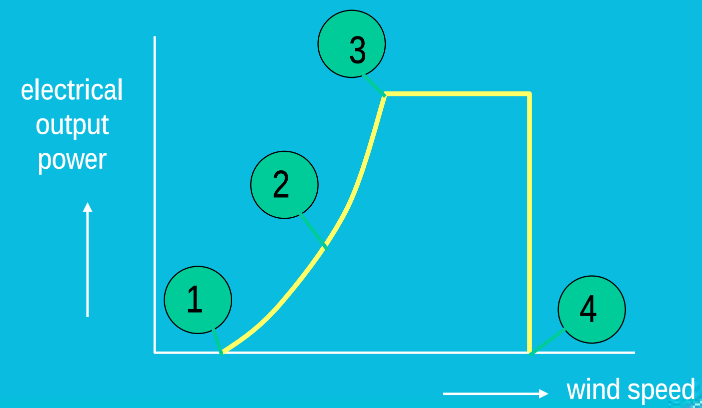
Wind resources over open sea (more than 10 km offshore) for five standard heights	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Wind energy production

- Energy in the wind (energy/m^2) is proportional to:
  - air density
  - cube of the wind speed

$$P = \frac{1}{2}\rho A v^3$$

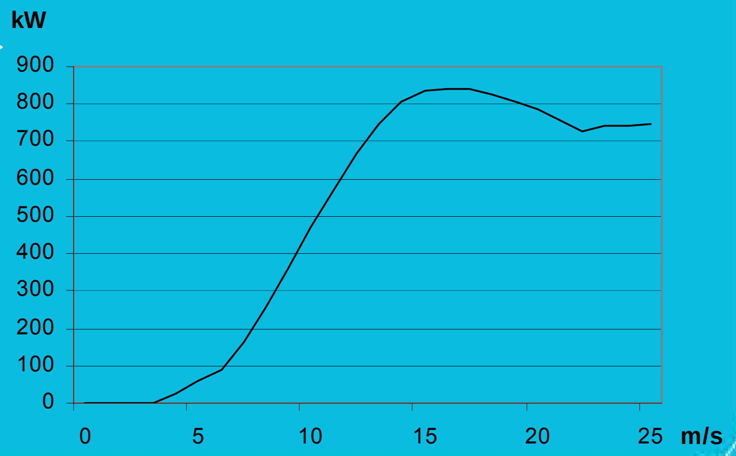
- Not all of can be used → Betz cofficient 16/27
- Energy from the wind (energy production of a wind turbine) differs from energy content because:
  1. only starts at “cut-in” speed
  2. efficiency varies
  3. reaches max generator power
  4. stops at extreme wind speeds



Wind energy production, II

➢ Electricity production

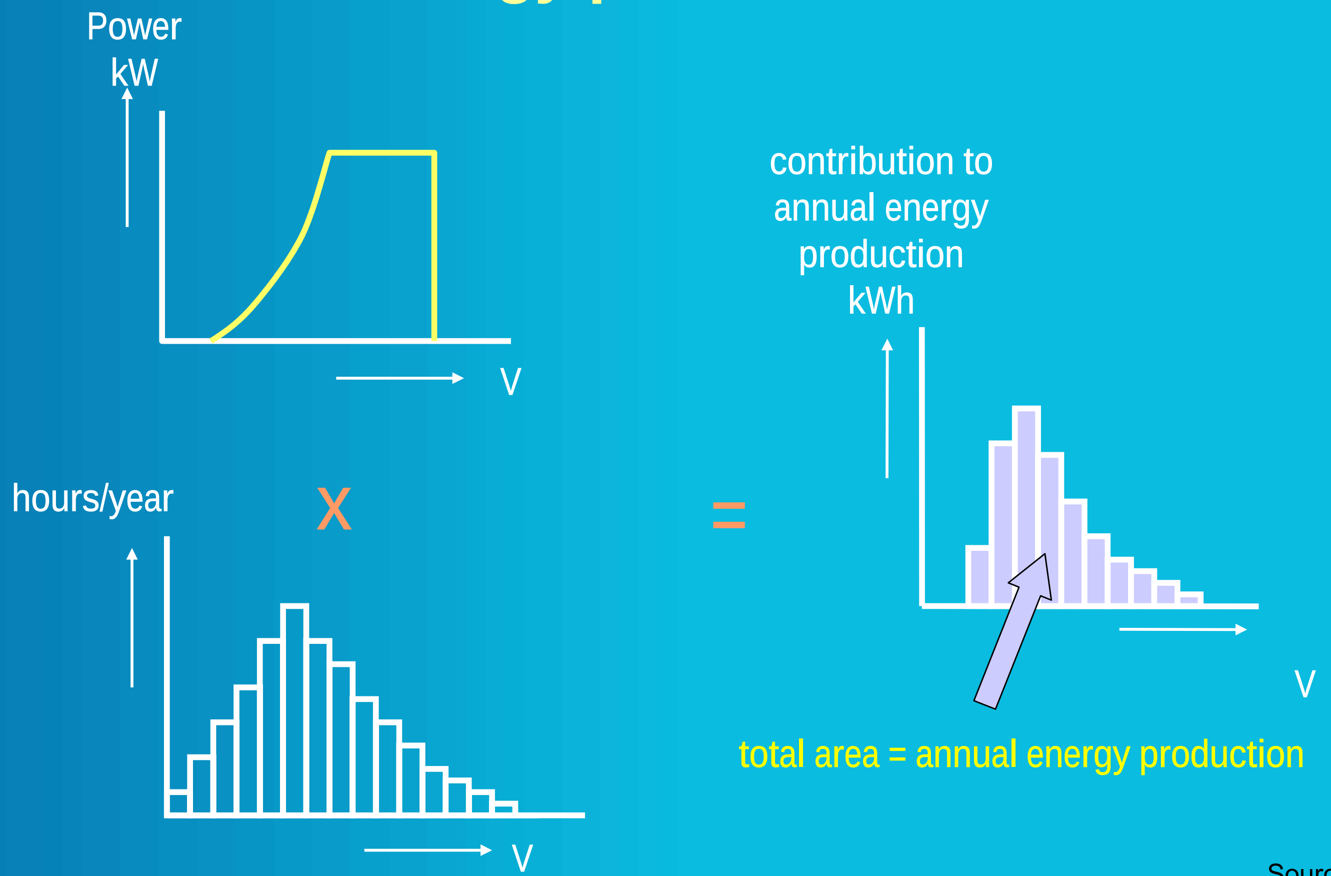
- wind turbine turns the kinetic energy of the wind into mechanical energy → conversion of mechanical to electrical energy
- the amount of electricity delivered is dependant on the **Weibull parameters** and the **power curve**
- power curve of a wind turbine → electrical power output at different wind speeds



$$E_T = T\int_0^\infty P_v\, p(v)\,dv$$

Wind energy production, III

- **Assessment of energy production**



Source: ALTENER

Further readings

http://www.windpower.org/

http://www.eere.energy.gov/

http://www.windatlas.dk/

Wind power technology

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Content of lectures

- Wind turbine design
  - Orientation of axis
  - Number of blades
  - Rotor power regulation
- Wind generator concepts
  - Constant speed turbines
  - Variable speed turbines
- Power system impacts
  - Local impacts
  - System-wide impacts
- Further readings

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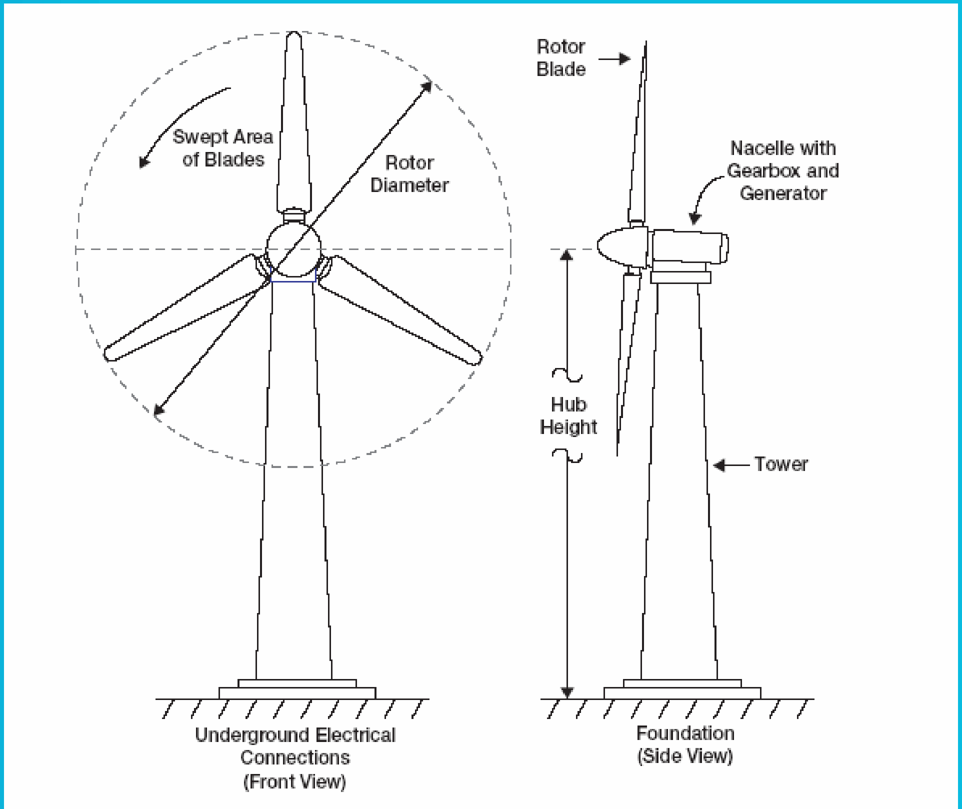
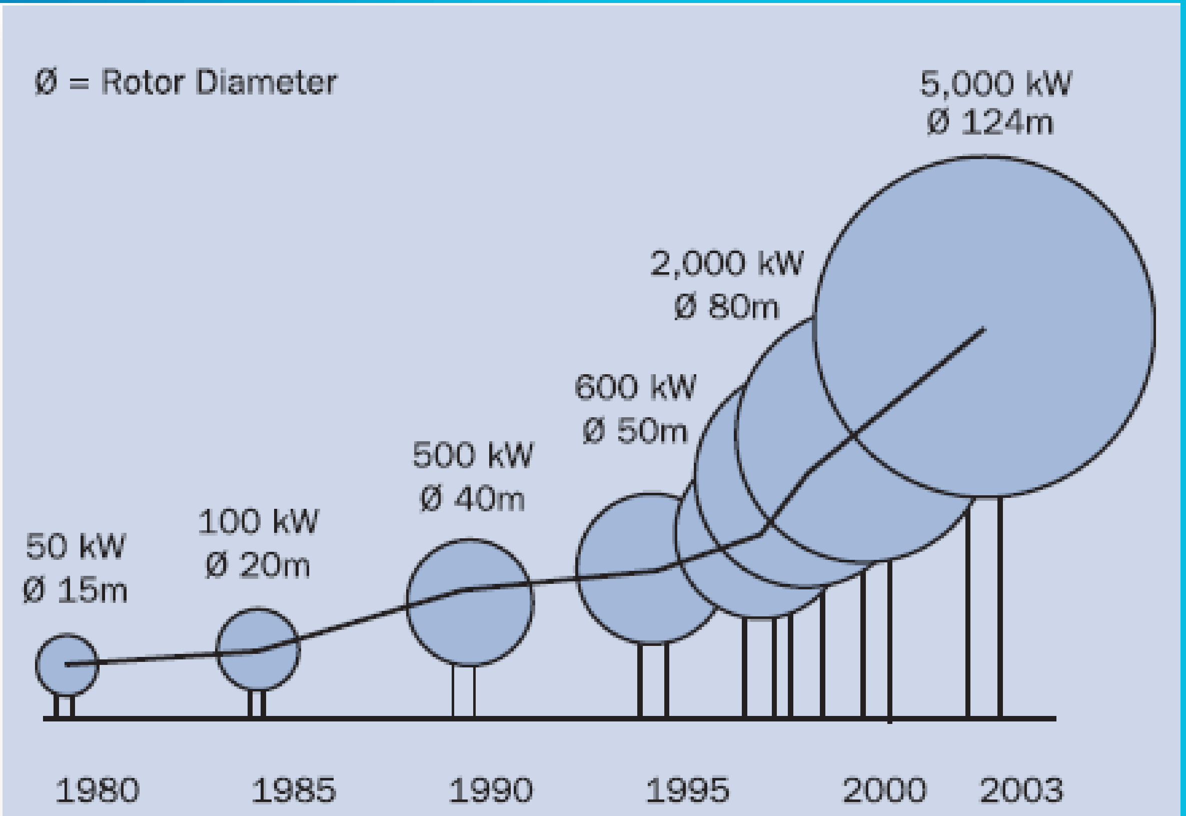
Wind turbine

- Wind turbine turns the kinetic energy of the wind into mechanical energy
- Mechanical energy is used to turn the rotor
- Energy is finally converted into electrical energy



Wind turbine development

→ growth in size



Source:EWEA

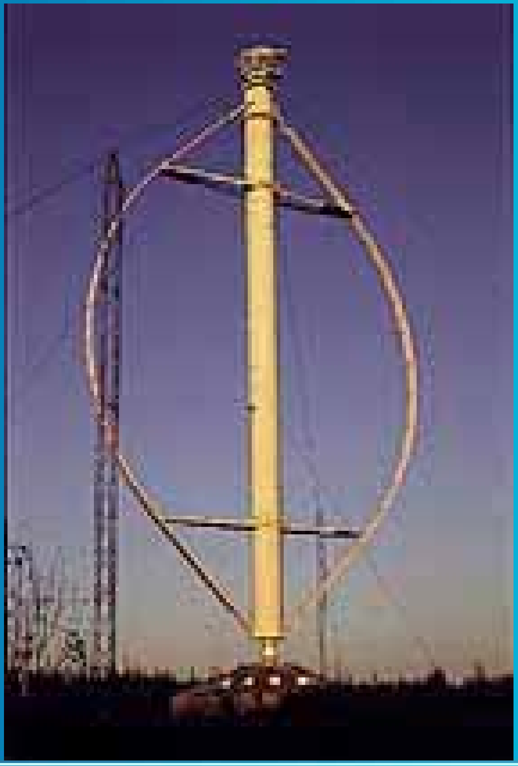
Wind turbine characteristics

- Orientation of axis
  - all modern wind turbines have horizontal axes
  - the only vertical axis turbine - Darrieus machine, (French engineer Georges Darrieus, patent in 1931)
    - characterised by its C-shaped rotor blades
  - advantages of a vertical axis machine - generator and gearbox are placed on the ground and no yaw mechanism is needed to turn the rotor against the wind
  - disadvantages of vertical axis machines - low wind speeds close to ground level, low efficiency of the machine and machine is not self-starting.

Wind turbine characteristics, II

- Orientation of axis

vertical



horizontal

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Wind turbine characteristics, III

- Number of blades
  - most modern wind turbines are three-bladed
  - two-bladed and one-bladed:
    - saving the cost of one or two rotor blade
    - lower turbine weight
    - require higher rotational speed to yield the same energy output
    - higher rotational speeds - disadvantage both in regard to noise and visual intrusion

Wind turbine characteristics, IV

- Rotor power control
  - Stall controlled
    - Passive
      - inherent aerodynamic properties of the blade determine power output
      - no moving parts to adjust
      - turbulence occurs behind the blade whenever the wind speed becomes too high
    - Active
      - Pitch at low wind speeds
      - At high wind speeds machine will pitch its blades in the opposite direction from what a pitch controlled machine does → blades go into a deeper stall, thus wasting the excess energy in the wind
  - Pitch controlled
    - angle of the rotor blades can be actively adjusted by the machine control system

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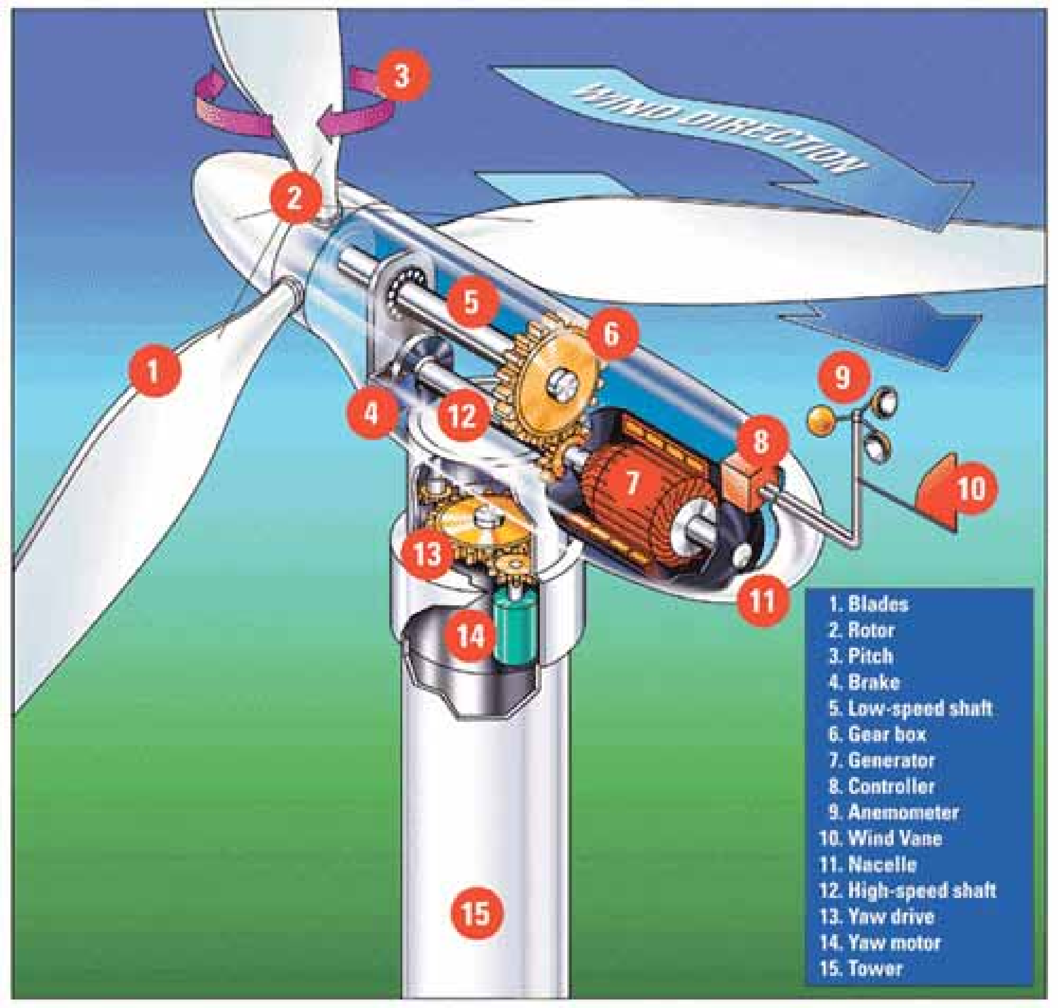
Wind turbine characteristics, IV



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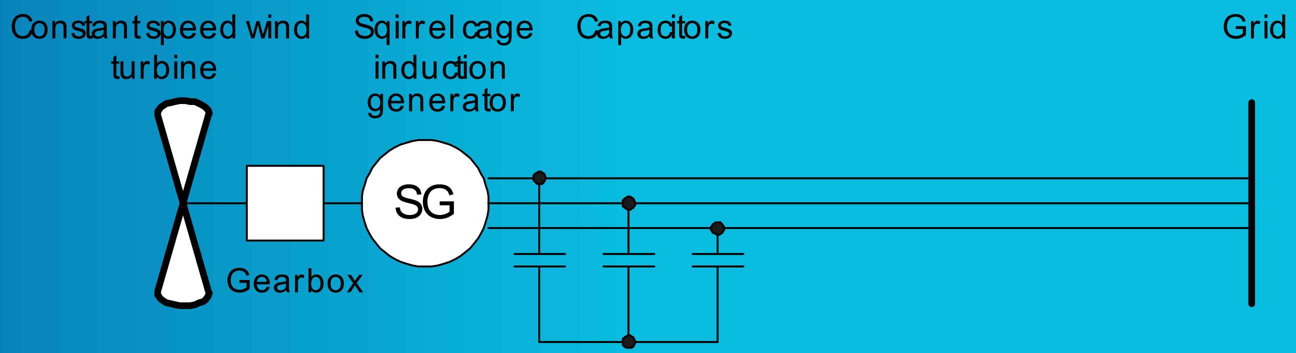
Wind generator concepts

- generating systems different from conventional synchronous generator:
  - constant speed turbines
    - squirrel cage induction generator
      - directly coupled to the grid
  - variable speed turbines
    - doubly fed induction generator
      - rotor is connected to the grid through a back-to-back voltage source converter which controls the excitation system in order to decouple the mechanical and electrical rotor frequency and to match the grid and rotor frequency
    - direct drive synchronous generator
      - completely decoupled from the grid by a power electronics converter connected to the stator winding

Wind generator concepts, II

➢ Squirrel-cage induction generator system



- the power converted is limited by designing the turbine rotor in such a way that its efficiency decreases in high wind speed
- always consumes reactive power
- not able to control and regulate the voltage level
- capacitors close are necessary to avoid a voltage decrease

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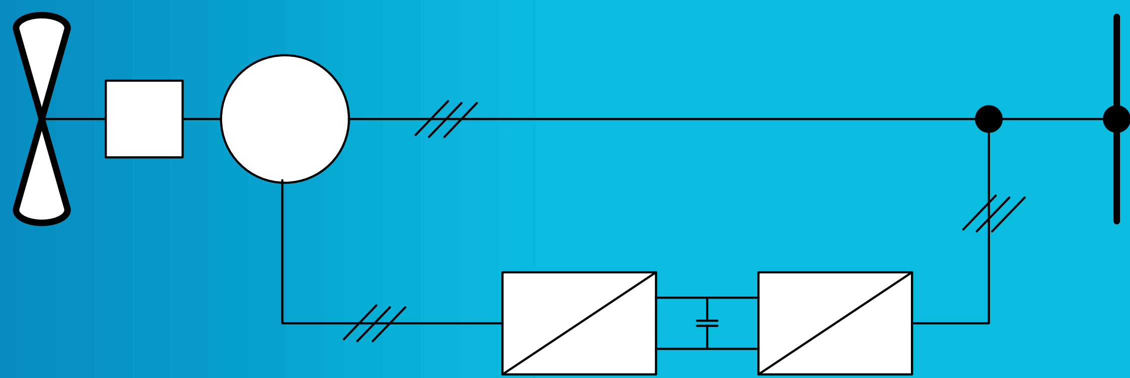
Wind generator concepts, III

➢ Doubly fed induction generator



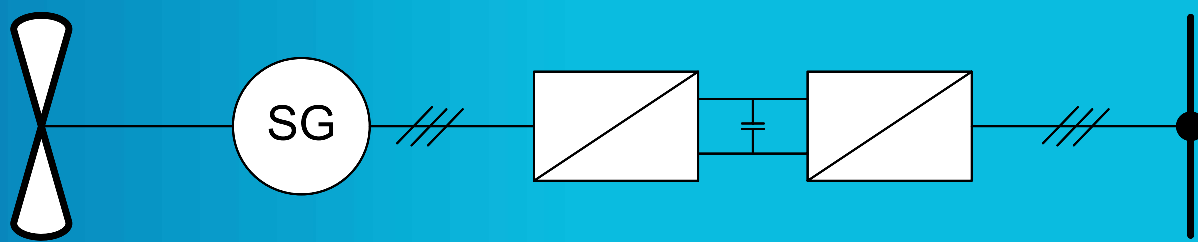
- due to power electronics regulation, generator operates over a relatively large speed range
- electrical power is independent from the speed
- the concept allows turbine operation at the aerodynamically optimal point for a certain wind speed range

Variable speed wind turbine

Doubly fed induction generator

Wind generator concepts, IV

➢ Direct drive synchronous generator

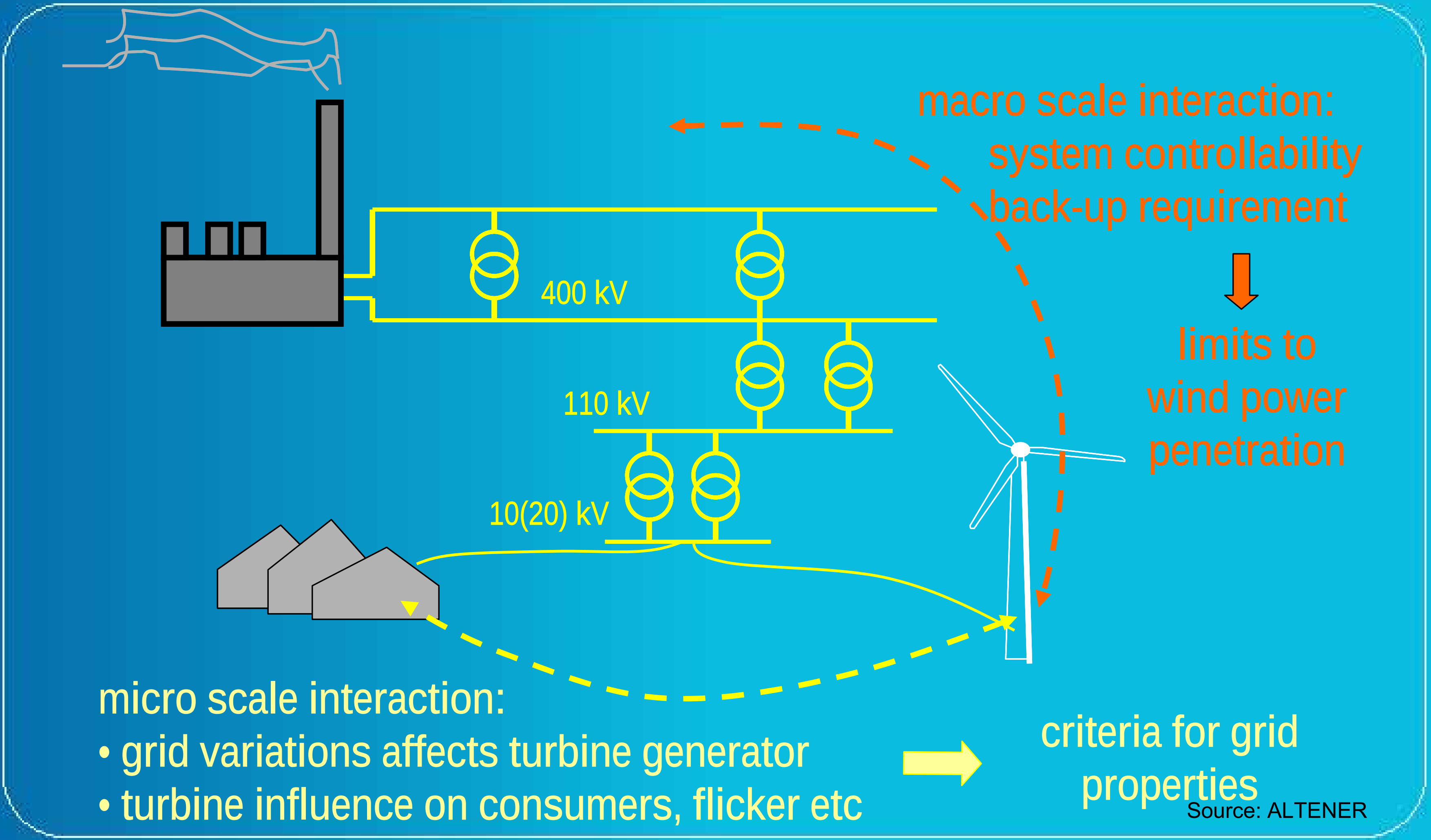


- turbine and generator are directly coupled, without gearbox
- generator used in such systems is high-pole synchronous generator designed for low speed – large generator, thus large nacelle
- solution is in direct drive concept but with single stage gear box with low ratio – lower number of poles required and smaller generator

Variable speed wind turbine

Direkt-drive synchronous generator

Integration into power system



Source: ALTENER

Power system impacts

- local impacts – occur in the electrical vicinity of the wind farm and can be attributed to a specific turbine or farm
  - branch flows and node voltages
  - protection schemes, fault currents, and switchgear ratings
  - power quality: harmonic distortion and flicker
- system-wide impacts
  - power system dynamics and stability
  - reactive power and voltage control
  - frequency control and load following/dispatch of conventional units
- TSO requests → improved wind prediction and ability of WPPs to deal with voltage dips without disconnection from the network

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Further readings

- **Guided tour on wind energy**
  http://www.windpower.org/en/tour.htm

- **Wind Energy – The Facts, Volume 1: Technology**, European Wind Energy Association (EWEA), http://www.ewea.org/index.php?id=91

- **UCTE Position Paper on Integrating wind power in the European power systems - prerequisites for successful and organic growth, 2004**
  http://www.ucte.org/pdf/Publications/2004/UCTE-position-on-wind-power.pdf

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Economics of wind power plants

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Content of lectures

- Energy project economics basics
- Wind power project economics
  - wind power project expenditures
    - cost of electricity production
  - wind power project revenues
  - generating costs of wind power
  - case study: WPP Stupišće
- Further readings

Project economics basics

- Economic analyses of investment projects are based on **the progress of future cash flows during the lifetime of the project**
- Evaluation of project cost effectiveness → **profitability indicators**
- Analysis with taking into account the time value of money → **discount rate**
- The most common and widely used presentation method of project's economic benefits assessment is a **cash flow analysis**

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Project economics basics, II

- **Net cash flow**

NCF = cash inflows – cash outflows
NCF = – investment + gross income (income from electricity sales) – O&M costs – taxes

*Tax = tax rate * (gross income – operating costs – depreciation – loan interest)*

NCF= – equity-financed capital expense + gross income – O&M expense – taxes – (debt principal + debt interest)

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Project economics basics, III

➢ Net cash flow – necessary input data

Financing terms		**Economic parameters**		**Expenditures and Revenues**	
Total investment	[€]	Economic lifetime	years	Annual income	[€]
Debt ratio	[%]	Inflation rate	[%]	Annual O&M costs	[€]
Debt interest rate	[%]	Income tax rate	[%]	Periodical maintenance costs	[€]
Debt term	years	Depreciation method	No/SL/DB	Salvage value	[€]

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Project economics basics, IV

➢ Profitability indicators

– Net Present Value

$$NPV = \sum_{t=1}^{N} \frac{PV_t}{(1+d)^t} - I$$

– Internal Rate of Return

$$\sum_{t=1}^{N} \frac{PV_t}{(1+R_i)^t} = I$$

– Payback period
  - simple
  - pay-off

NPV	-	net present value
PV_t	-	present value in year t
N	-	project lifetime
d	-	discount rate
I	-	initial (investment) costs

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Project economics basics, V

- **Sensitivity analysis**
  - Determine which factor(s) of interest may vary from the most likely estimated value,
  - Select the probable range and increment of variation for every factor,
  - Select the profitability factor to be calculated,
  - Calculate the results for every factor,
  - To better interpret the results, graphically display the cost factor versus the profitability indicator.

Wind power project economics

- The main parameters governing wind power project economics:

  - Investment costs;
  - Operation and maintenance (O&M) costs;
  - Electricity production/average wind speed;
  - Turbine lifetime (lifetime of the project);
  - Discount rate.

- Selecting the right site is critical to achieving economic viability!

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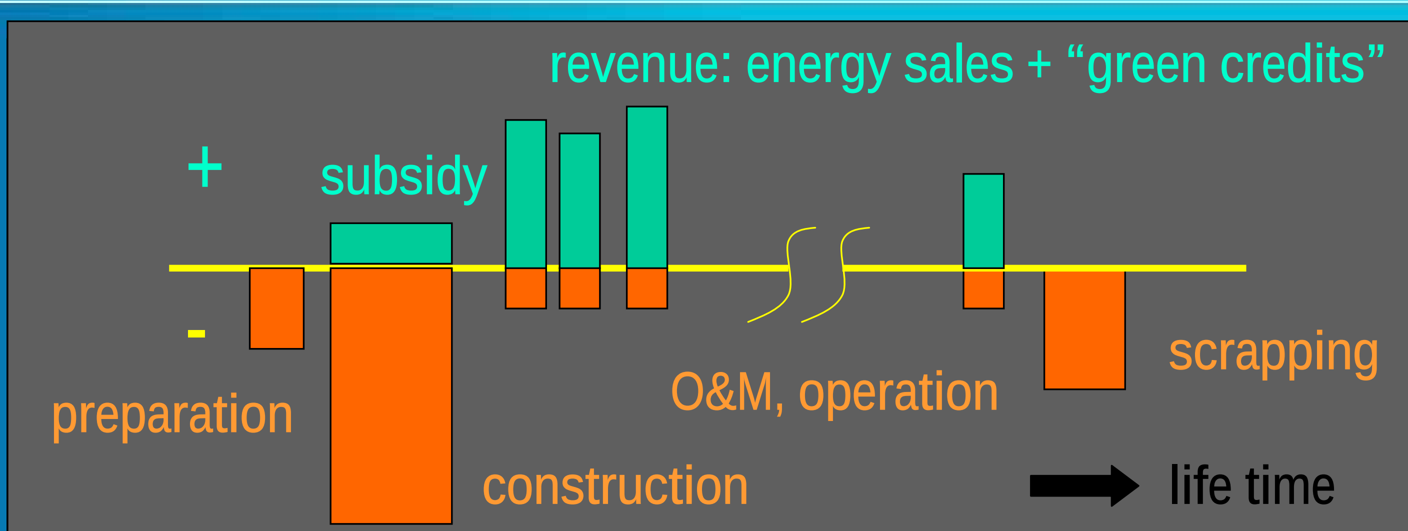
Wind power project viability



project is viable when:

- **sum (" + ") – sum ("-") = required profit**
- **depending on risk profile**
- **investors specific criteria**

based on NPV and/or IRR analysis methods

Source: ALTENER

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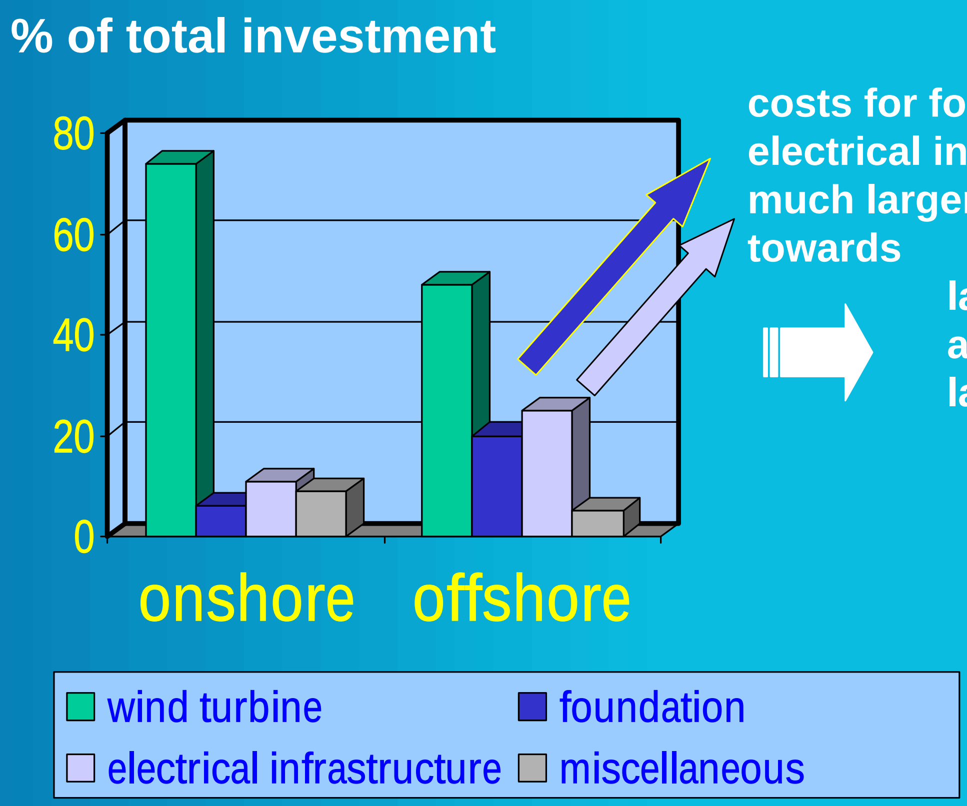
Wind power project expenditures

- Investment costs

Cost category	Large Wind Farm (%)	Small Wind Farm (%)
Feasibility Study	<2	1-7
Development	1-8	4-10
Engineering	1-8	1-5
Energy Equipment	67-80	47-71
Balance of Plant	17-26	13-22
Miscellaneous	1-4	2-15

- Specific investment costs 900 €/kW to 1.150 €/kW

Wind power project expenditures, II



costs for foundation and electrical infrastructure offshore much larger than onshore, drive towards

large wind turbines and large wind farms

Source: ALTENER

Wind power project expenditures, III

- Investment costs
  - up to 80% are wind turbine costs
- Operation and maintenance costs
  - no fuel costs
  - land lease, insurance, transmission lines maintenance, parts and labour, administrative costs
- Cost of capital
  - strong influence of discount/interest rate
- Depreciation
- Profit tax
  - in Croatia 20%

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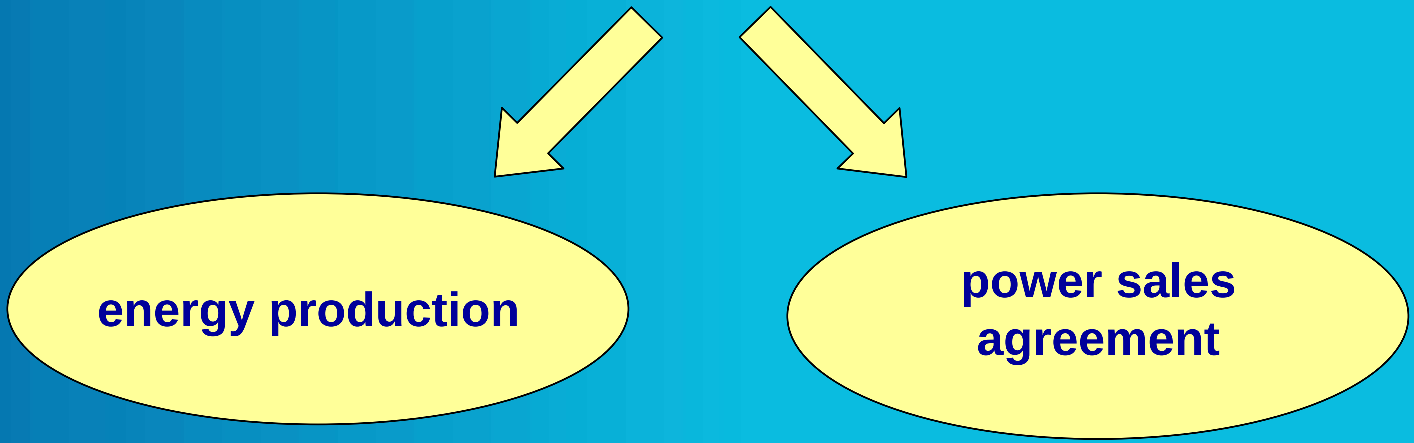
Wind power project revenues



- wind resource
- wind farm wake losses
- wind turbine power curve
- wind farm downtime

- fixed tariffs
- time linked (day, season)
- capacity credit
- charges for reactive power
- "green certificates"

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Wind power project revenues, II

- Guaranteed purchase price for the whole amount of electricity produced
  - guaranteed in its full amount
  - prescribed as a price cap on the electricity market price
  - aimed at reflecting the environmental benefits of the technology
  - prescribed purchase price for every RES type
  - differentiation according to the installed power
- Lack of complete regulatory framework can be a serious problem!

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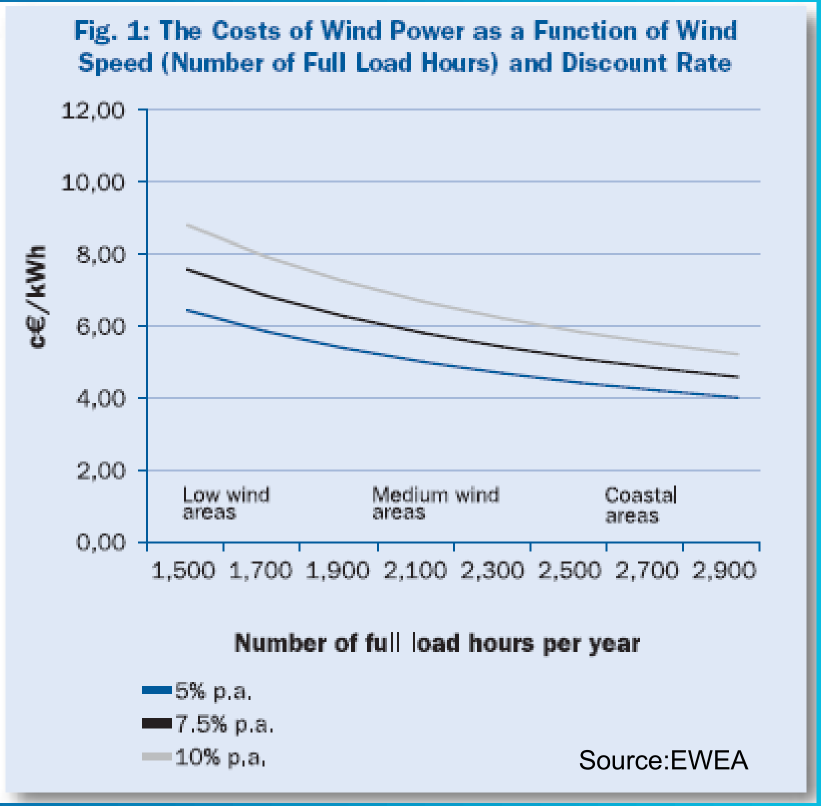
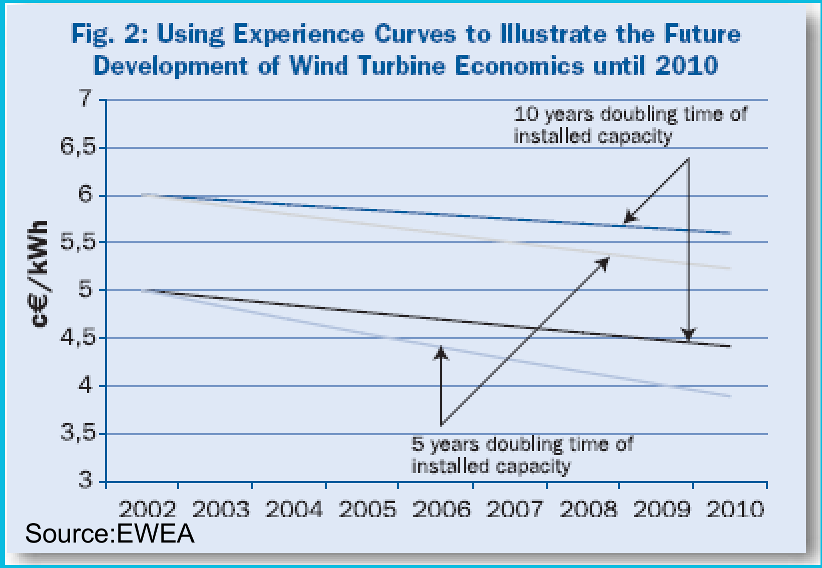
Generating costs of wind power

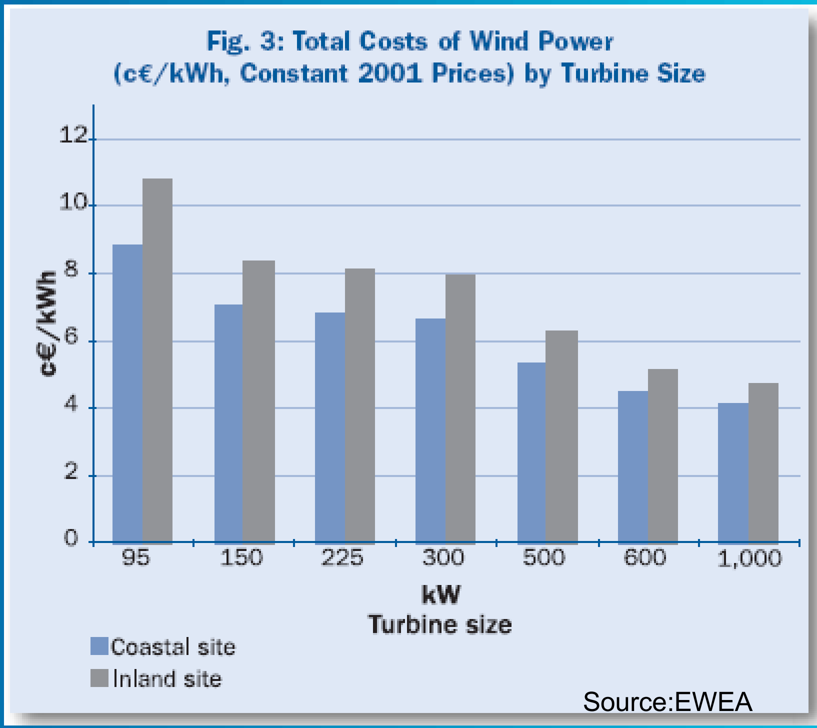
- Calculated by discounting and levelising investment and O&M costs over the lifetime of wind turbine, divided by the annual electricity production.
- Approx. 4-5 €cents/kWh at sites with very good wind velocities; 6-8 €cents/kWh at sites with low wind velocities
- Cost reduction of over 50% in the last 15 years
- With a doubling of total installed capacities, the cost of production per kWh from new wind turbines will fall by between 9% and 17 %

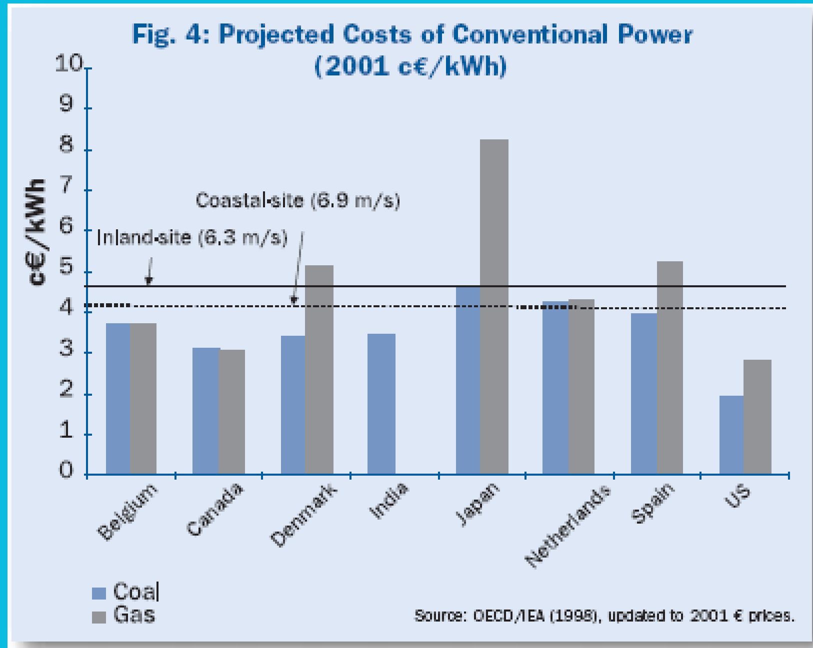
Generating costs of wind power, II





Generating cost of wind power, III





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Case Study: WPP Stupišće

- preparation work began in 1996
- pilot project proposed within national wind energy programme ENWIND (all following data are taken from ENWIND)
- the average wind velocity 20 meters above the ground is equal to 6,73 m/s and average power equals 431 W/m2 (analyses done by WAsP methodology)
- Conceptual design:
  - seven NEG Micon 900 kW wind turbines,
  - hub height 55 m
  - rotor diameter 52,2 m
  - annual net electricity production is assessed to 15.282 MWh.

Case Study: WPP Stupišće, II

- Specific investment costs 980 €/kW
- With additional substation 35/10(20) kV, 8 MVA specific investment costs are 1.100 €/kW

The structure of the investment	**HRK**
Preparation work on the micro-location Project documentation Preparation civil engineering work Equipment, transportation, instalment, etc. Cable connection 10 kV and 35 kV	900.000 750.000 4.065.000 36.784.000 3.674.000
Total WPP Stupišće (till grid connection place)	46.173.000
Substation 35/10(20) kV Stupišće	6.372.000
Total	52.545.000

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Case Study: WPP Stupišće, III

- Maintenance costs assessed according to all material costs to 1,7% of the investment (equipment and civil engineering work)
- Labour costs are assessed according to the 1 employee with annual gross income of 10.000 €
- Operation costs are calculated as 0,3% of total investment and
- Miscellaneous costs are assessed to 10 % of personnel costs
- O&M costs also include material property insurance which equals to 0,8% of the investment (equipment and civil engineering work)

Case Study: WPP Stupišće, IV

INPUT DATA		
Construction time	year	1
Economic lifetime	year	20
Generator rated power	kW	900
Number of units		7
Total installed power	MW	6,3
Average annual wind velocity	m/s	7,3
Investments – financing mode and terms		
Total investment cost	000 HRK	46.173
Debt ratio	%	75
Debt term	year	8
Debt interest rate	%	8,0
Grace period	half-year	2
Number of debt payments	half-year	16
Required internal rate of return	%	10,0
Electricity production		
Operational hours	h/year	2.426
Electricity production	MWh	15.282
Depreciation (straight-line model)		
Depreciation rate for civil works	%	5,0
Depreciation rate for equipment	%	6,67
Depreciation rate for non material assets	%	20,0
Employment		
Number of employees	person	1
Specific labour costs (annual gross)	HRK/per.	75.000
Operation and maintenance costs		
Maintenance costs (% from investment in civil works and equipment)	%	1,7
Insurance costs (% from investment in civil works and equipment)	%	0,8
Operation costs (% from total investment)	%	0,3
Miscellaneous	%	10
Income tax	%	20
Electricity price	HRK/kWh	0,427
RESULTS		
Pay back period	year	9,8
Internal rate of return	%	8,4
Net present value	HRK	-4.383

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Case Study: WPP Stupišće, V

- Sensitivity analysis

VARIABLE PARAMETER Electricity selling price (HRK/kWh)	NPV (000 HRK)	IRR (%)	SPB (years)
0,380	-9.204	6,51	11,27
0,427	*-4.383*	*8,40*	*9,8*
0,470	0	10,00	8,8
0,522	4.955	11,76	7,8
0,569	**9.445**	**13,29**	**7,1**

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Further reading

Wind Energy – The Facts, Volume 2: Costs & Prices

European Wind Energy Association (EWEA)

http://www.ewea.org/index.php?id=91

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Environmental impacts of wind power plants

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Content of lectures

- Global impacts
  - emission of CO_2 and effect on climate change
- Regional impacts
  - emission of other pollutants and production of waste
- Local impacts
  - nuisance
  - ecological
  - other
- External costs
- Further readings

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General

- Wind energy has strong positive effects on the **global** and **regional** environment
- Possible negative effects on the **local** environment; these can be avoided through proper planning
- Major public opposition is related to actual and imaginary nuisance; can be reduced through a fair and careful information campaign

Not In My Back Yard Syndrome

POSITIVE
global and regional effects

- less CO_2 emission
- less global warming
- less acid rain

fear and resistance of local residents
block wind energy development at planning stage
despite support for wind energy in general

NEGATIVE
(perceived)
local effects

- visual impacts
- dead birds
- noise
- fabricated imaginary influences

Source: ALTENER

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Global impacts

- Atmospheric emissions (energy chain):
  - Emissions are two orders of magnitude lower then from fossil fuel power plants
- CO_2 equivalent emissions (energy cycle):
  - Wind power plant 6-9 g/kWh
  - Coal power plant 800 g/kWh
  - Natural gas power plant 260 g/kWh
- Each kWh wind energy saves 800 ~ 1000 g CO_2
- 600 kW turbine saves 1000 ~ 2000 ton CO_2 annually, modern (larger) turbines 4000 ton CO_2

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Regional impacts

- A unit of wind turbine electricity displaces a unit of electricity which would have been produced by a conventional power station, and thus prevents the emission of polluting chemicals:
  - Acidifications agents: SO_2 and NO_x
  - Dust particles
  - Solid waste, ash, slugs
  - Photochemical smog agents: hydrocarbons and NO_x

Local impacts

- Human perception (nuisance)
  - visual impacts on landscape
  - land use: interference with other activities, such as farming, fishing
  - moving shadows
  - noise
  - electromagnetic interference
- Ecological
  - birds
  - effects from construction activities
  - hydrological disruption
  - effects on marine life (offshore)

Nuisance

- visual impact
  - visible change in the landscape
  - perception is highly subjective

Remedies:

use of
- three bladed machines
- slender tubular towers
- attractive design

landscape architecture to carefully integrate wind farm into landscape

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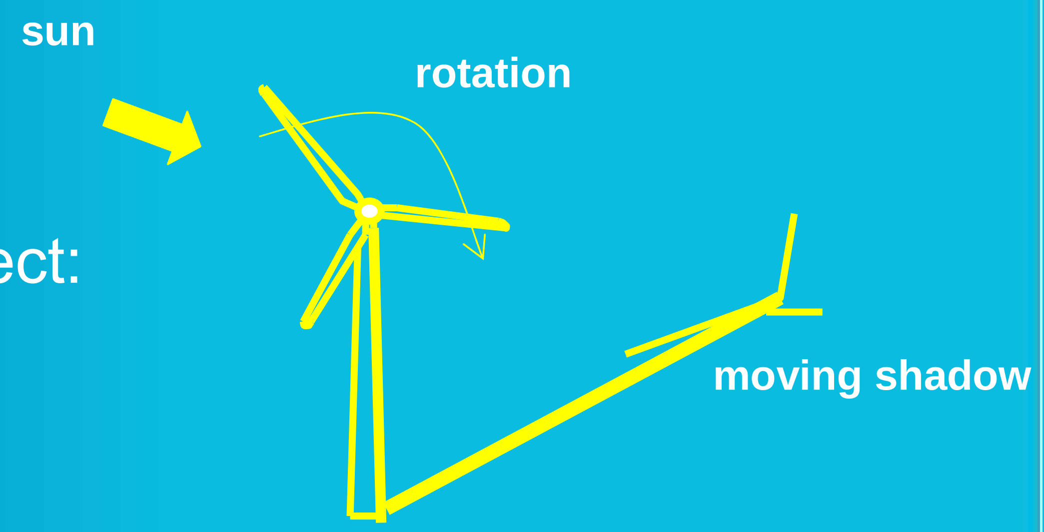
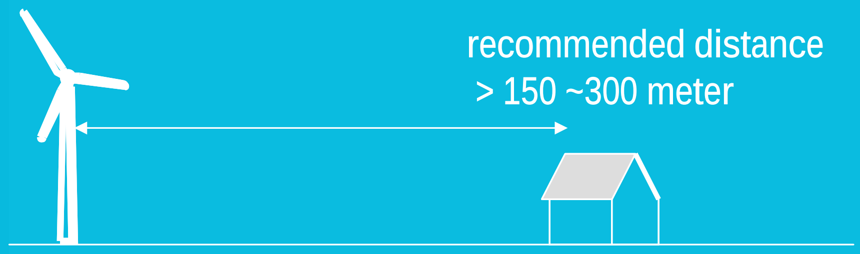
Nuisance, II

- shadow flickering
  - occurs only during bright sunlight
  - can be exactly predicted
  - it is a very local effect: worst case within distance < 7 ~10 diameters



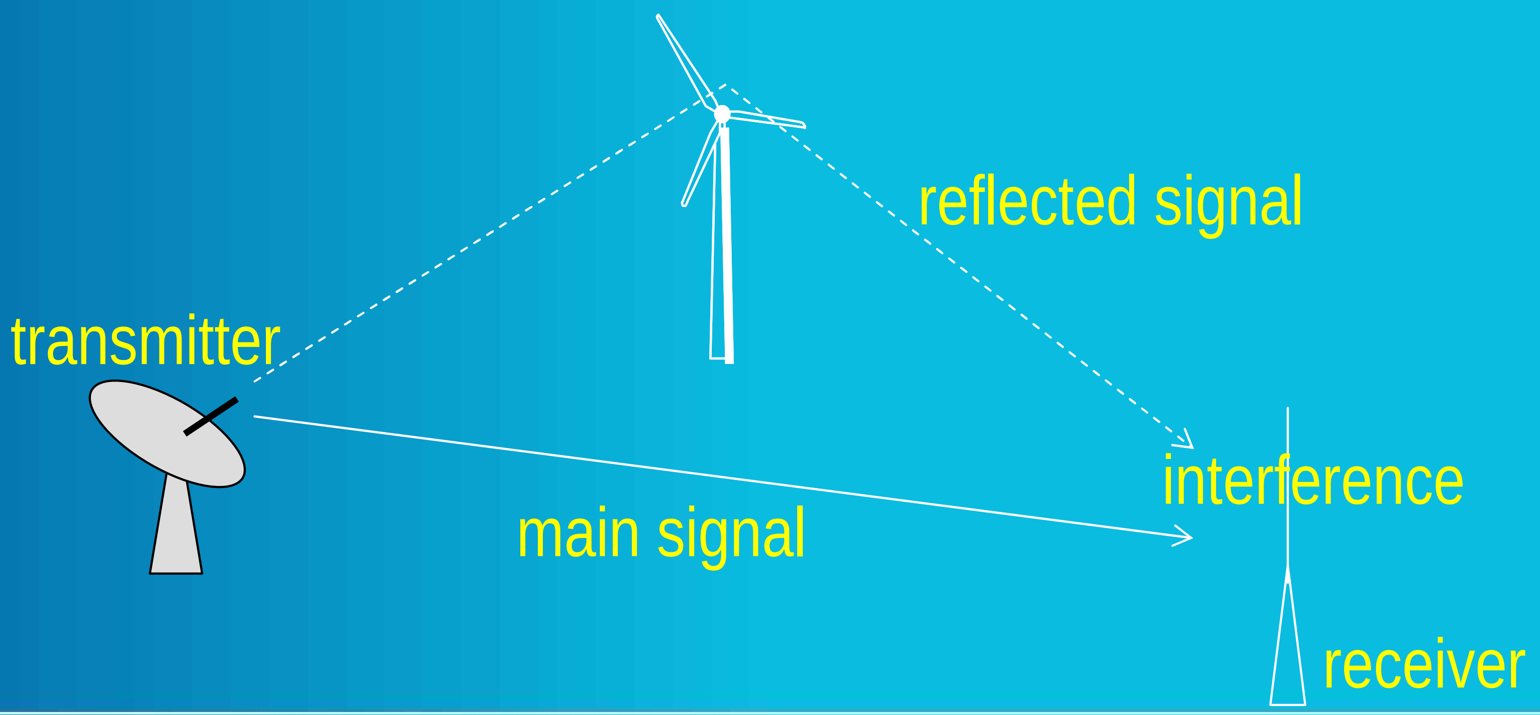
Nuisance, III

- noise
  - noise level on 300 m distance: **35 - 45 dB**
    - quiet bedroom 35 dB
    - busy office 60 dB
    - pneumatic hammer (7 m) 95 dB
    - pain limit 140 dB



Nuisance, IV

- electromagnetic interference
  - solved by proper sitting of WPP



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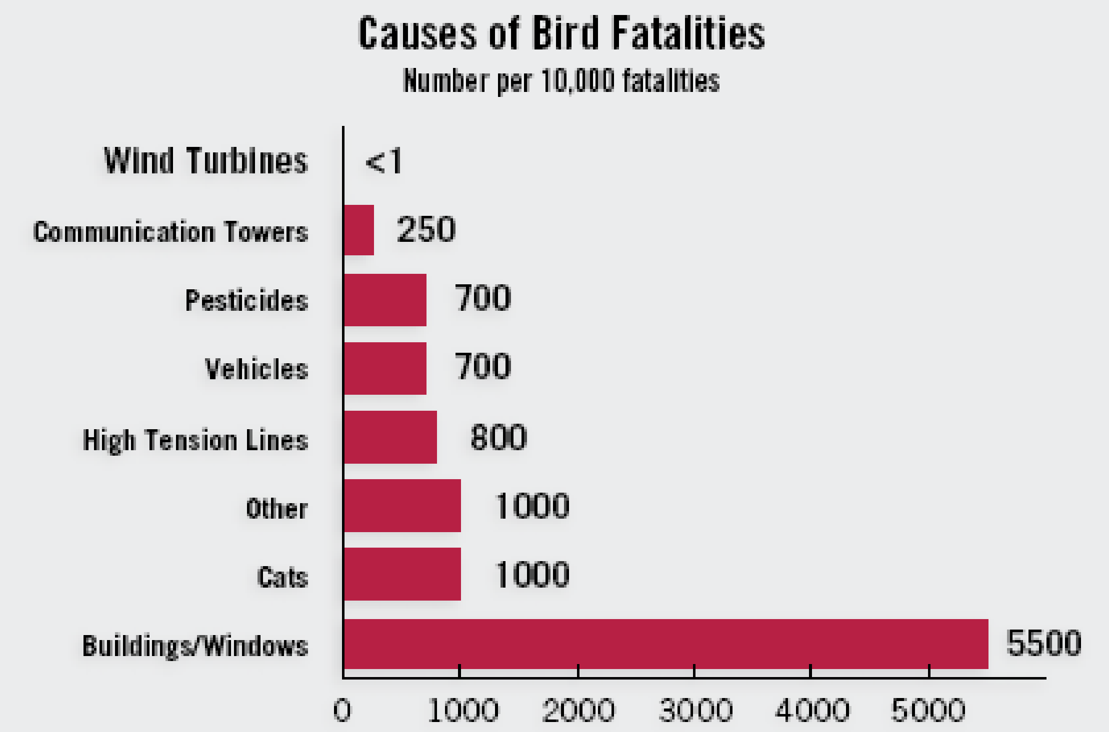
Ecological effects

- birds
  - 3,1 bird mortality per installed MW
  - collisions
    - birds shift flight paths to avoid collision
  - disturbance
    - birds tend to avoid windpark area or get accustomed



Source: Erickson et al., 2002, Summary of Anthropogenic Causes of Bird Mortality.

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Other interesting complaints

- wind turbines are dangerous
- horses are frightened
- wind turbines cause headaches
- promote lice on potato’s and disturb agriculture

NON ARE TRUE!

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External costs

“ ***benefits and costs which arise when the social or economic activities of one group of people have an impact on another, and when the first group fails to fully account for their impacts*** ”

(European Commission, 1994).

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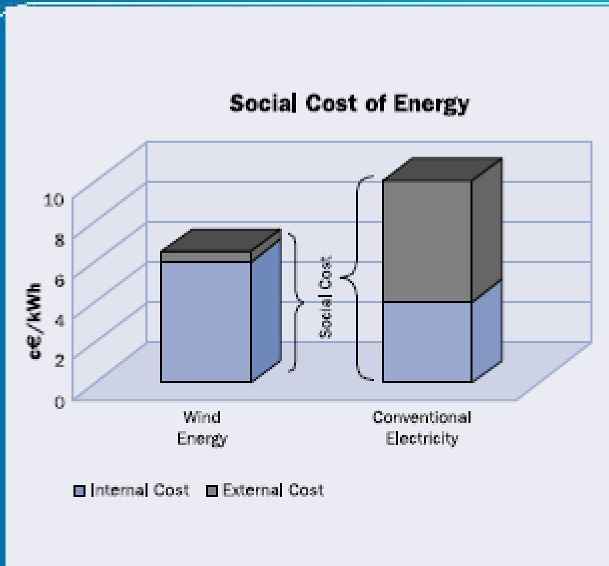
External costs, II



Source:EWEA

Costs	600 kW WT	1,000 kW WT
Cost of Wind c€/kWh	4.4	4.1
External Cost* c€/kWh	0.09 – 0.16	0.09 – 0.16
Social Cost	4.49 – 4.56	4.19 – 4.26

Internalisation of external costs makes wind energy competitive with conventional energy sources!

	Coal			Gas		
Costs	Spain	Denmark	Germany[a]	Spain	Denmark	Germany[b]
Internal cost[a] c€/kWh	3.93	3.41	3.14	5.2	5.23	2.85
External Cost c€/kWh	4.8 - 7.7	3.5 - 6.5	3.0 - 5.5	1.1 - 2.2	1.5 - 3.0	1.2 - 2.3
Total Cost	8.73 - 11.63	6.91 - 9.91	6.14 - 8.64	6.3 - 7.4	6.73 - 8.23	4.05 - 5.15

Further readings

Wind Energy – The Facts, Volume 4: Environment

European Wind Energy Association (EWEA)

http://www.ewea.org/index.php?id=91

Implementation of wind power projects

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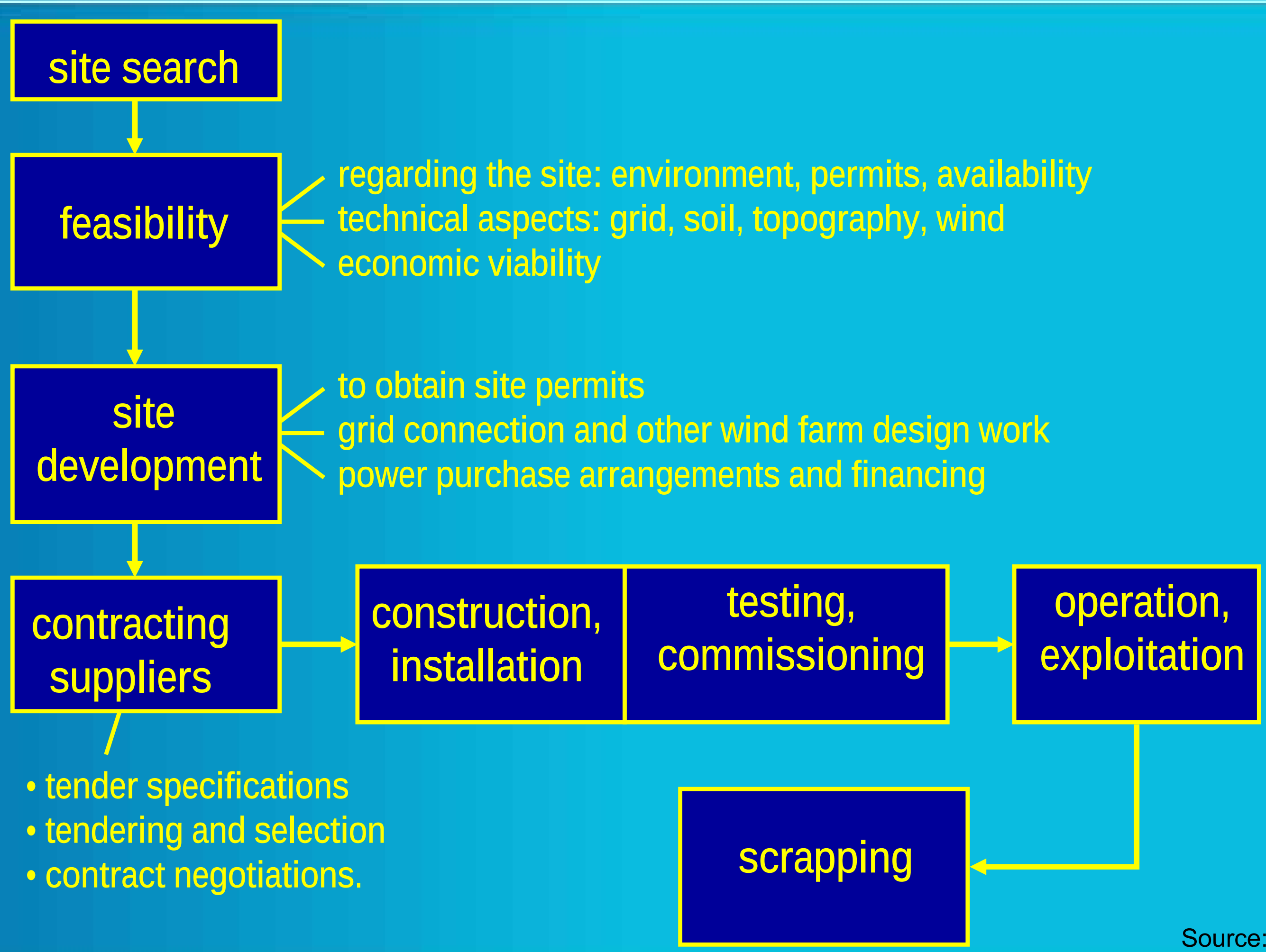
Wind farm cycle



Source: ALTENER

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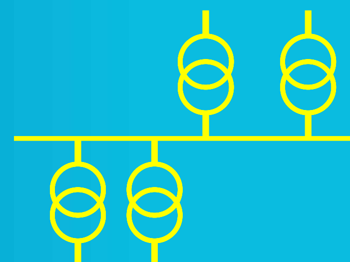
Feasibility study

is site available ?

technical feasible ?



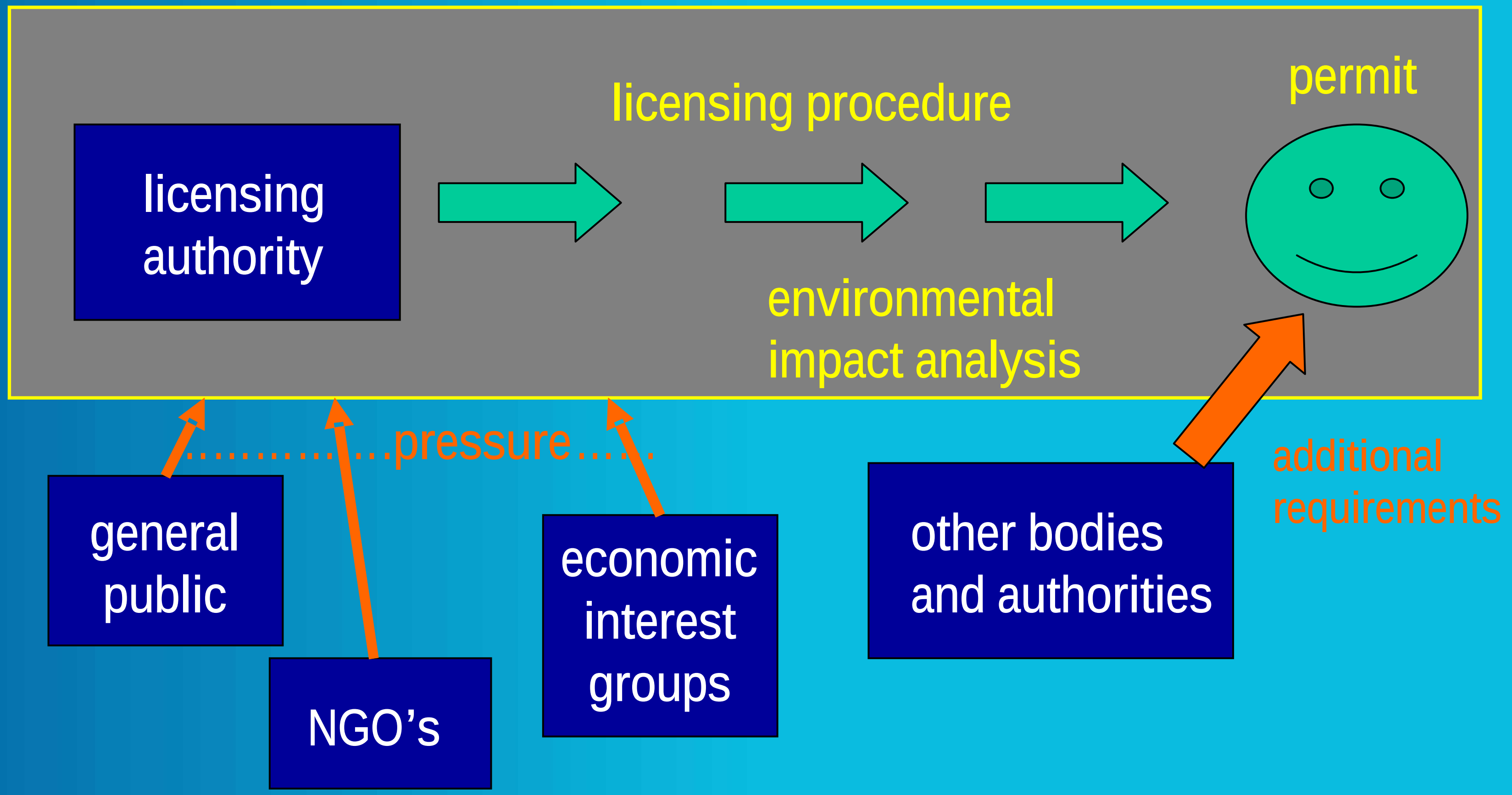
economic feasible ?

YES

proceed with site development

Source: ALTENER

Site development



Source: ALTENER

Construction

- permit → contracting → construction
- construction
  - manufacturing
  - construction work on site
  - transportation
  - erection and assembly of turbines
  - installation of electrical equipment
  - testing
  - commissioning

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Conclusion:
Benefits from wind energy use

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In a nutshell

- Improved security of energy supply → reduced energy dependence through reduced energy imports
- Environmental benefits → emission reductions due to less energy produced from fossil fuel fired power plants
- Improvement of overall economic situation in the country → development of small and medium-size enterprises and creation of new jobs

Sources and useful links

Sources (lectures preparation):

- **ALTENER project AL/68/22** Renewable Energy Course Materials CD (Courses ENG6, ENG7, ENG8)
- **VBPC-RES Publications,** available at http://www.vbpc-res.org/

Links:

- The World Wind Energy Association http://www.wwindea.org/
- The European Wind Energy Association http://www.ewea.org/
- The British Wind Energy Association http://www.bwea.com/
- Danish Wind Industry Association http://www.windpower.org/en/core.htm
- The American Wind Association http://www.awea.org/
- U.S.DOE Energy Efficiency and Renewable Energy http://www.eere.energy.gov/

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Renewable Energy Sources Technology, Economics and Policy Curriculum

Technology-Source Combination module

Hydropower: small hydro

Authors: Suad Halilčević, PhD EE
Vlado Madžarević, PhD EE
University of Tuzla
Faculty of Electrical Engineering

SMALL HYDRO BACKGROUND
SMALL HYDRO PROJECT MODEL

Hydrology
Load
Energy Production
Project Costing
Validation
Summary

Hydroelectricity is one of the most mature forms of renewable energy, providing more than 19% of the world's electricity consumption from both large and small power plants.

Countries such as Brazil, the United States, Canada and Norway produce significant amounts of electricity from very large hydroelectric facilities.

SMALL HYDRO BACKGROUND

- However, there are also many regions of the world that have a significant number of small hydro power plants in operation,
- In China, for example, more than 19,000 MW of electricity is produced from 43,000 small hydro facilities.

SMALL HYDRO BACKGROUND

Small Hydro Project Analysis

There is no universally accepted definition of the term "small hydro" which, depending on local definitions can range in size from a few kilowatts to 50 megawatts or more of rated power output.

Internationally, "small" hydro power plant capacities typically range in size from 1 MW to 50 MW, with projects in the 100 kW to 1 MW range sometimes referred to as "mini" hydro and projects under 100 kW referred to as "micro" hydro.

SMALL HYDRO BACKGROUND

Small Hydro Project Analysis

Installed capacity, however, is not always a good indicator of the size of a project.
For example, a 20 MW, low-head “small” hydro plant is anything but small as low-head projects generally use much larger volumes of water, and require larger turbines as compared with high-head projects.

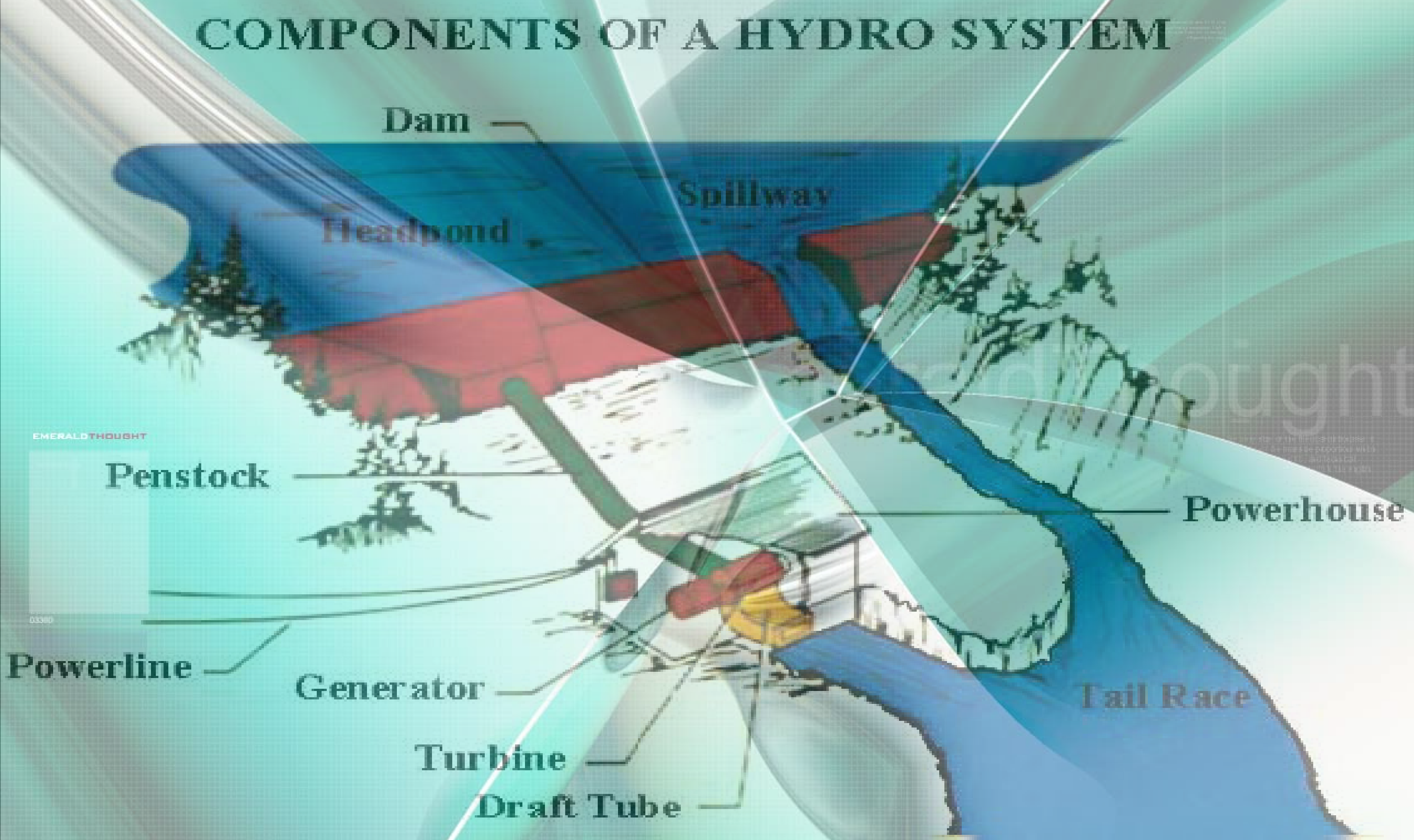
Description of Small Hydro Power Plants

A small hydro generating station can be described under two main headings:

- civil works, and
- electrical and mechanical equipment.

Figure below is for a schematic of a typical small hydro power plant.

Description of Small Hydro Power Plants



Description of Small Hydro Power Plants
- Civil works

The main civil works of a small hydro development are:

- the diversion dam or weir,
- the water passages, and
- the powerhouse

Description of Small Hydro Power Plants - Civil works

The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet.

The water then passes through the turbine, spinning it with enough force to create electricity in a generator.

The water then flows back into the river via a tailrace.

Generally, small hydro projects built for application at an isolated area are run-of-river developments, meaning that water is not stored in a reservoir and is used only as it is available.

Description of Small Hydro Power Plants - Civil works

The cost of large water storage dams cannot normally be justified for small waterpower projects and consequently, a low dam or diversion weir of the simplest construction is normally used.

Construction can be of:

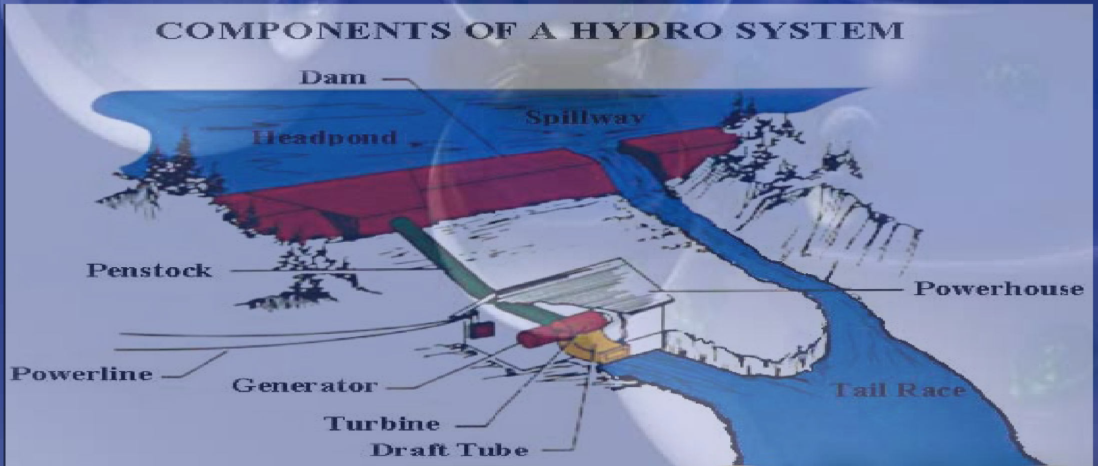
- concrete,
- wood,
- masonry, or
- a combination of these materials.

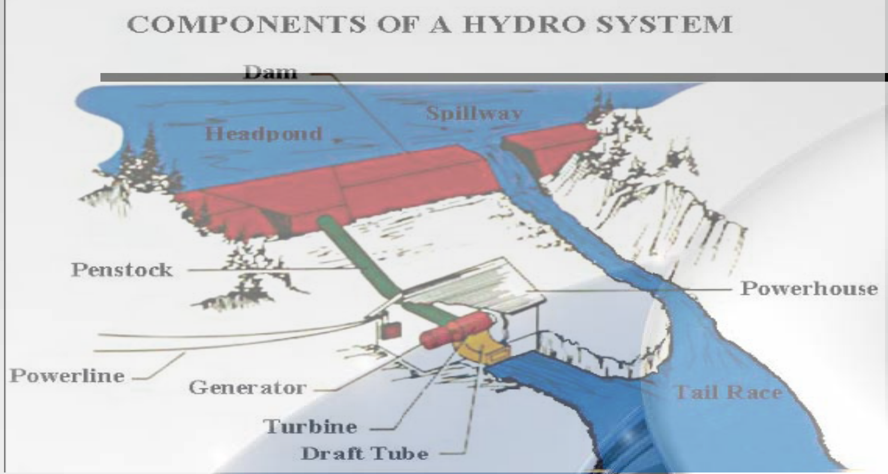
Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable.

The water passages of a small hydro project comprise the following:

- An intake which includes trashracks, a gate and an entrance to a canal, penstock or directly to the turbine depending on the type of development.

- The intake is generally built of reinforced concrete, the trashrack of steel, and the gate of wood or steel.

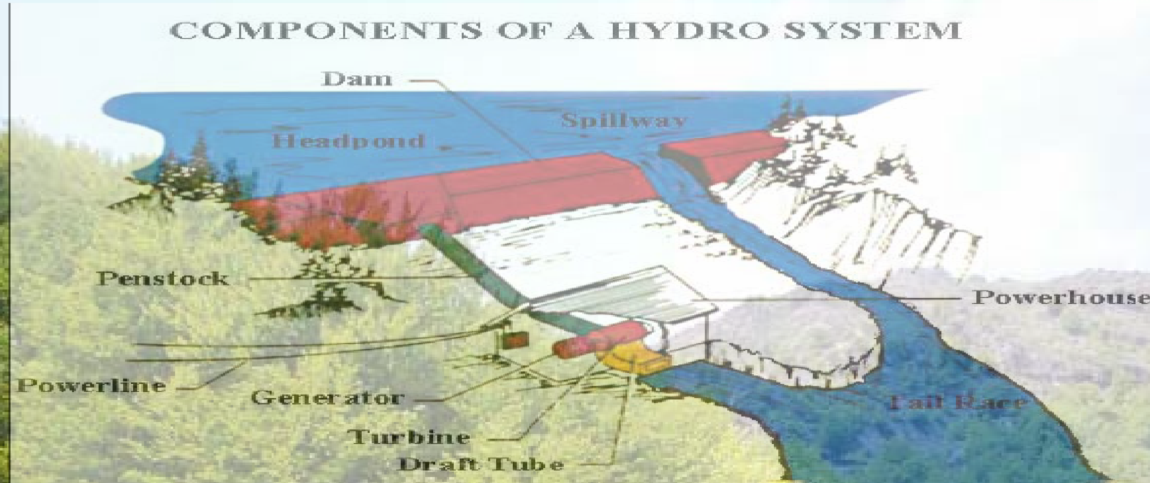




A canal, tunnel and/or penstock, which carries the water to the powerhouse in developments where the powerhouse is located at a distance downstream from the intake.

Canals are generally excavated and follow the contours of the existing terrain.

Tunnels are underground and excavated
by drilling and blasting.
Penstocks, which convey water under pressure, can be made of steel, iron, fibreglass, plastics, concrete or wood.



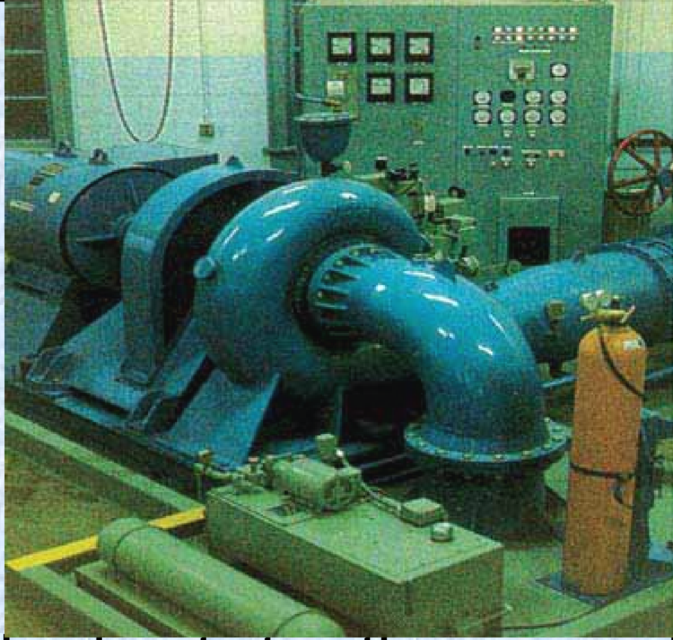
The entrance and exit of the turbine, which include the valves and gates necessary to shut off flow to the turbine for shutdown and maintenance.

These components are generally made of steel or iron.

Gates downstream of the turbine, if required for maintenance, can be made of wood.

A tailrace, which carries the water from the turbine exit back to the river. The tailrace, like the canal, is excavated.

The powerhouse



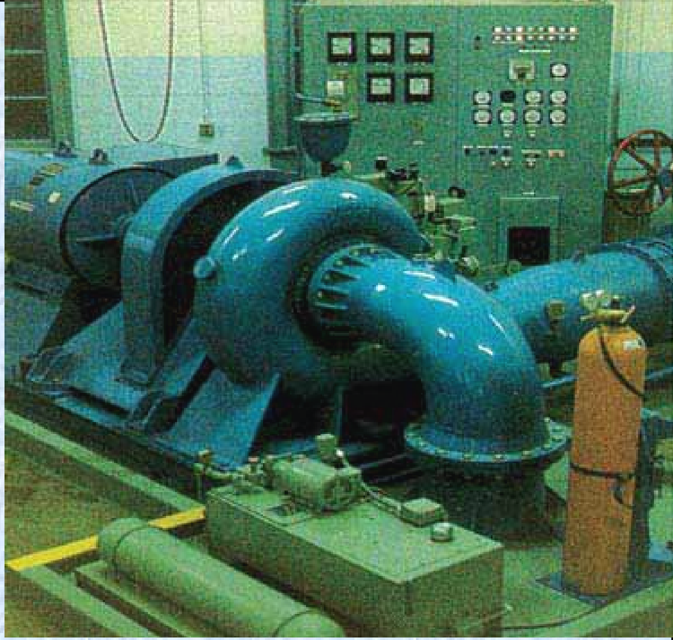
The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment.

Small hydro powerhouses are generally kept to the minimum size possible while still providing adequate foundation strength, access for maintenance, and safety.

Construction is of concrete and other local building materials.

Simplicity in design, with an emphasis on practical, easily constructed civil structures is of prime concern for a small hydro project in order to keep costs at a minimum.

Electrical and mechanical equipment



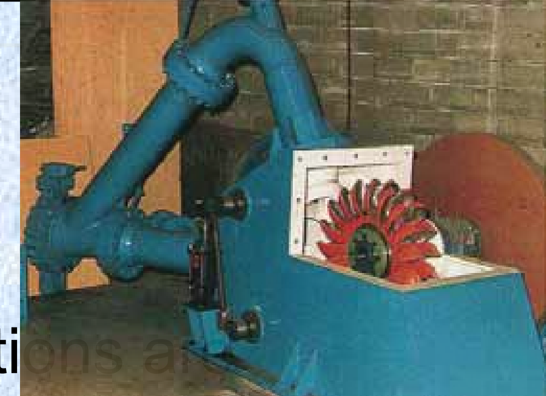
Francis turbine

The primary electrical and mechanical components of a small hydro plant are the turbine(s) and generator(s).

Turbines

A number of different types of turbines have been designed to cover the broad range of hydropower site conditions found around the world.
Turbines used for small hydro applications are scaled-down versions of turbines used in conventional large hydro developments.

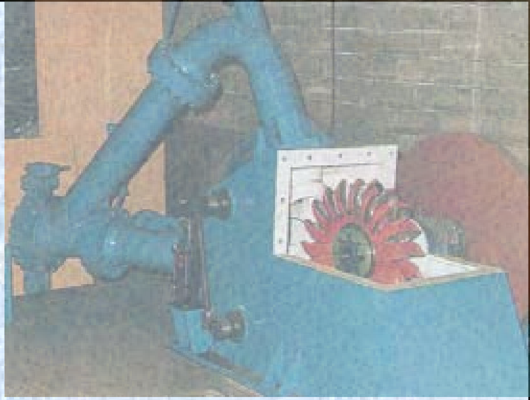
Turbines



Turbines used for low to medium head applications are usually of the reaction type:
Francis,
and fixed and variable pitch (Kaplan) propeller turbines.
The runner or turbine "wheel" of a reaction turbine is completely submersed in water.

Turbines used for high-head applications are generally referred to as impulse turbines. Impulse turbines:
Pelton,
Turgo, and
crossflow designs.
The runner of an impulse turbine spins in the air and is driven by a high-speed jet of water.

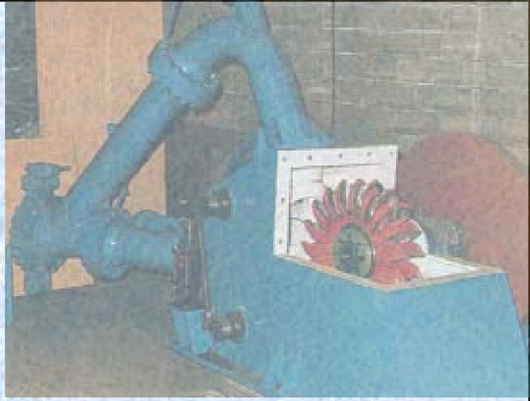
Turbines



Small hydro turbines can attain efficiencies of about 90%.

Care must be given to selecting the preferred turbine design for each application as some turbines only operate efficiently over a limited flow range
(e.g. propeller turbines with fixed blades and Francis turbines).

Turbines



For most run-of-river small hydro sites where flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred (e.g. Kaplan, Pelton, Turgo and crossflow designs).

Alternatively, multiple turbines that operate within limited flow ranges can be used.

Generators

There are two basic types of generators used in small hydro plants:

- ➢synchronous, and
- ➢induction (asynchronous).

A synchronous generator can be operated in isolation while
an induction generator must normally be operated in conjunction with other generators.

Synchronous generators are used as the primary source of power produced by utilities and
for isolated diesel-grid and stand-alone small hydro applications.

Generators

Induction generators with capacities less than about 500 kW are generally best suited for small hydro plants providing energy to a large existing electricity grid.

Other mechanical and electrical components of a small hydro plant include:

- Speed increaser to match the ideal rotational speed of the turbine to that of the generator (if required);
- Water shut-off valve(s) for the turbine(s);
- River by-pass gate and controls (if required);
- Hydraulic control system for the turbine(s) and valve(s);
- Electrical protection and control system;
- Electrical switchgear;
- Transformers for station service and power transmission;

Other mechanical and electrical components of a small hydro plant include:

- Station service including lighting and heating and power to run control systems and switchgear;
- Water cooling and lubricating system (if required);
- Ventilation system;
- Backup power supply;
- Telecommunication system;
- Fire and security alarm systems (if required); and
- Utility interconnection or transmission and distribution system.


Small Hydro Project Development

The development of small hydro projects typically takes from 2 to 5 years to complete, from conception to final commissioning.

This time is required to undertake studies and design work, to receive the necessary approvals and to construct the project.

Once constructed, small hydro plants require little maintenance over their useful life, which can be well over 50 years.

Normally, one part-time operator can easily handle operation and routine maintenance of a small hydro plant.

Periodic maintenance of the larger components of a plant usually requiring help from outside contractors.

The technical and financial viability of SHPP

The technical and financial viability of each potential small hydro project are very site specific.

Power output depends on the available water (flow) and head (drop in elevation).

The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year.

The economics of a site depends on the power (capacity) and the energy that a project can produce, whether or not the energy can be sold, and the price paid for the energy.

The technical and financial viability of SHPP

In an isolated area (off-grid and isolated-grid applications) the value of energy generated for consumption is generally significantly more than for systems that are connected to a central-grid.

However, isolated areas may not be able to use all the available energy from the small hydro plant and, may be unable to use the energy when it is available because of seasonal variations in water flow and energy consumption.

The technical and financial viability of SHPP

A conservative, “rule-of-thumb” relationship is that power for a hydro project is equal to seven times the product of the flow (Q) and gross head (H) at the site (P = 7QH).

Producing 1 kW of power at a site with 100 m of head will require one-tenth the flow of water that a site with 10 m of head would require.

The hydro turbine size depends primarily on the flow of water it has to accommodate. Thus, the generating equipment for higher-head, lower-flow installations is generally less expensive than for lower-head, higher-flow plants.

The technical and financial viability of SHPP

The same cannot necessarily be said for the civil works components of a project which are related much more to the local topography and physical nature of a site.

Types of small hydro developments

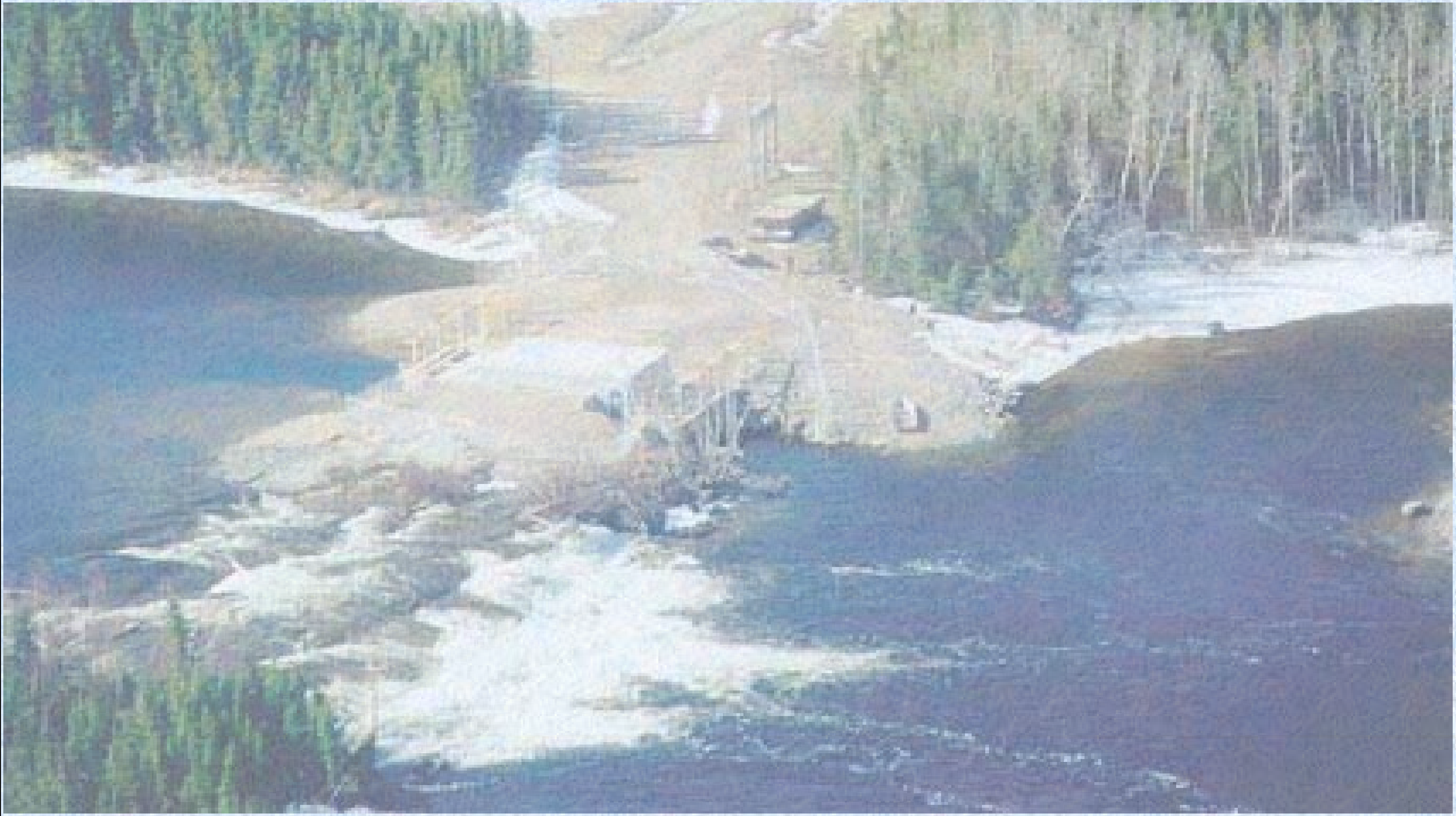
Small hydro projects can generally be categorised as:

1. "run-of-river developments", and/or

2. "water storage (reservoir) developments".

Run-of-river developments

Run-of-River Small Hydro Project in a Remote Community.



“Run-of-river” SHPP

- “Run-of-river” refers to a mode of operation in which the hydro plant uses only the water that is available in the natural flow of the river,
- “Run-of-river” implies that there is no water storage and that power fluctuates with the stream flow.

"Run-of-river" SHPP

- The power output of run-of-river small hydro plants fluctuates with the hydrologic cycle, so they are often best suited to provide energy to a larger electricity system.
- Individually, they do not generally provide much firm capacity. Therefore, isolated areas that use small hydro resources often require supplemental power.
- A run-of-river plant can only supply all of the electrical needs of an isolated area or industry if the minimum flow in the river is sufficient to meet the load's peak power requirements.

“Run-of-river” SHPP

- Run-of-river small hydro can involve diversion of the flow in a river. Diversion is often required to take advantage of the drop in elevation that occurs over a distance in the river.
- Diversion projects reduce the flow in the river between the intake and the powerhouse. A diversion weir or small dam is usually required to divert the flow into the intake.

Water storage (reservoir) developments

For a hydroelectric plant to provide power on demand, either to meet a fluctuating load or to provide peak power, water must be stored in one or more reservoirs.

Unless a natural lake can be tapped, providing storage usually requires the construction of a dam or dams and the creation of new lakes.

This impacts the local environment in both negative and positive ways, although the scale of development often magnifies the negative impacts.

Water storage (reservoir) developments

This often presents a conflict, as larger hydro projects are attractive because they can provide “stored” power during peak demand periods.

Due to the economies of scale and the complex approval process, storage schemes tend to be relatively large in size.

Water storage (reservoir) developments

The creation of new storage reservoirs for small hydro plants is generally not financially viable except, possibly, at isolated locations where the value of energy is very high.

Storage at a small hydro plant, if any, is generally limited to small volumes of water in a new head pond or existing lake upstream of an existing dam.

Pondage is the term used to describe small volumes of water storage. Pondage can provide benefits to small hydro plants in the form of increased energy production and/or increased revenue.

Water storage (reservoir) developments

Another type of water storage development is “pumped storage” where water is “recycled” between downstream and upstream storage reservoirs.

Water is passed through turbines to generate power during peak periods and pumped back to the upper reservoir during off-peak periods.

The economics of pumped storage projects depends on the difference between the values of peak and off-peak power.

Water storage (reservoir) developments

Due to the inefficiencies involved in pumping versus generating, the recycling of water results in a net consumption of energy.

Energy used to pump water has to be generated by other sources.

The environmental impacts of SHPP

The environmental impacts that can be associated with small hydro developments can vary significantly depending on the location and configuration of the project.

The effects on the environment of developing a run-of-river small hydro plant at an existing dam are generally minor and similar to those related to the expansion of an existing facility.

Development of a run-of-river small hydro plant at an undeveloped site can pose additional environmental impacts. A small dam or diversion weir is usually required.

The most economical development scheme might involve flooding some rapids upstream of the new small dam or

The environmental impacts of SHPP

The environmental impacts that can be associated with hydroelectric developments that incorporate water storage (typically larger in size) are mainly related to the creation of a water storage reservoir.

The creation of a reservoir involves the construction of a relatively large dam, or the use of an existing lake to impound water.

The creation of a new reservoir with a dam involves the flooding of land upstream of the dam.

The environmental impacts of SHPP

The use of water stored in the reservoir behind a dam or in a lake results in the fluctuation of water levels and flows in the river downstream.

In that case, a rigorous environmental assessment is typically required for any project involving water storage.

Hydro project engineering phases

There are normally four phases for engineering work required to develop a hydro project:

- Reconnaissance surveys and hydraulic studies,
- Pre-feasibility study,
- Feasibility study,
- System planning and project engineering.

Hydro project engineering phases– Reconnaissance surveys and hydraulic studies

This first phase of work frequently covers numerous sites and includes:

- map studies;
- delineation of the drainage basins;
- preliminary estimates of flow and floods;
- a one day site visit to each site (by a design engineer and geologist or geotechnical engineer);

Hydro project engineering phases– Reconnaissance surveys and hydraulic studies

- preliminary layout;
- cost estimates (based on formulae or computer data);
- a final ranking of sites based on power potential; and
- an index of cost.

Hydro project engineering phases–
Pre-feasibility study

Work on the selected site or sites would include:

- site mapping and geological investigations

(with drilling confined to areas where foundation uncertainty would have a major effect on costs);

- a reconnaissance for suitable borrow areas (e.g. for sand and gravel);
- a preliminary layout based on materials known to be available;

Hydro project engineering phases–Pre-feasibility study

- Preliminary selection of the main project characteristics (installed capacity, type of development, etc.);
- a cost estimate based on major quantities;
- the identification of possible environmental impacts; and
- production of a single volume report on each site.

Hydro project engineering phases– feasibility study

Work would continue on the selected site with the next investigation programme:

- delineation and testing of all borrow areas;
- estimation of diversion, design and probable maximum floods;
- determination of power potential for a range of dam heights and installed capacities for project optimisation;
- determination of the project design earthquake and the maximum credible earthquake;

Hydro project engineering phases – feasibility study

Work would continue on the selected site with the next investigation programme:

- design of all structures in sufficient detail to obtain quantities for all items contributing more than about 10% to the cost of individual structures;
- determination of the dewatering sequence and project schedule;
- optimisation of the project layout, water levels and components;

Hydro project engineering phases – feasibility study

Work would continue on the selected site with the next investigation programme:

- production of a detailed cost estimate;

and finally,

- an economic and financial evaluation of the project including an assessment of the impact on the existing electrical grid along with a multi-volume comprehensive feasibility report.

Hydro project engineering phases– System planning and project engineering

This work would includes:

- ➢studies and final design of the transmission system;
- ➢Integration of the transmission system;
- ➢integration of the project into the power network to determine precise operating mode;
- ➢production of tender drawings and specifications;

Hydro project engineering phases – System planning and project engineering

- analysis of bids and detailed design of the project;

- production of detailed construction drawings and review of manufacturer’s equipment drawings.

However, the scope of this phase would not include site supervision nor project management, since this work would form part of the project execution costs.

SMALL HYDRO POWER PLANT PROJECT MODEL

Small Hydro Project Model should provide a means to assess:

❖ the available energy at a potential small hydro site that could be provided to a central-grid or, for isolated loads, and

❖ the portion of this available energy that could be harnessed by a local electric utility (or used by the load in an off-grid system).

The model should address both run-of-river and reservoir developments, and to incorporate sophisticated formulae for calculating efficiencies of a wide variety of hydro turbines.

SHPP PROJECT MODEL

The SHPP Project Model has been developed primarily to determine whether work on the small hydro project should proceed further or be dropped in favour of other alternatives.

Each hydro site is unique, since about 75% of the development cost is determined by the location and site conditions.

Only about 25% of the cost is relatively fixed, being the cost of manufacturing the electromechanical equipment.

SHPP PROJECT MODEL

Six worksheets should be provided in the SHPP Project Model:

✓*(Energy Model, Hydrology Analysis and Load Calculation (Hydrology & Load),*

✓*Equipment Data,*

✓*Cost Analysis,*

✓*Greenhouse Gas Emission Reduction Analysis (GHG Analysis),*

✓*Financial Summary,* and

✓*Sensitivity and Risk Analysis (Sensitivity))*.

SHPP PROJECT MODEL

The ***Energy Model***, ***Hydrology & Load*** and ***Equipment Data*** worksheets are completed first.

The ***Cost Analysis*** worksheet should then be completed, followed by the ***Financial Summary*** worksheet.

The ***GHG Analysis*** and ***Sensitivity*** worksheets are optional analysis.

The *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project.

The *Sensitivity* worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters.

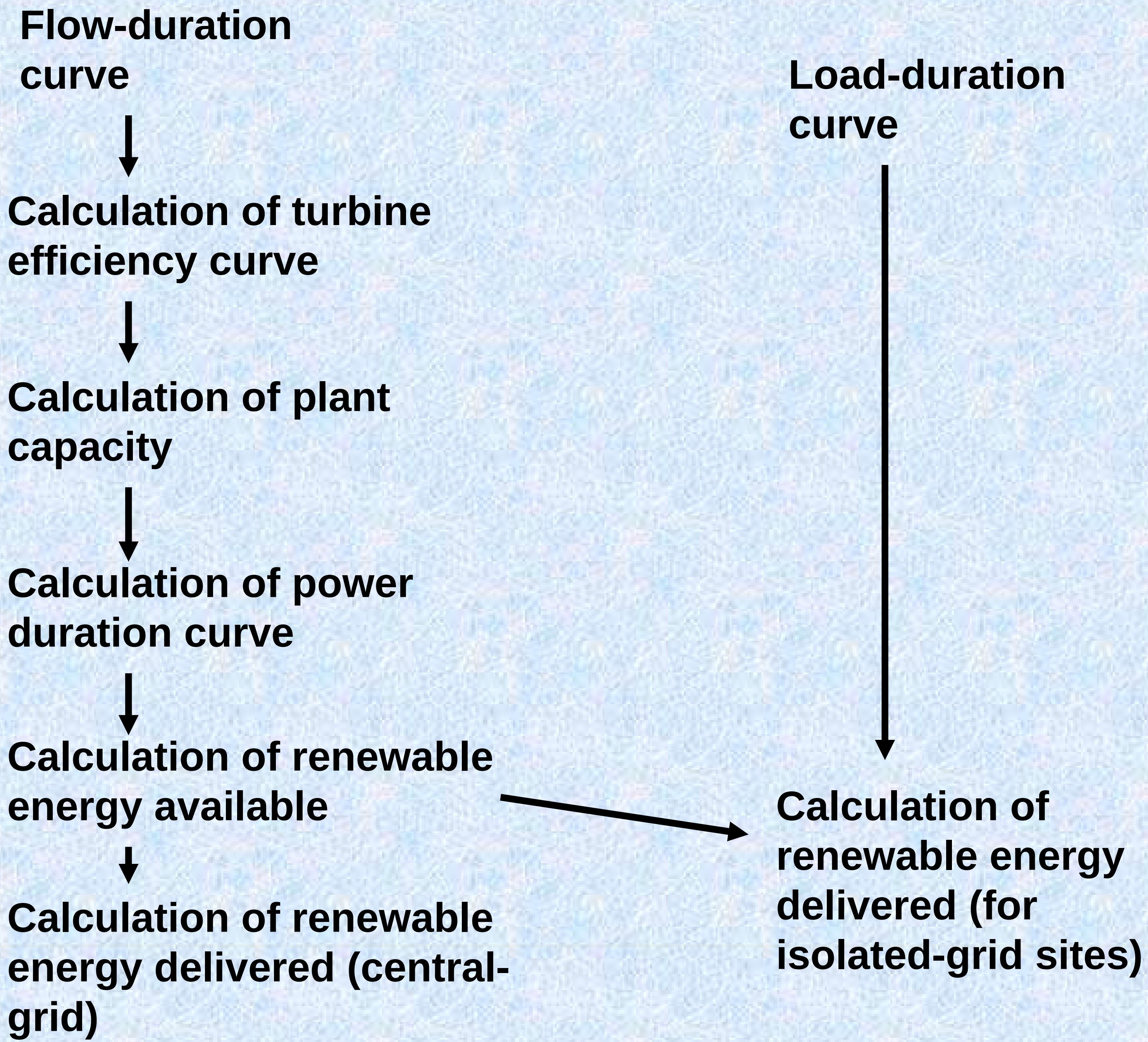
SHPP PROJECT MODEL

In general, the user can work from top-down for each of the calculation phase.

This process can be repeated several times in order to help optimise the design of the SHPP project from an energy use and cost standpoint.

Algorithm to calculate, on an annual basis, the energy production of SHPP

A flowchart of the algorithm:



Flow-duration curve
Calculation of turbine efficiency curve
Calculation of plant capacity
Calculation of power duration curve
Calculation of renewable energy available
Calculation of renewable energy delivered (central-grid)
Load-duration curve
Calculation of renewable energy delivered (for isolated-grid sites)

Hydrology

Hydrological data are specified as a flow-duration curve, which is assumed to represent the flow conditions in the river being studied over the course of an average year.

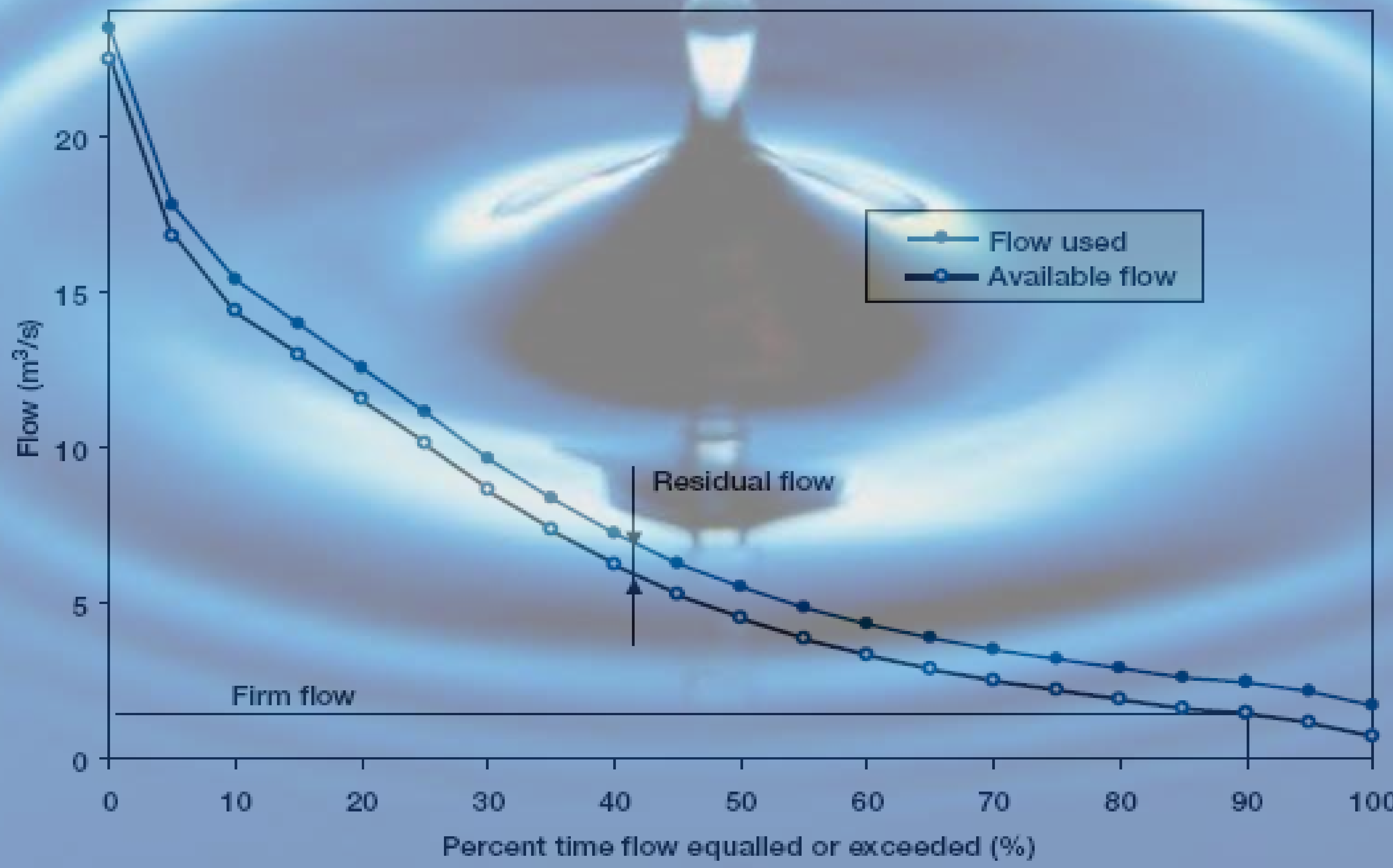
A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow.

Hydrology
Flow-duration curve

The flow-duration curve is used to assess the anticipated availability of flow over time, and consequently the power and energy, at a site.

Then we can calculate the firm flow that will be available for electricity production based on the flow-duration curve data, the percent time the firm flow should be available and the residual flow.

Flow-duration curve



Hydrology
Flow-duration curve

The flow-duration curve is expressed in normalised form, i.e. relative to the mean flow.

The mean flow *Q* is calculated as:

$$\bar{Q} = R\,A_D$$

where *R* is the specific run-off and A_D is the drainage area.

Hydrology
Flow-duration curve

The actual flow data Q_n is computed from the normalised flow data q_n extracted from the weather database through:

$$Q_n = q_n \, \overline{Q}$$

q_n is dimensionlessness variable.

Hydrology
Available flow

A certain amount of flow must be left in the river throughout the year for environmental reasons.

This *residual flow* Q_r is specified by the user and must be subtracted from all values of the flow-duration curve for the calculation of plant capacity, firm capacity and renewable energy available.

The *available flow* Q'_n is defined by:

$$Q'_n = \max\left(Q_n - Q_r, 0\right)$$

Hydrology
Firm flow

The firm flow is defined as the flow being available *p*% of the time, where *p* is a percentage specified by the user and usually equal to 95%.

The firm flow is calculated from the available flow-duration curve.

If necessary, a linear interpolation between 5% intervals is used to find the firm flow.

In the example of above presented Fig. the firm flow is equal to 1.5 m3/s with *p* set to 90%.

SHPP Project Model
Load

If the small hydro power plant is connected to a central-grid, then it is assumed that the grid absorbs all of the energy production and the load does not need to be specified.

If on the other hand the system is off-grid or connected to an isolated-grid, then the portion of the energy that can be delivered depends on the load.

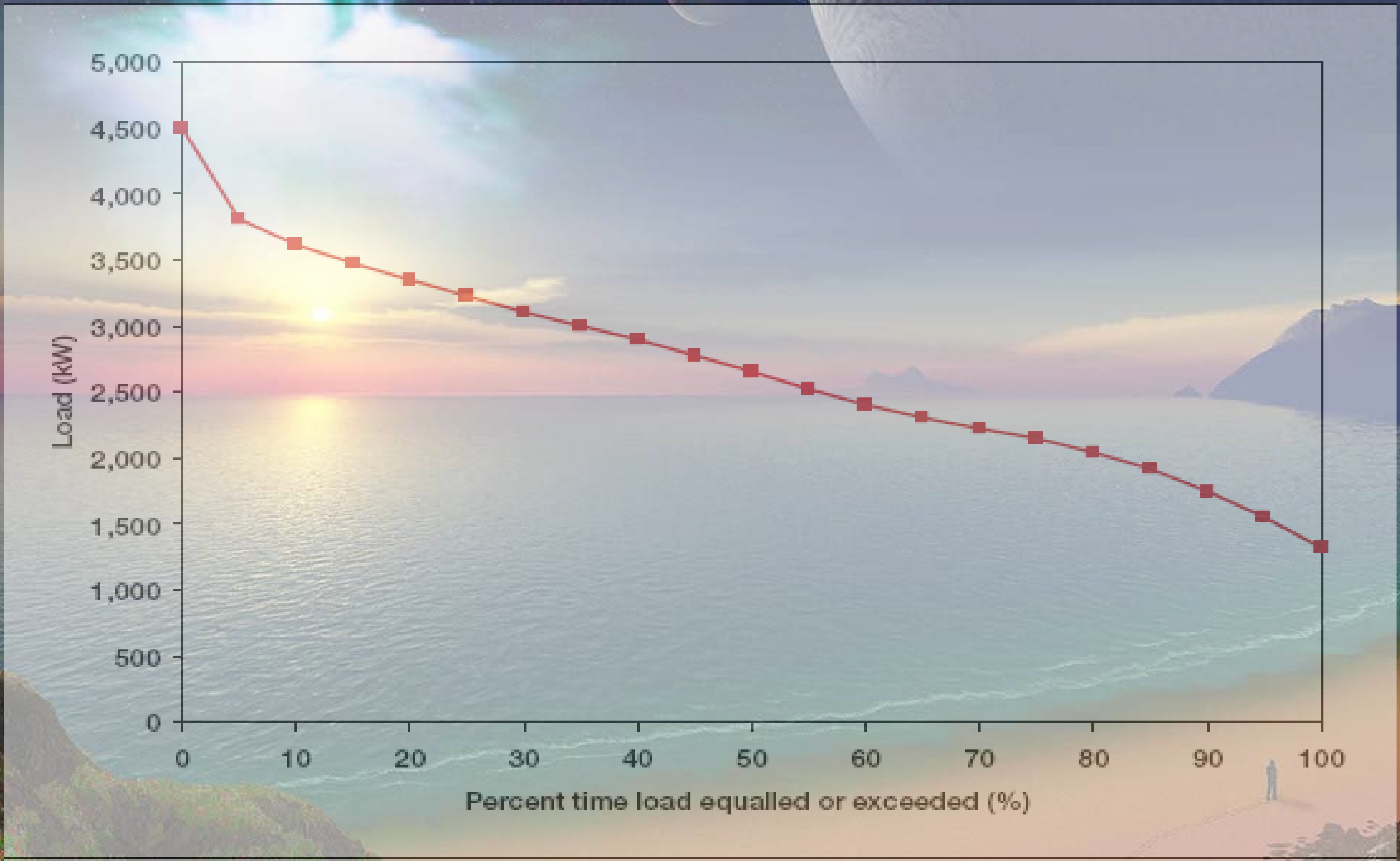
SHPP Project Model
Load

Load demand can be represented by a load-duration curve.

The load-duration curve can be specified for example, by twenty-one values L_0 L_5 L_{100} , …, defining the load on the load-duration curve in 5% increments.

L_k represents the load that is equalled or exceeded *k* % of the time.

SHPP Project Model
Load



SHPP Project Model
Load
Energy demand

Daily energy demand is calculated by integrating the area under the load-duration curve over one day.

A simple trapezoidal integration formula is used. The daily demand D_d expressed in kWh is therefore calculated as:

$$D_d = \sum_{k=1}^{20} \left(\frac{L_{5(k-1)} + L_{5k}}{2} \right) \frac{5}{100} 24$$

L is expressed in kW.

SHPP Project Model
Load
Energy demand

The annual energy demand *D* is obtained by multiplying the daily demand by the number of days in a year, 365:

$$D = 365\,D_d$$

SHPP Project Model
Load
Average load factor

The average load factor $\bar{L}$ is the ratio of the average daily load ($D_d / 24$) to the peak load (L_0):

$$\bar{L} = \frac{D_d / 24}{L_0}$$

This quantity is simply provided to the user to give an indication of the variability of the load.

SHPP Project Model
Energy Production

This part calculates the estimated renewable energy delivered (MWh) based on the next variables:

- adjusted available flow (adjusted flow-duration curve),
- the design flow,
- the residual flow,
- the load (load-duration curve),
- the gross head, and
- the efficiencies/losses.

The calculation involves comparing the daily renewable energy available to the daily load-duration curve for each of the flow-duration curve values.

SHPP Project Model
Energy Production
Turbine efficiency curve

Standard turbine efficiencies curves can be developed for the following turbine types:

- Kaplan (reaction turbine),
- Francis (reaction turbine),
- Propellor (reaction turbine),
- Pelton (impulse turbine),
- Turgo (impulse turbine), and
- Cross-flow (generally classified as an impulse turbine).

SHPP Project Model
Energy Production
Turbine efficiency curve

The type of turbine is selected based on its suitability to the available head and flow conditions.

The calculated turbine efficiency curves take into account a number of factors including:

- rated head (gross head less maximum hydraulic losses),
- runner diameter (calculated),
- turbine specific speed (calculated for reaction turbines), and
- the turbine manufacture/design coefficient.

SHPP Project Model
Energy Production
Turbine efficiency curve

The efficiency equations were derived from a large number of manufacture efficiency curves for different turbine types and head and flow conditions.

Follow the turbine efficiency equations

FRANCIS, KAPLAN AND PROPELLOR TURBINES (REACTION TURBINES):

ITEM	FORMULA
Reaction turbine runner size (d)	$$d = kQ_d^{0.473}$$ where: d = runner throat diameter in m k = 0.46 for $d < 1.8$ = 0.41 for $d \geq 1.8$ Q_d = design flow (flow at rated head and full gate opening in m^3/s)
Specific speed (n_q)	$$n_q = kh^{-0.5}$$ where: n_q = specific speed based on flow k = 800 for propeller and Kaplan turbines = 600 for Francis turbines h = rated head on turbine in m (gross head less maximum hydraulic losses)

SHPP Project Model
Energy Production
Turbine efficiency curve

FRANCIS TURBINES:	
ITEM	FORMULA
Specific speed adjustment to peak efficiency ($\hat{e}_{nq}$)	$$\hat{e}_{nq} = \{(n_q - 56)/256\}^2$$
Runner size adjustment to peak efficiency ($\hat{e}_d$)	$$\hat{e}_d = (0.081 + \hat{e}_{nq})(1 - 0.789 d^{-0.2})$$
Turbine peak efficiency (e_p)	$$e_p = (0.919 - \hat{e}_{nq} + \hat{e}_d) - 0.0305 + 0.005\ R_m$$ where: R_m = turbine manufacture/design coefficient (2.8 to 6.1; default = 4.5). Refer to online manual.

SHPP Project Model

Energy Production

Turbine efficiency curve - Francis turbines

Peak efficiency flow (Q_p)	$Q_p = 0.65\ Q_d\ n_q^{0.05}$
Efficiencies at flows below peak efficiency flow (e_q)	$e_q = \left\{1 - \left[1.25\left(\frac{(Q_p - Q)}{Q_p}\right)^{(3.94-0.0195 n_q)}\right]\right\} e_p$
Drop in efficiency at full load ($\hat{}e_p$)	$\hat{}e_p = 0.0072\ n_q^{0.4}$
Efficiency at full load (e_r)	$e_r = (1 - \hat{}e_p)\ e_p$
Efficiencies at flows above peak efficiency flow (e_q)	$e_q = e_p - \left[\left(\frac{Q - Q_p}{Q_d - Q_p}\right)^2 (e_p - e_r)\right]$

Turbine efficiency curve

KAPLAN AND PROPELLOR TURBINES:	
ITEM	FORMULA
Specific speed adjustment to peak efficiency ($\hat{}e_{nq}$)	$\hat{}e_{nq} = \{(n_q - 170)/700\}^2$
Runner size adjustment to peak efficiency ($\hat{}e_d$)	$\hat{}e_d = (0.095 + \hat{}e_{nq})(1 - 0.789 d^{-0.2})$
Turbine peak efficiency (e_p)	$e_p = (0.905 - \hat{}e_{nq} + \hat{}e_d) - 0.0305 + 0.005\ R_m$ where: R_m = Turbine manufacture/design coefficient (2.8 to 6.1; default 4.5). Refer to online manual.

Energy Production

Turbine efficiency curve

KAPLAN TURBINES:	
ITEM	FORMULA
Peak efficiency flow (Q_p)	$Q_p = 0.75\ Q_d$
Efficiency at flows above and below peak efficiency flow (e_q)	$e_q = \left[1 - 3.5\left(\frac{Q_p - Q}{Q_p}\right)^6\right] e_p$

Energy Production
Turbine efficiency curve

PROPELLOR TURBINES:	
ITEM	FORMULA
Peak efficiency flow (Q_p)	$Q_p = Q_d$
Efficiencies at flows below peak efficiency flow (e_q)	$e_q = \left[1 - 1.25\left(\frac{Q_p - Q}{Q_p}\right)^{1.13}\right] e_p$

Energy Production

Turbine efficiency curve

PELTON TURBINES:

ITEM	FORMULA
Rotational speed (n)	$$n = 31\left(h\,\frac{Q_d}{j}\right)^{0.5}$$ where: j = Number of jets (user-selected value from 1 to 6)
Outside diameter of runner (d)	$$d = \frac{49.4\,h^{0.5}\,j^{0.02}}{n}$$
Turbine peak efficiency (e_p)	$$e_p = 0.864\;d^{0.04}$$
Peak efficiency flow (Q_p)	$$Q_p = (0.662 + 0.001\,j)\,Q_d$$

Energy Production

Turbine efficiency curve – Pelton turbines

Efficiency at flows above and below peak efficiency flow (e_q)	$$e_q = \left[1 - \left\{ (1.31 + 0.025j) \left| \left(\frac{Q_p - Q}{Q_p} \right) \right|^{(5.6+0.4j)} \right\} \right] e_p$$

SHPP Project Model
Energy Production
Turbine efficiency curve

TURGO TURBINES:

ITEM	FORMULA
Efficiency (e_q)	Pelton efficiency minus 0.03

SHPP Project Model
Energy Production
Turbine efficiency curve

CROSS-FLOW TURBINES:	
ITEM	FORMULA
Peak efficiency flow (Q_p)	$Q_p = Q_d$
Efficiency (e_q)	$e_q = 0.79 - 0.15\left(\dfrac{Q_d - Q}{Q_p}\right) - 1.37\left(\dfrac{Q_d - Q}{Q_p}\right)^{14}$

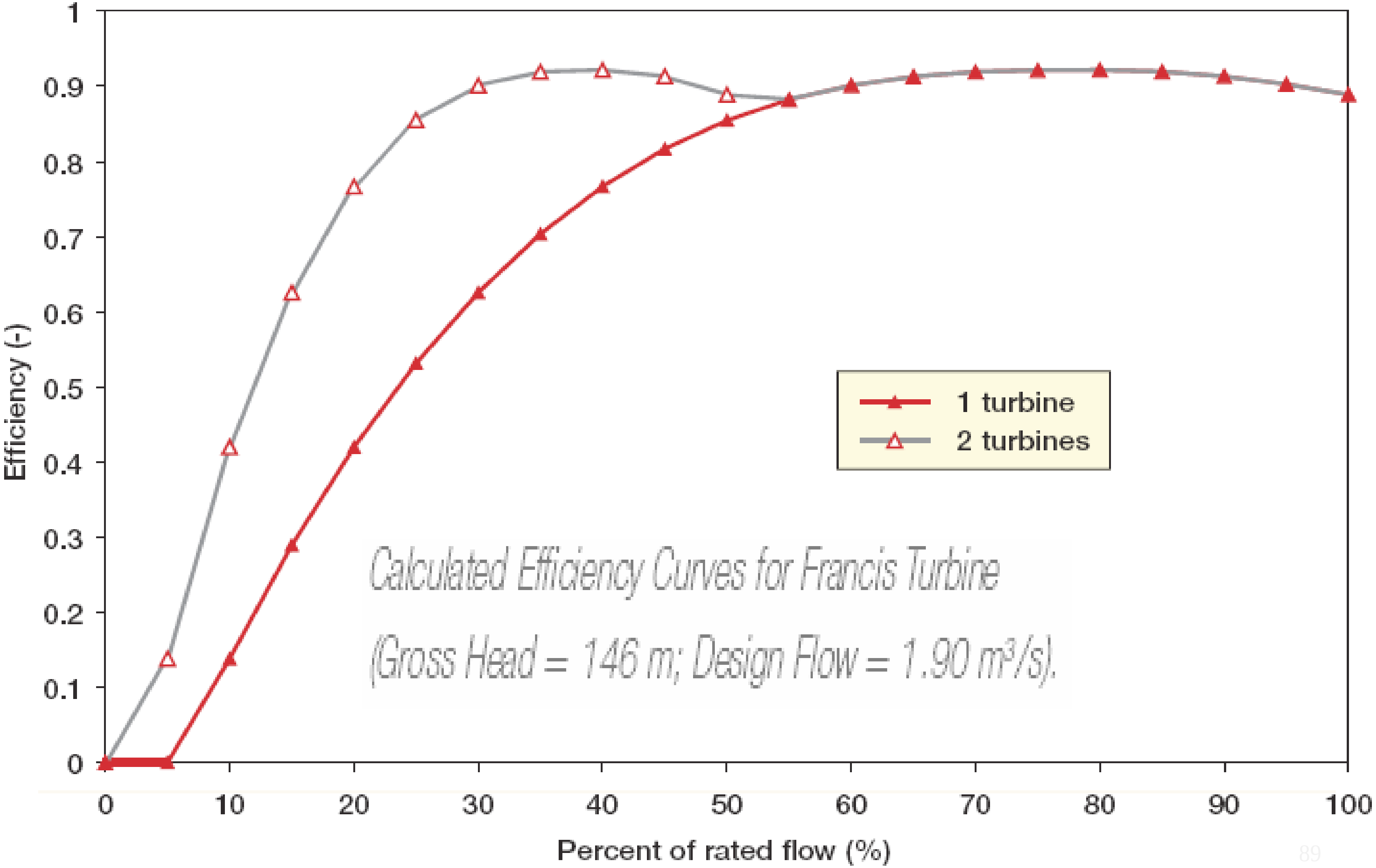
Energy Production

Turbine efficiency curve

The turbine efficiency equations and the number of turbines are used to calculate plant turbine efficiency from 0% to 100% of design flow (maximum plant flow) at 5% intervals.

An example turbine efficiency curve is shown in next figure for 1 and 2 turbines.

SHPP Project Model
Energy Production
Turbine efficiency curve



Energy Production

Power available as a function of flow

Actual power *P* available from the small hydro plant at any given flow value *Q* is given by the following equation, in which the flow-dependent hydraulic losses and tailrace reduction are taken into account:

$$P = \rho\, g\, Q \left[H_g - \left(h_{hydr} + h_{tail} \right) \right] e_t\, e_g\, (1 - l_{trans})\left(1 - l_{para}\right)$$

where:

ρ is the density of water (1,000 kg/m3),

g the acceleration of gravity (9.81 m/s2),

H_g the gross head,

h_{hydr} and h_{tail} are respectively the hydraulic losses and tailrace effect associated with the flow;

Power available as a function of flow

$$P = \rho\, g\, Q \left[H_g - \left(h_{hydr} + h_{tail} \right) \right] e_t\, e_g \left(1 - l_{trans}\right)\left(1 - l_{para}\right)$$

*

e_t - the turbine efficiency at flow *Q*,
e_g - the generator efficiency,
l_{trans} - the transformer losses, and
l_{para} - the electricity losses.

Power available as a function of flow

Hydraulic losses are adjusted over the range of available flows based on the following relationship:

$$h_{hydr} = H_g \, l_{hydr,max} \frac{Q^2}{Q_{des}{}^2}$$

Power available as a function of flow

$l_{hydr,max}$ is the maximum hydraulic losses specified by the user, and Q_{des} the design flow.

Similarly the maximum tailrace effect is adjusted over the range of available flows with the following relationship:

$$h_{tail} = h_{tail,max} \frac{\left(Q - Q_{des}\right)^2}{\left(Q_{max} - Q_{des}\right)^2}$$

Power available as a function of flow

$$h_{tail} = h_{tail,max} \frac{\left(Q - Q_{des}\right)^2}{\left(Q_{max} - Q_{des}\right)^2}$$

where $h_{tail,max}$ is the maximum tailwater effect, i.e. the maximum reduction in available gross head that will occur during times of high flows in the river.

Q_{max} is the maximum river flow.

This equation is applied only to river flows that are greater than the plant design flow (i.e. when $Q > Q_{des}$).

Energy Production

Plant capacity

when $Q \leq Qdes$

Plant capacity P_{des} is calculated at the design flow Q_{des}

$$P_{des} = \rho \; g \; Q_{des} \, H_g \left(1 - l_{hydr}\right) e_{t,des} \; e_g \left(1 - l_{trans}\right) \left(1 - l_{para}\right)$$

where P_{des} is the plant capacity and $e_{t,des}$ the turbine efficiency at design flow.

Power-duration curve

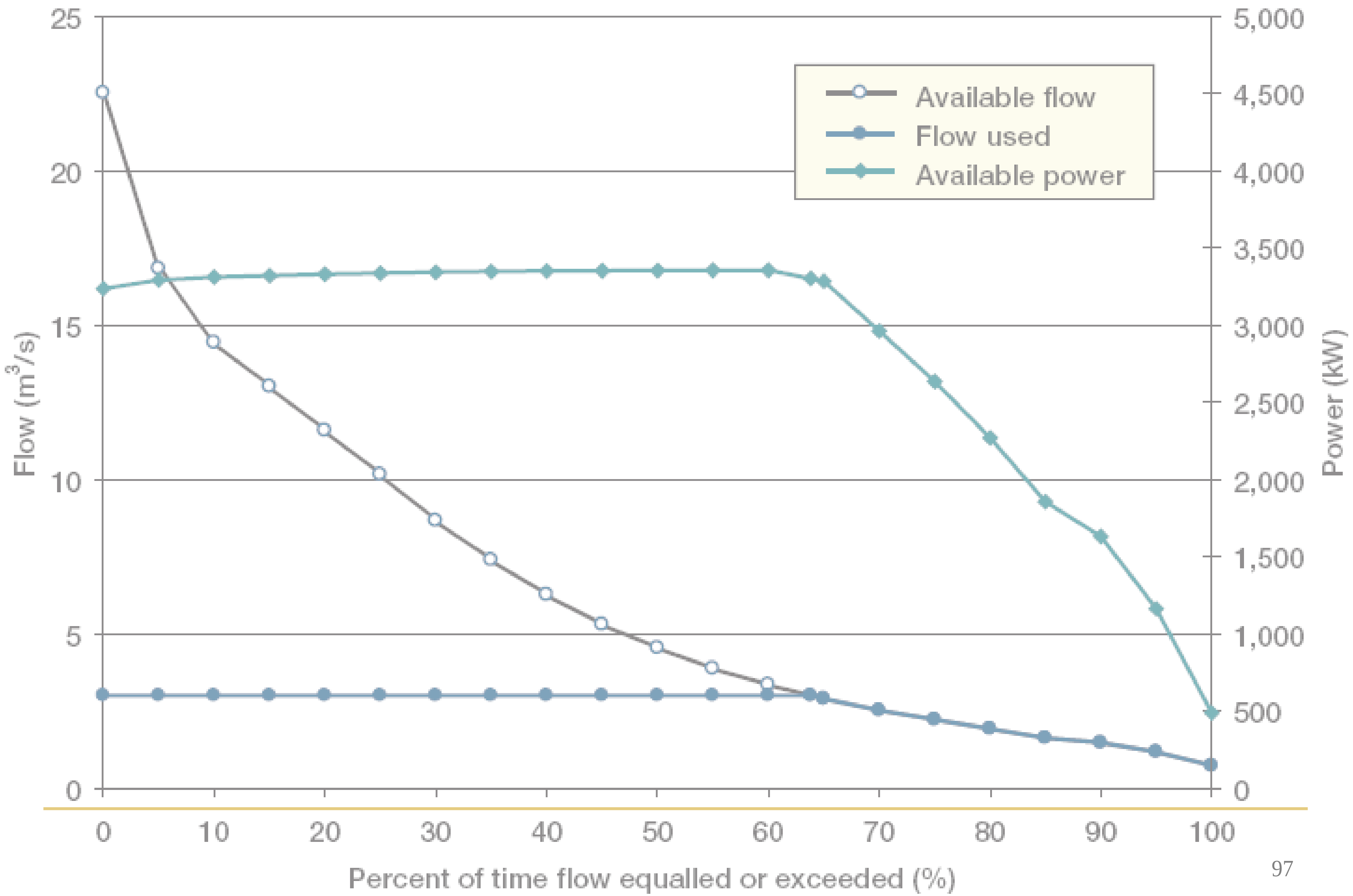
Calculation of power available as a function of flow using equation (*) for all 21 values of the available flow Q_0' Q_5' , ... , Q_{100}' , used to define the flow duration curve,

leads to 21 values of available power P_0 P_1 ,…, P_{100} , defining a power-duration curve.

An example power-duration curve is shown in next ***Figure***, with the design flow equal to 3 m^3/s.

SHPP Project Model

Energy Production- Power-duration curve



Renewable energy available

Renewable energy available is determined by calculating the area under the power curve assuming a straight-line between adjacent calculated power output values.

Given that the flow-duration curve represents an annual cycle, each 5% interval on the curve is equivalent to 5% of 8,760 hours (number of hours per year).

Renewable energy available

The annual available energy E_{avail} (in kWh/yr) is therefore calculated from the values P (in kW) by:

$$E_{avail} = \sum_{k=1}^{20} \left(\frac{P_{5(k-1)} + P_{5k}}{2} \right) \frac{5}{100} \; 8760 \; (1 - l_{dt})$$

where l_{dt} is the annual downtime losses as specified by the user.

In the case where the design flow falls between two 5% increments on the flow-duration curve (as in above *Figure***)** the interval is split in two and a linear interpolation is used on each side of the design flow.

Energy Production- Renewable energy available

The fore equation defines the amount of renewable energy available.

The amount actually delivered depends on the type of grid.

Renewable energy delivered - central-grid

For central-grid applications, it is assumed that the grid is able to absorb all the energy produced by the small hydro power plant.

Therefore, all the renewable energy available will be delivered to the central-grid and the renewable energy delivered, E_{dlvd} , is simply:

$$E_{dlvd} = E_{avail}$$

Renewable energy delivered - isolated-grid and off-grid

For isolated-grid and off-grid applications the procedure is slightly more complicated because the energy delivered is actually limited by the needs of the local grid or the load, as specified by the load-duration curve.

The following procedure is used: for each 5% increment on the flow-duration curve, the corresponding available plant power output (assumed to be constant over a day) is compared to the load-duration curve (assumed to represent the daily load demand).

Renewable energy delivered - isolated-grid and off-grid

The portion of energy that can be delivered by the small hydro plant is determined as the area that is under both the load-duration curve and the horizontal line representing the available plant power output.

Twenty-one values of the daily energy delivered G_0, G_5 ,…, G_{100} corresponding to available power P_0, P_5, …, P_{100} , are calculated.

For each value of available power P_n , daily energy delivered G_n is given by:

$$G_n = \sum_{k=1}^{20} \left(\frac{P'_{n,5(k-1)} + P'_{n,5k}}{2} \right) \frac{5}{100} 24 \quad **$$

Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid

where P_{nk}', is the lesser of load L_k and available power P_n :

$$P'_{n,k} = \min\left(P_n, L_k\right)$$

Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid

EXAMPLE

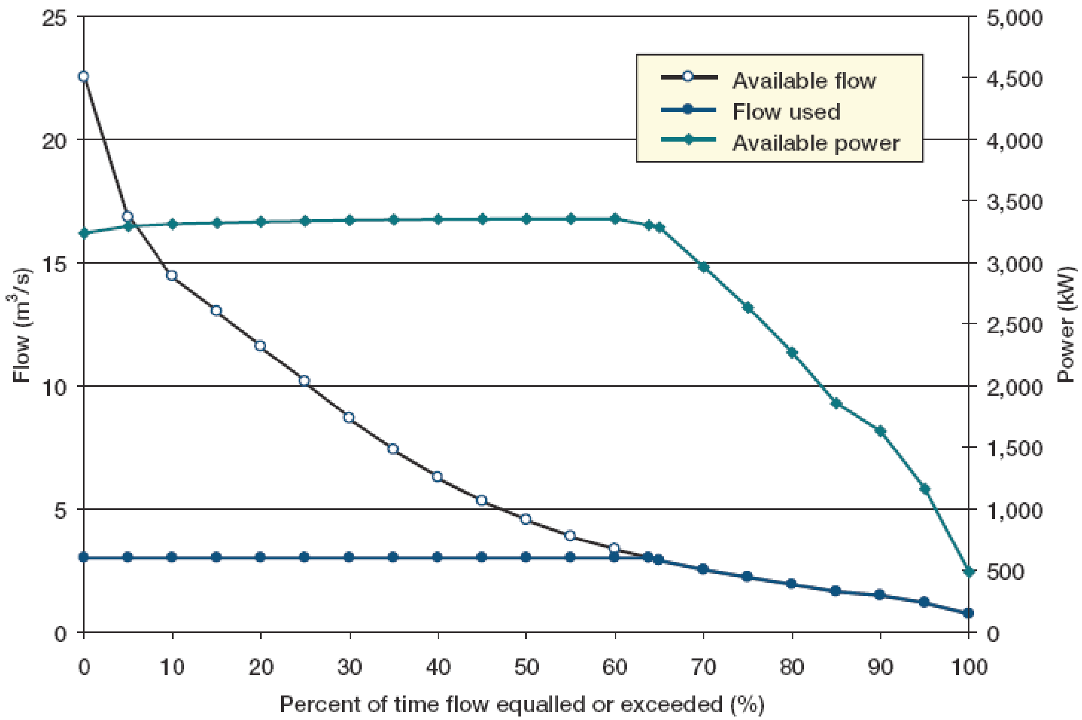
The procedure is illustrated by an example:

We use the load-duration curve and values from the power-duration curve from before given Figures.

The goal is to determine the daily renewable energy G_{75} delivered for a flow that is exceeded 75% of the time.

Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid - EXAMPLE



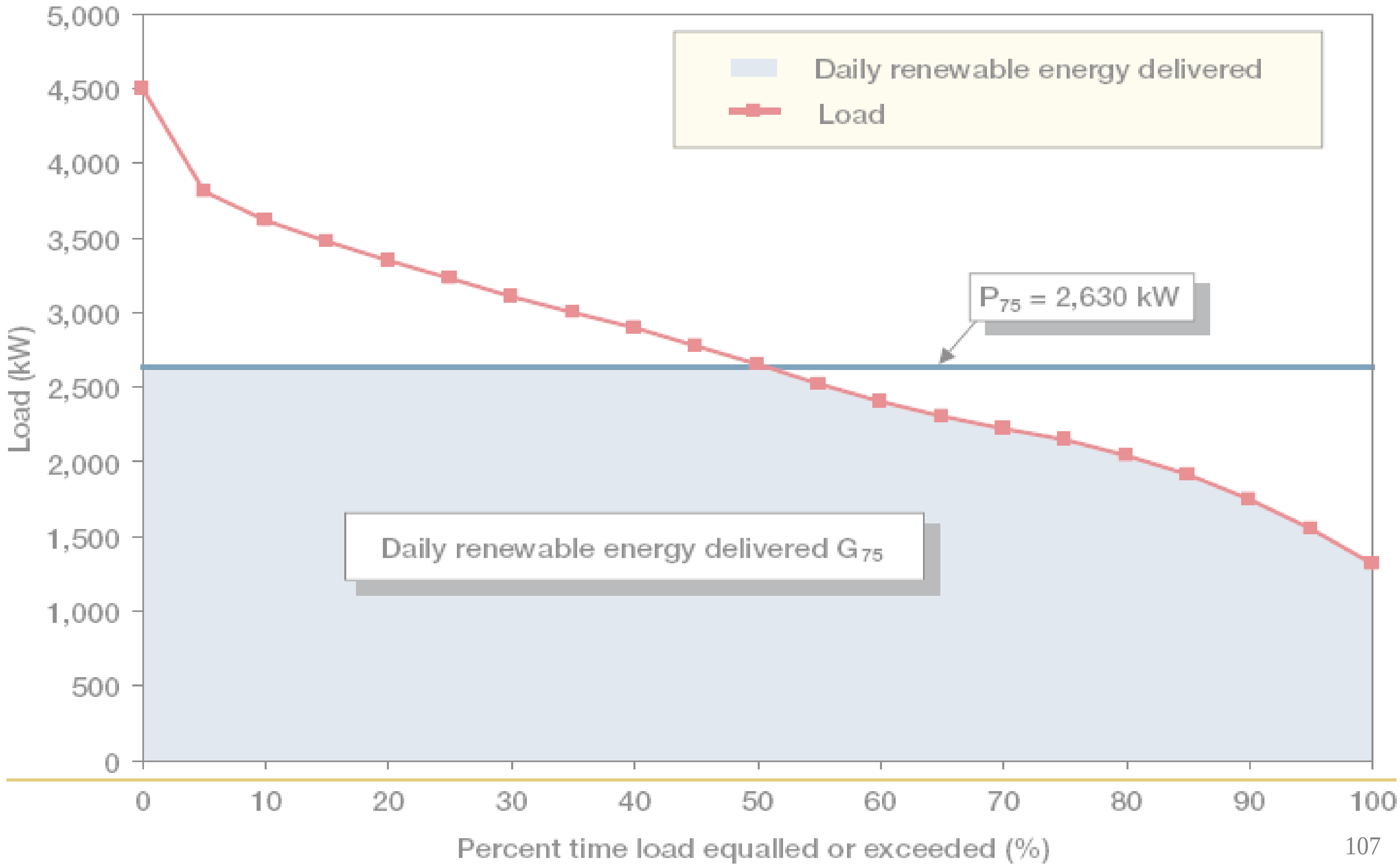
Power-Duration Curve

Firstly, we should determine the corresponding power level:

P_{75}=2,6 kW

Energy Production- Renewable energy available

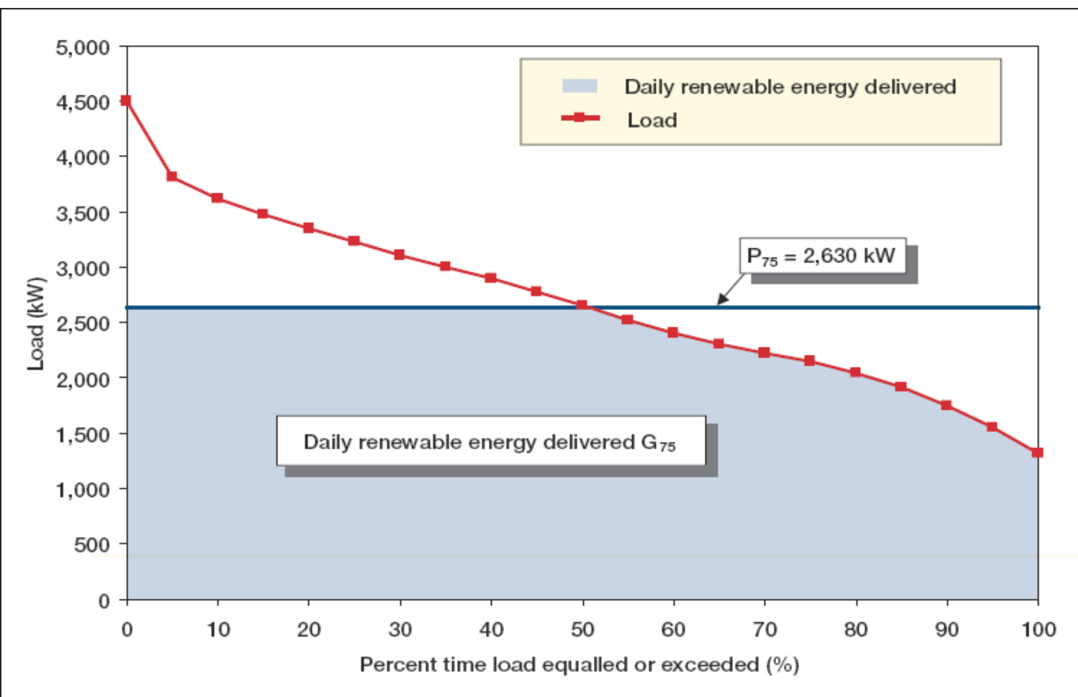
Renewable energy delivered - isolated-grid and off-grid - EXAMPLE



Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid - EXAMPLE

Then we draw the horizontal line on the load-duration curve, as shown in Figure. The area that is both under the load-duration curve and the horizontal line is the renewable energy delivered per day for the plant capacity that corresponds to flow *Q75* ;



** Integration with formula gives the result:

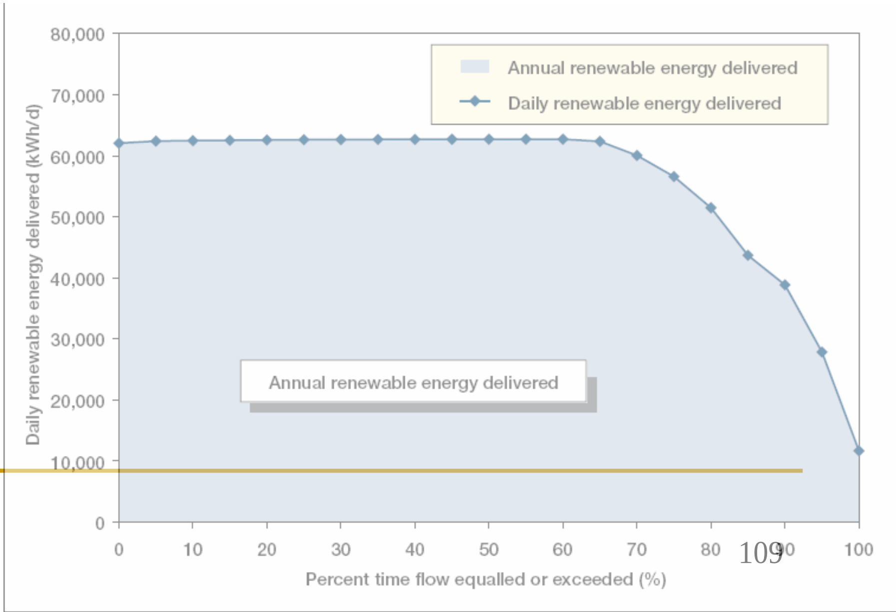
$$G_{75} = 56.6 \text{ MWh/d}$$

Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid - EXAMPLE

The procedure is repeated for all values P_0 P_5 ,…, P_{100} to obtain twenty one values of the daily renewable energy delivered G_0 G_5 ,…, G_{100} , as a function of percent time the flow is exceeded as shown in down Figure.

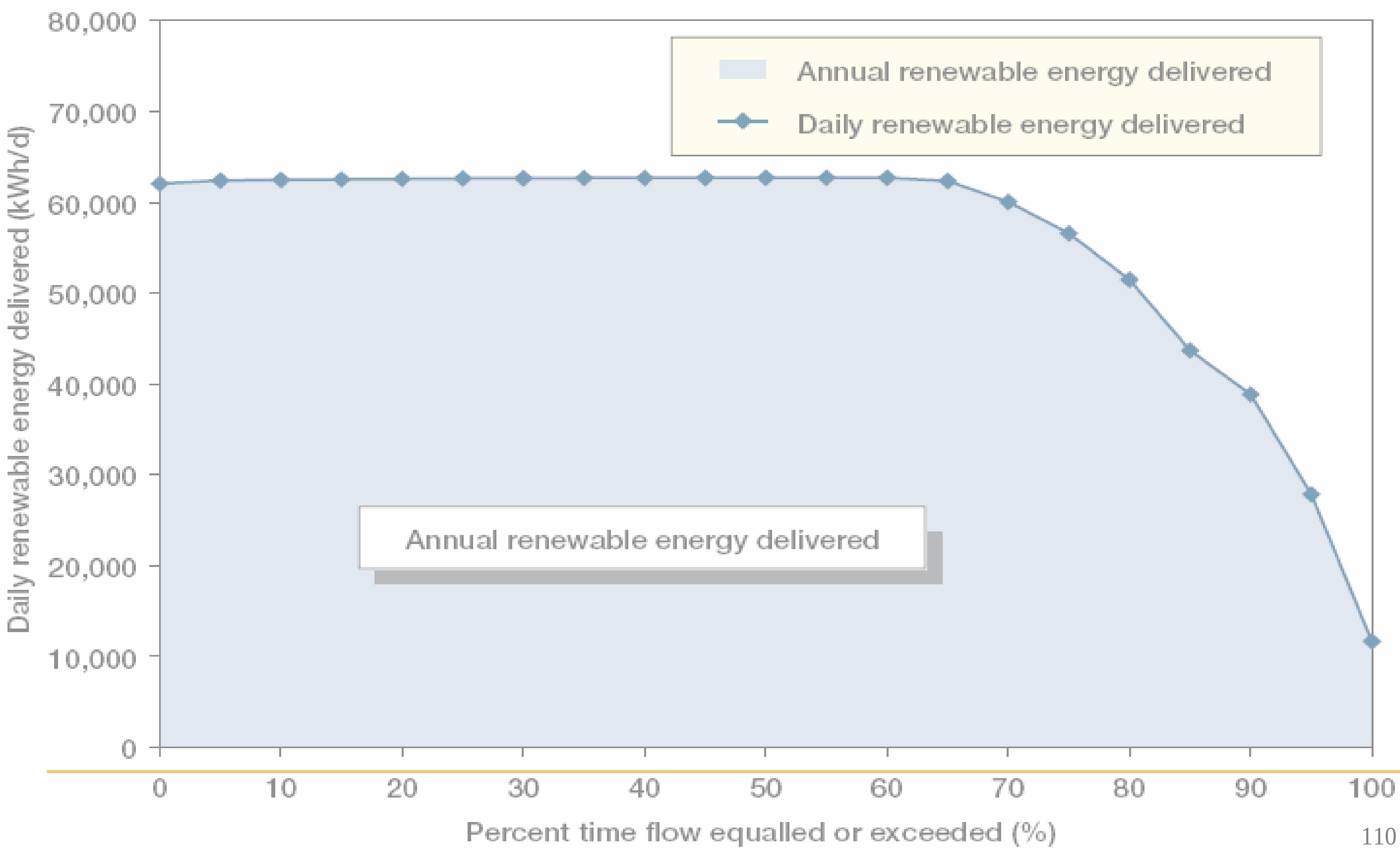
The annual renewable energy delivered E_{dlvd} is obtained simply by calculating the area under the curve of Figure, again with a trapezoidal rule:



Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid – EXAMPLE

of Calculation of Annual Renewable Energy Delivered



Energy Production- Renewable energy available

Renewable energy delivered - isolated-grid and off-grid – EXAMPLE

$$E_{dlvd} = \sum_{n=1}^{20} \left(\frac{G_{5(n-1)} + G_{5n}}{2} \right) \frac{5}{100} \; 365 \; (1 - l_{dt})$$

where, as before, l_{dt} is the annual downtime losses as specified by the user.

SHPP Project Model

Energy Production - Renewable energy available

Small hydro plant capacity factor

The annual capacity factor *K* of the small hydro power plant is a measure of the available flow at the site and how efficiently it is used.

It is defined as the average output of the plant compared to its rated capacity:

$$K = \frac{E_{dlvd}}{8760\, P_{des}}$$

SHPP Project Model

Energy Production - Renewable energy available

Excess renewable energy available

Excess renewable energy available E_{excess} is the difference between the renewable energy available E_{avail} and the renewable energy delivered E_{dlvd} :

$$E_{excess} = E_{avail} - E_{dlvd}$$

SMALL HYDRO PROJECT MODEL

Project costs

SMALL HYDRO PROJECT MODEL
Project costs

The Small Hydro Project can be moduled in that way to offer two methods for project costing: the detailed costing method, or alternatively, the formula costing method.

The detailed costing method follows invoices.
The formula costing method is based on empirical formulae that have been developed to relate **project costs** to key **project parameters**.

The costs of numerous projects have been used to develop the formulae. The formulae will be given in the learning material.

SMALL HYDRO PROJECT MODEL Example II

A turbine efficiency curve as calculated by RETScreen should be compared to manufacturer's efficiency data for an installed unit with the same characteristics.

The following provides a summary of the project and the turbine performance data as provided by the manufacturer:

SMALL HYDRO PROJECT MODEL Example II

Project name:
XYZ Hydro Project
Project location:
Approximately 40 km south of Fojnica
on the confluence of T and E River.
Project features:
600 m rock tunnel tapping into Lake, 50 m of 1.5 m diameter steel penstock, single horizontal Francis turbine, horizontal synchronous generator, 1,500 m of submarine power cable, substation and connection to distribution network at 35 kV. Automatic operation and remote monitoring.
Date commissioned:
December 2007
Turbine manufacturer:
GEC Alsthom (runner by Neyrpic)
Turbine type:
Francis

SMALL HYDRO PROJECT MODEL
Example II

Nameplate rating:
6,870 kW at 103.6 m net head

Maximum rated power:
7,115 kW at 105.6 m net head

RPM:
514

Diameter:
1,100 mm

Number of blades:
13

Efficiency data from manufacturer (see ***Table***):

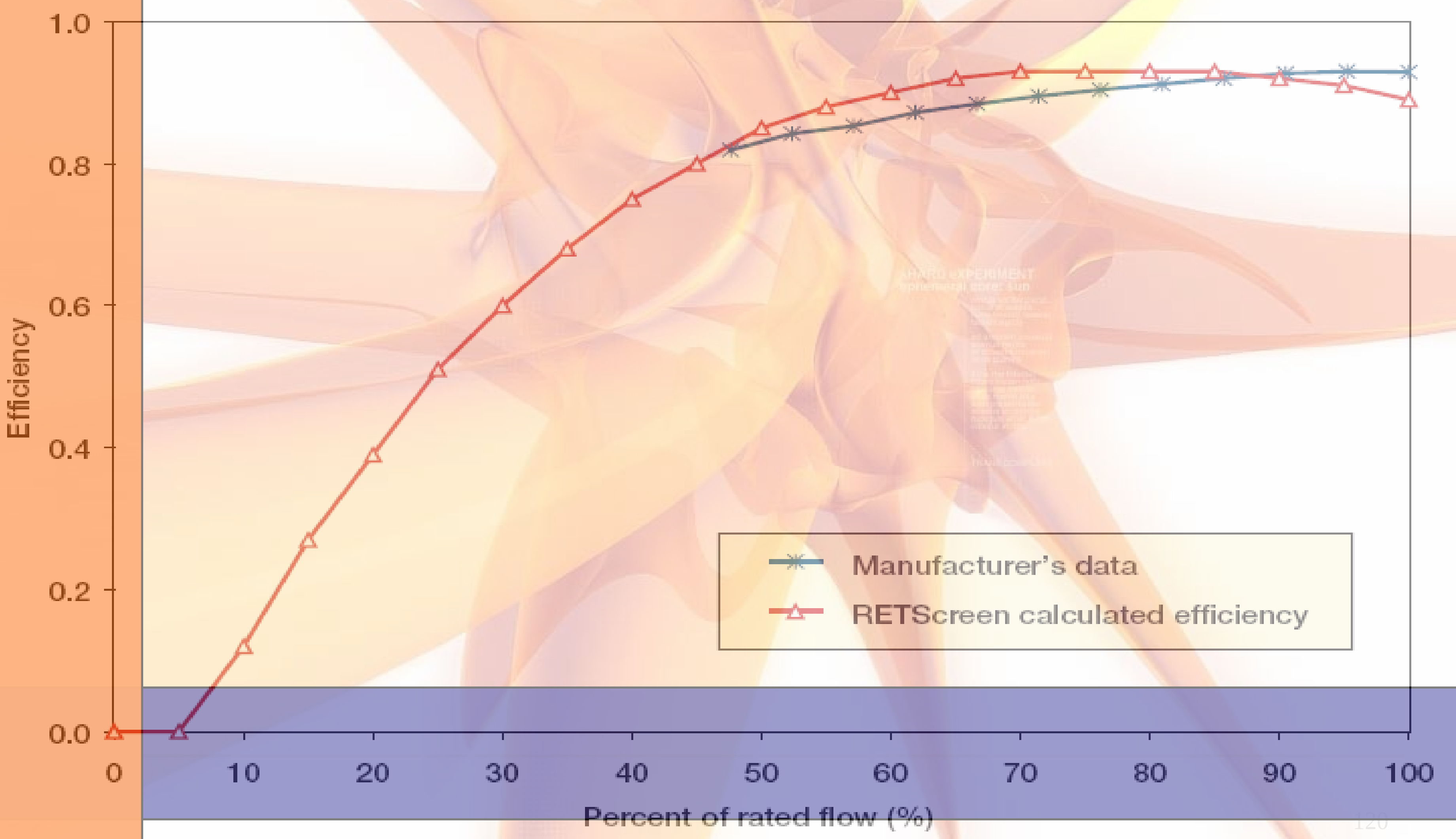
Flow (m^3/s)	Efficiency
7.35	0.93
7.00	0.93
6.65	0.93
6.30	0.92
5.95	0.91
5.60	0.90
5.25	0.90
4.90	0.88
4.55	0.87
4.20	0.85
3.85	0.84
3.50	0.82

SMALL HYDRO PROJECT MODEL Example II

A gross head value of 109.1 m was entered into RETScreen, which corresponds to a net head of 103.6 m with maximum hydraulic losses of 5%.

Comparison between the manufacturer's efficiency data and the efficiency curve generated by RETScreen is shown in next Figure.

SMALL HYDRO PROJECT MODEL
Example II



SMALL HYDRO PROJECT MODEL Example III

Plant capacity and annual renewable energy delivered

A comparison between the RETScreen Small Hydro Project Model and another software program called HydrA.

HydrA is a software package used to estimate the hydropower potential at any location in the United Kingdom or Spain.

HydrA incorporates a regional flow estimation model derived from extensive statistical analysis of national river flow data and catchment information.

SMALL HYDRO PROJECT MODEL Example III

Plant capacity and annual renewable energy delivered – Input data

Mean flow: 1.90 m³/s

Residual flow: 0.27 m³/s

Rated turbine flow: 1.63 m³/s

Gross hydraulic head: 65.0 m

Net hydraulic head: 58.5 m

SMALL HYDRO PROJECT MODEL

Example III

Plant capacity and annual renewable energy delivered – Results

It may be concluded from this simple test that there is little difference in the energy calculations.

Applicable Turbines	Gross Annual Av. Output MWh	Net Annual Av. Output MWh	Maximum Power Output kW	Rated Capacity kW	Minimum Operational Flow m³/s
RETScreen					
Francis		3 092		819.0	
Crossflow		2 936		745.0	
Turgo		3 125		758.0	
HydrA					
Francis	3 270.3	3 107	858.7	824.4	0.76
Crossflow	3 072.7	2 919	748.3	700.5	0.51
Turgo	3 163.1	3 005	809.1	728.2	0.43

SMALL HYDRO PROJECT MODEL
Example IV
Project costs

Project costs as calculated by RETScreen using the Formula Costing Method were compared to a detailed as-built cost evaluation prepared for the existing 6 MW Rose Blanche hydroelectric development in Newfoundland, Canada.

SMALL HYDRO PROJECT MODEL
Example IV
Project costs

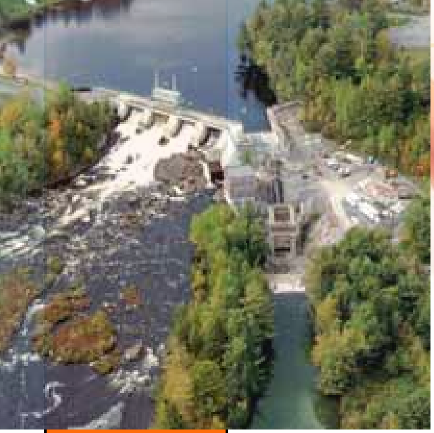
The key parameters of the SHPP project are summarised below:

Project name:
Fojnica

Owner/developer:
B&H

Project location:
Fojnica suburb, approximately 45 km east
Of Fojnica Center.

Date commissioned:
December 2007



The key parameters of the SHPP project are summarised below:

Project name:
Fojnica

Owner/developer:
B&H

Project location:
Fojnica suburb, approximately 45 km east Of Fojnica Center.

Date commissioned:
December 2002

Project type:

Run-of-river (with several days' storage)

Installed capacity:

6 MW

Design net head:

114.2 m

Rated fl ow:

6.1 m3/s

Turbine/generator:

Twin Francis turbines connected to a single generator.

Other project features:

Small dam with minimal storage, 1,300 m penstock, short transmission line (approximately 3 km).

Required Input parameters

RETScreen[fl] Cost Analysis - Small Hydro Project

Search Marketplace

Costing method: Formula | Currency: $ | Cost references: None

Formula Costing Method				Notes/Range
Input Parameters				
Project country		Canada		
Cold climate?	yes/no	Yes		
Frost days at site	day	200	See Map	Visit NASA satellite data site
Number of turbines	turbine	2		
Flow per turbine	m³/s	3.1		
Approx. turbine runner diameter (per unit)	m	0.8		
Project classification:				
Suggested classification	-	Mini		
Selected classification	-	Small		
Existing dam?	yes/no	No		
New dam crest length	m	250.0		
Rock at dam site?	yes/no	Yes		
Maximum hydraulic losses	%	5%		

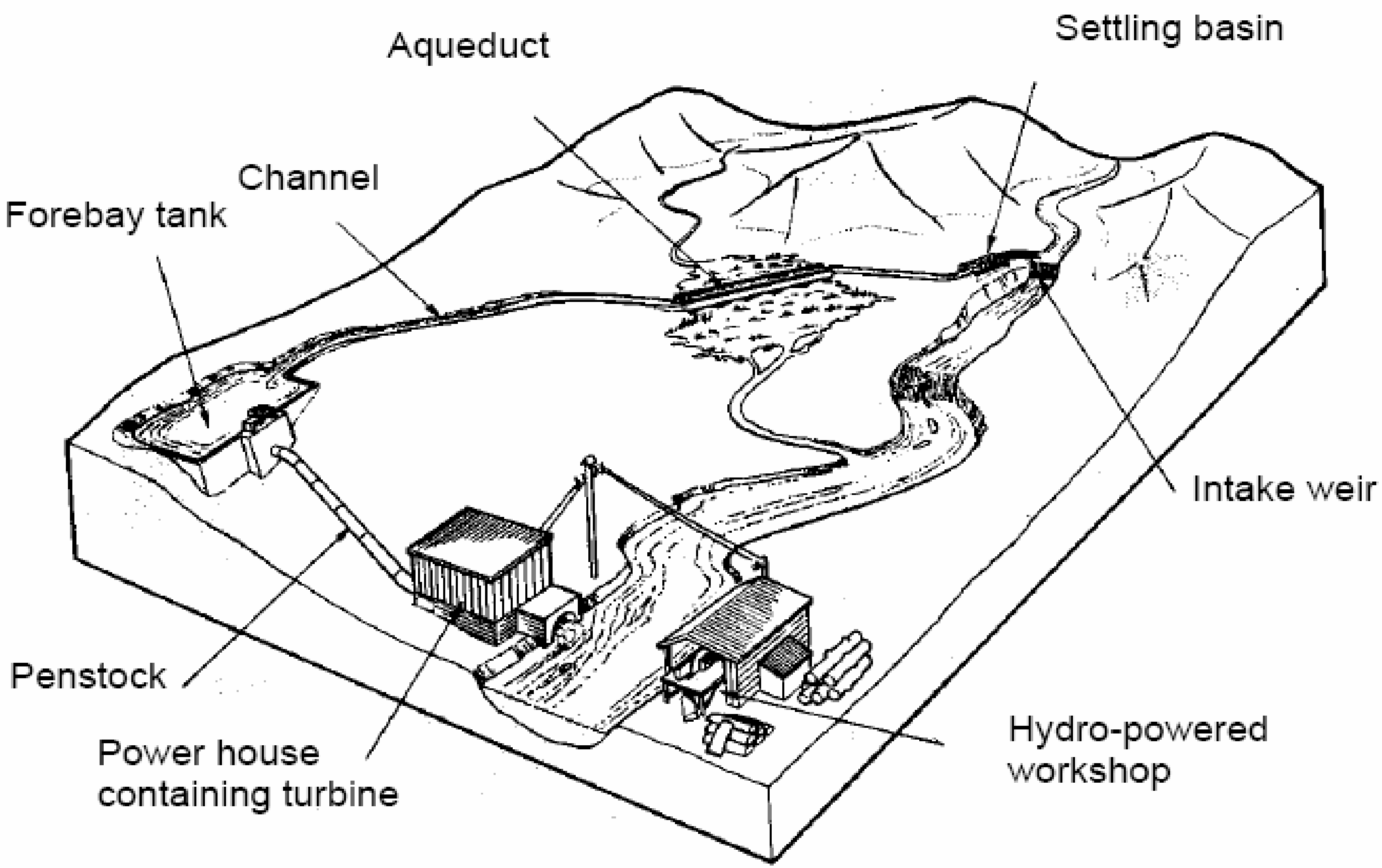
Intake and miscellaneous losses	%	1%	1% to 5%
Access road required?	yes/no	Yes	
Length	km	5.0	
Tote road only?	yes/no	No	
Difficulty of terrain	-	3.0	1.0 to 6.0
Tunnel required?	yes/no	No	
Canal required?	yes/no	No	
Penstock required?	yes/no	Yes	
Length	m	1,300.0	
Number of identical penstocks	penstock	1	
Allowable penstock headloss factor	%	4.0%	1.0% to 4.0%
Pipe diameter	m	1.61	
Average pipe wall thickness	mm	8.1	
Distance to borrow pits	km	3.0	
Transmission line			
Length	km	5.0	
Difficulty of terrain	-	1.0	1.0 to 2.0
Voltage	kV	44.0	
Interest rate	%	9.0%	

Initial Costs (Formula Method)		Cost (local currency)	Adjustment Factor	Amount (local currency)	Relative Costs
Feasibility Study		$ 504,000	1.00	$ 504,000	3.1%
Development		$ 529,000	1.00	$ 529,000	3.3%
Land rights				$ -	0.0%
Development Sub-total:				$ 529,000	3.3% 6.4
Engineering		$ 537,000	1.00	$ 537,000	3.3%
Energy Equipment		$ 3,032,000	1.00	$ 3,032,000	18.6%
Balance of Plant					
Access road		$ 1,096,000	1.00	$ 1,096,000	6.7%
Transmission line		$ 217,000	1.00	$ 217,000	1.3%
Substation and transformer		$ 175,000	1.00	$ 175,000	1.1%
Penstock		$ 1,831,000	1.00	$ 1,831,000	11.3%
Canal		$ -	1.00	$ -	0.0%
Tunnel		$ -	1.00	$ -	0.0%
Civil works (other)		$ 6,326,000	1.00	$ 6,326,000	38.9%
Balance of Plant Sub-total:		$ 9,645,000		$ 9,645,000	59.3%
Miscellaneous		$ 2,015,000	1.00	$ 2,015,000	12.4%
GHG baseline study and MP	Cost	$ -		$ -	0.0%
GHG validation and registration	Cost	$ -		$ -	0.0%
Miscellaneous Sub-total:				$ 2,015,000	12.4%
Initial Costs - Total (Formula Method)		$ 16,262,000		$ 16,262,000	100.0%

SMALL HYDRO PROJECT MODEL
CONCLUSION regarding RetScreen

Condensed formulae enable the estimation of project costs; alternatively, a detailed costing method can be used.

The accuracy of the model, with respect to both energy production and cost estimation, is excellent for pre-feasibility stage studies for small hydro projects.


Aqueduct
Settling basin
Channel
Forebay tank
Intake weir
Penstock
Power house
containing turbine
Hydro-powered
workshop

Project Information

ProjectName
sssssss

Quantity of Turbines
2

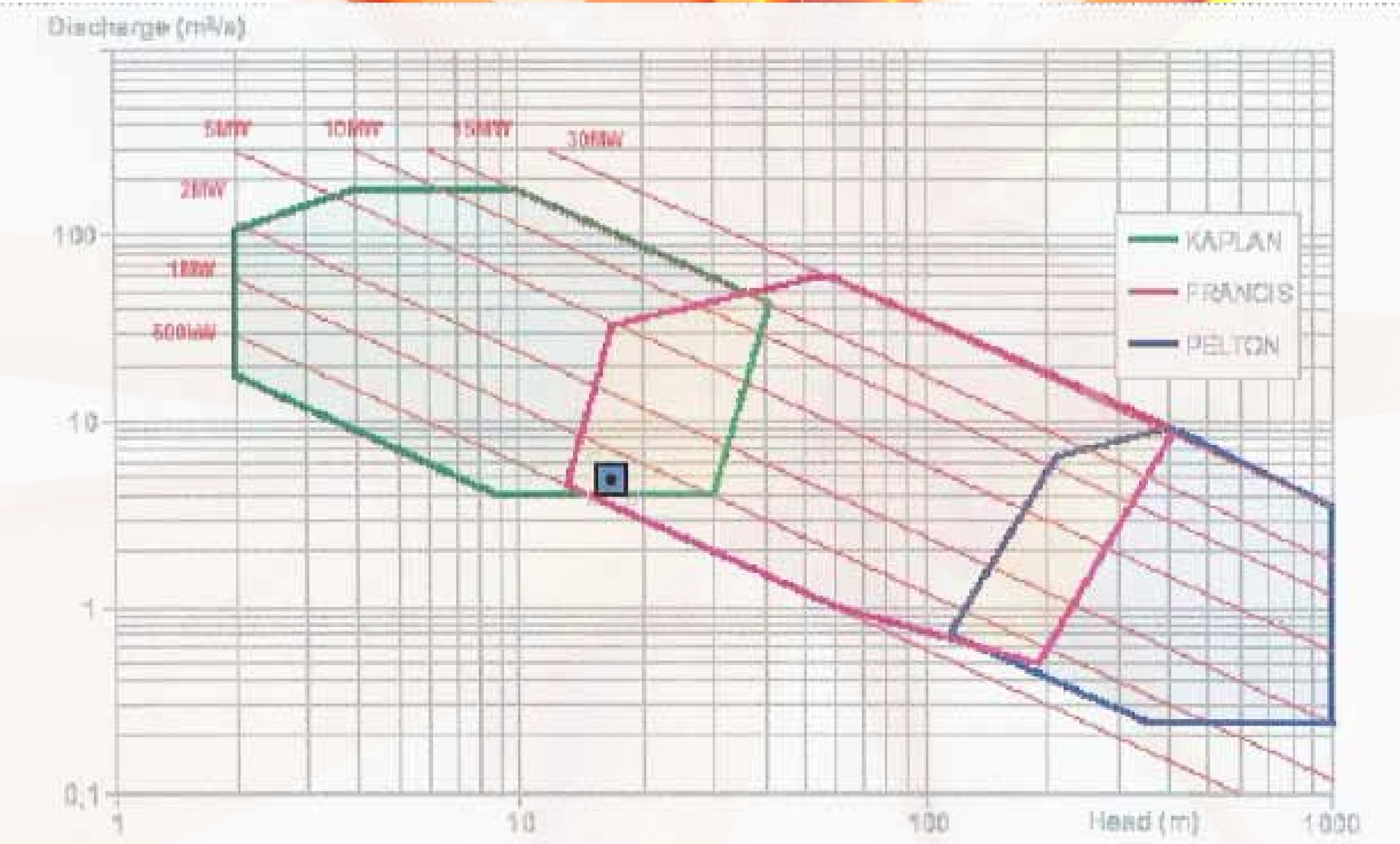
Net head H(m)
16,82

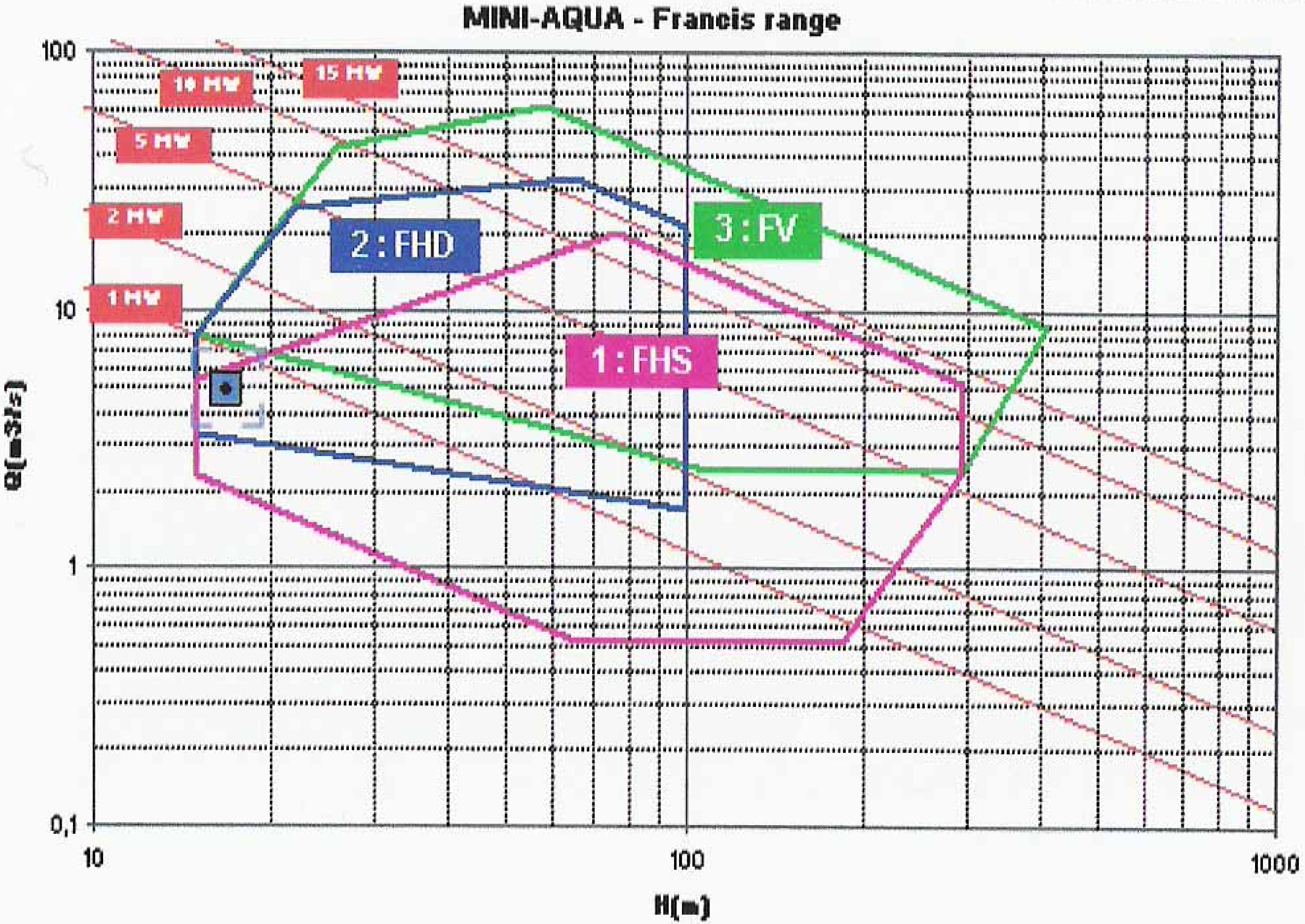
Discharge per Unit
Q *(m3/s)*
4,88

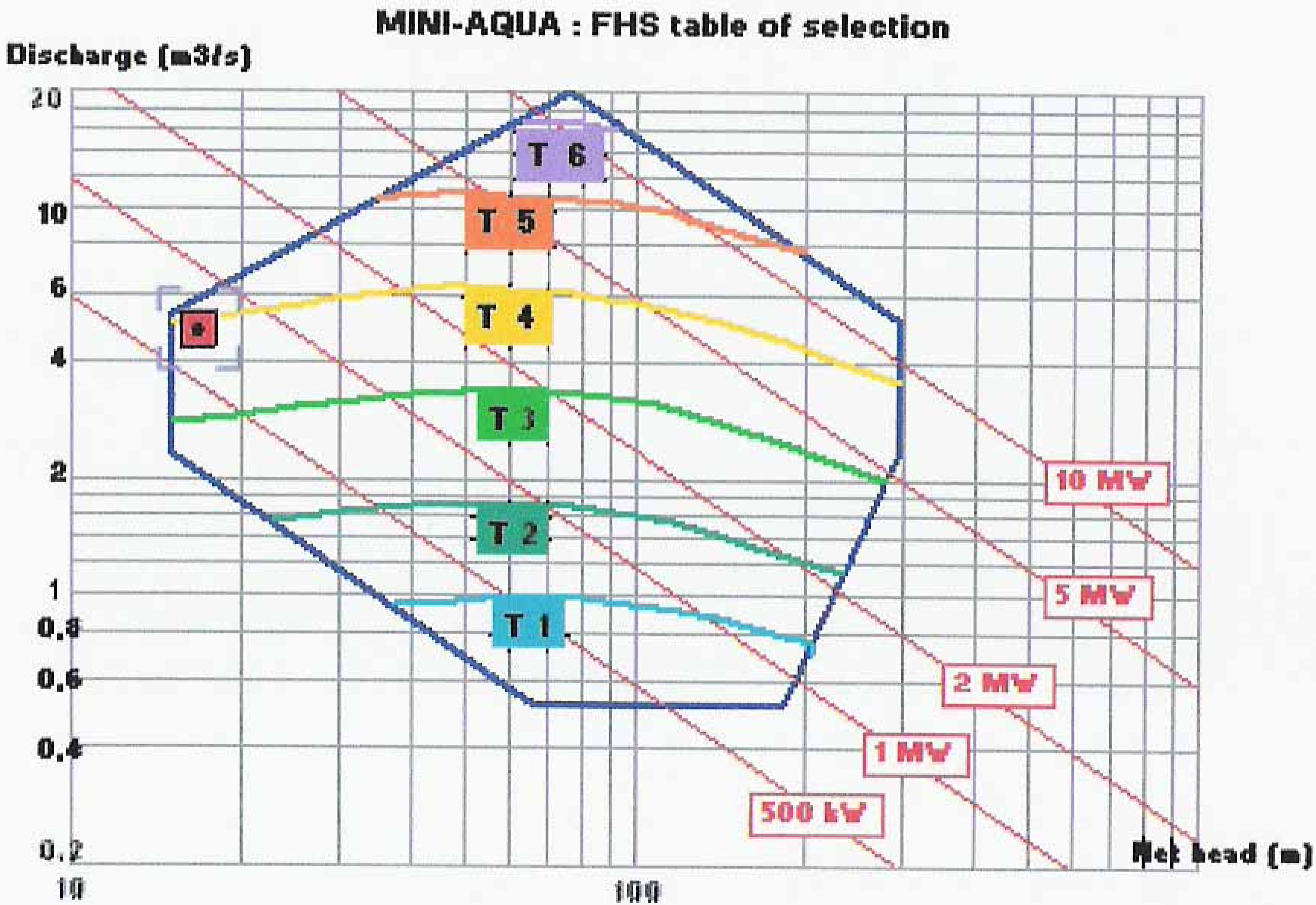
Power Output per
Unit P (MW)
0.73

Frequency (Hz)
50

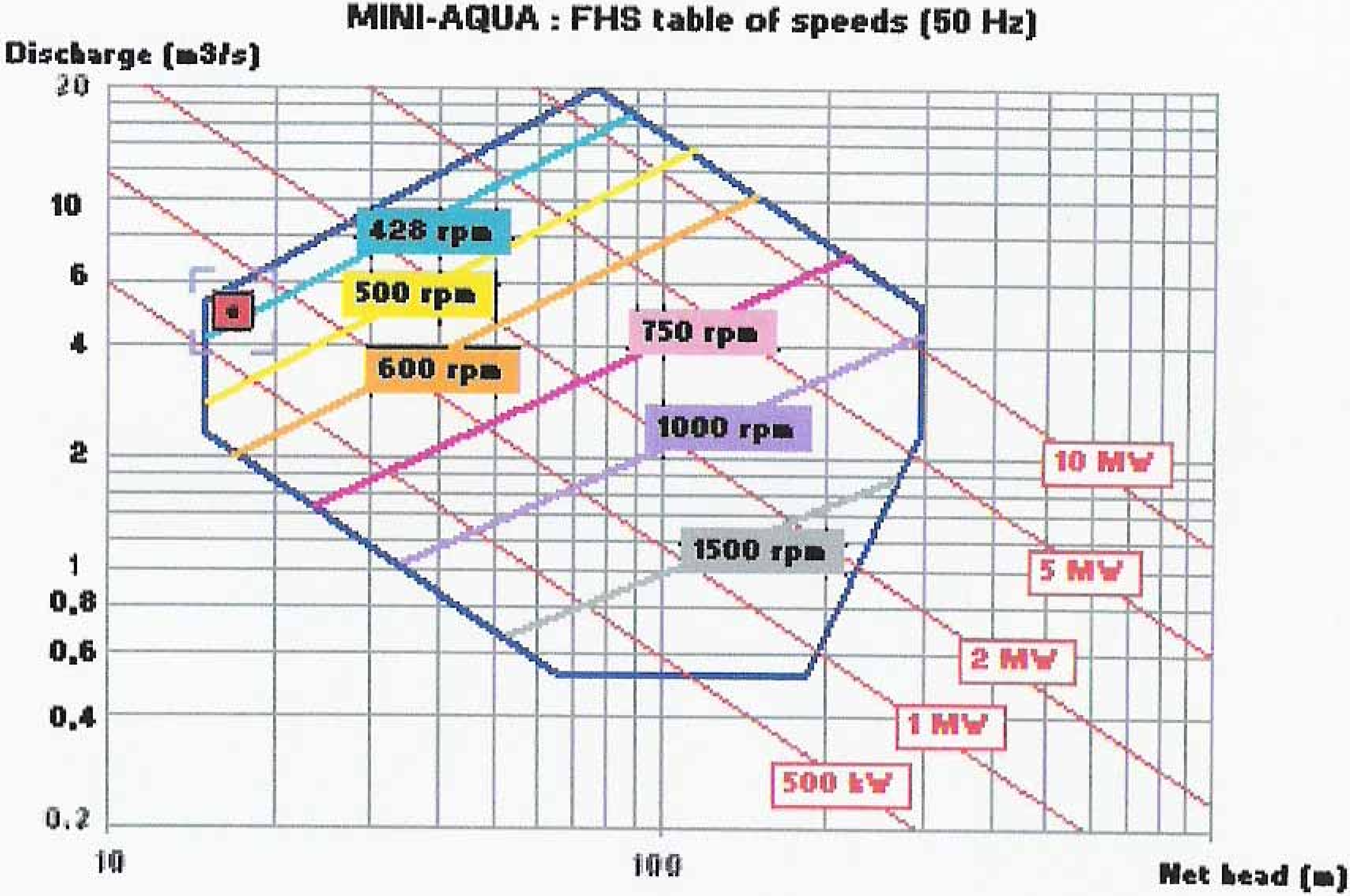
ProjectDefinition- MiniAqua Configurator



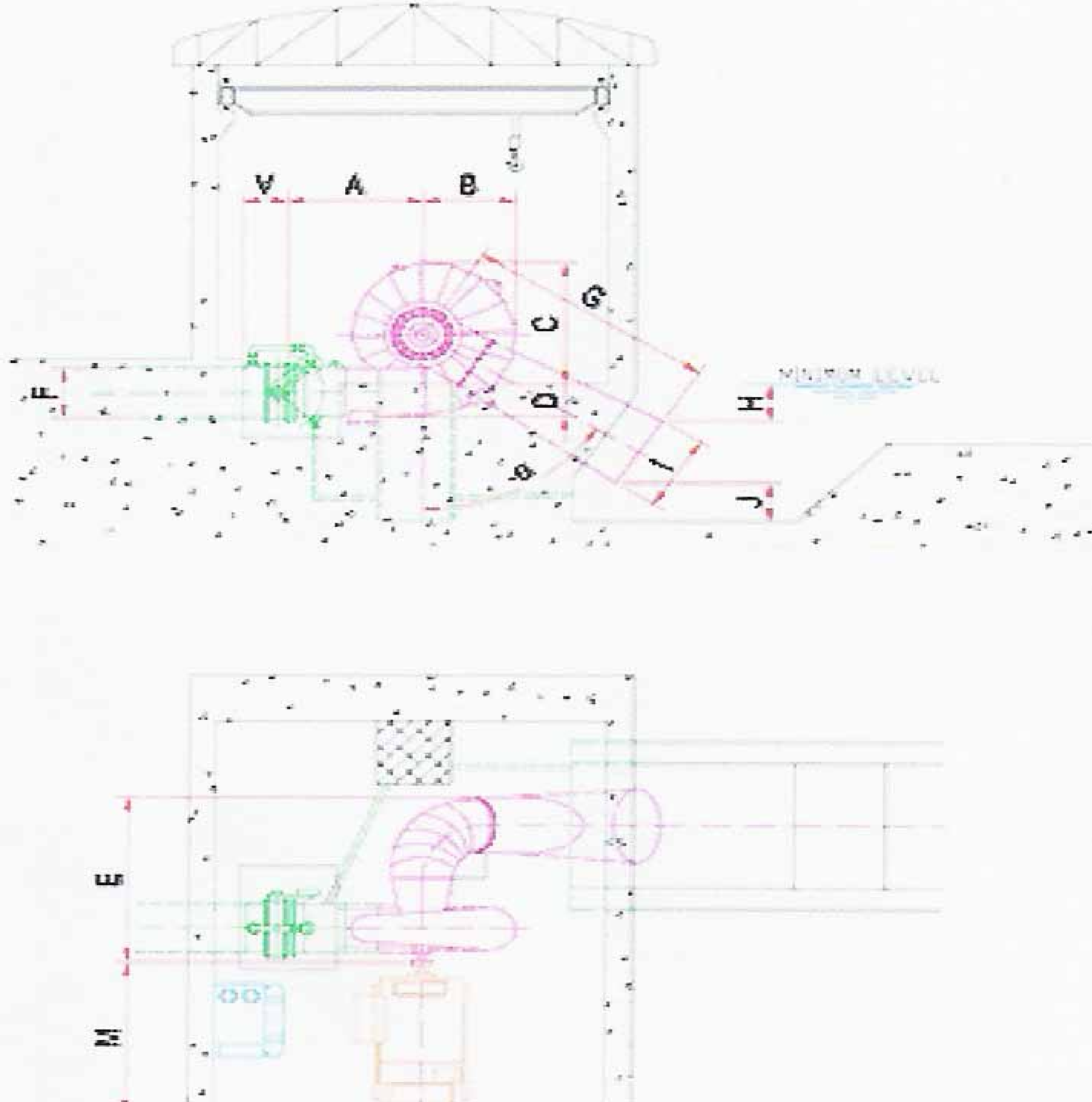

MINI-AQUA - Francis range
15 MW
10 MW
5 MW
2 MW
1 MW
2 : FHD
3 : FV
1 : FHS
Q(m3/s)
H(m)
100
10
1
0,1
10
100
1000


MINI-AQUA : FHS table of selection
Discharge (m3/s)
20
10
6
4
2
1
0,8
0,6
0,4
0,2
10
100
Net head (m)
T 6
T 5
T 4
T 3
T 2
T 1
10 MW
5 MW
2 MW
1 MW
500 kW

DIAMETER = T4



SPEED = 428 rpm



V
A
B
C
D
E
F
G
H
I
J
M

TURBINE SIZE	R	T4
Inlet length	A	2.5(
Spiral case ray	B	1.9(
External height	C	3.1(
Embedment	D	0.7(
Turbine width	E	4.0(
Inlet diameter	F	1.2(
Draft tube length	G	5.6(
Outlet submergence	H	Min 0.
Outlet diameter	I	2.0(
Outlet altitude	J	J=I * (1-
Inlet valve length	**V**	**1.1**

Outlet altitude J J=I * (1-

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Renewable Energy Sources Technology, Economics and Policy Curriculum

Technology-Source Combination module
Biomass: wood chips, pellets, forest residues, animal waste

Production of energy out of biomass

Sixth Framework Programme, DG Research, International Cooperation
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VIRTUAL BALKAN POWER CENTRE

RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

WOODFUEL PELLETS AND AUTOMATIC BOILERS FOR DOMESTIC ROOM HEATING

Andreja Urbančič, Borut Del Fabbro

VBPC-RES Workshop, Guidelines for RES Technologies,

Tuzla, 11.-12. March 2005

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PELLETS

- Wood pellets are a densified biomass fuel made exclusively out of wood.

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PELLET CHARACTERISTICS

Key physical and chemical characteristics and its impacts:

- Water contents: storability, calorific value, losses
- Calorific value: fuel utilisation, plant design
- Ash content: particle emissions, costs for use or disposal of ash
- Bulk density: transport & logistical planning
- Share of dust: usage
- N content: NOx, HCN and N2O emissions

During pelletisation changes:

- phisical characteristics,
- water contents and its distribution.

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PELLET PRODUCTION

The manufacture of wood pellets involves the following processes:

1. Grinding
2. Drying
3. Pelletizing
4. Cooling
5. Separation of fine particles
6. Bagging

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QUALITY STANDARDS

In EUROPE fuel quality standards already exists in:

- Austria (ONORM M 7135);
- Sweden (SS 187120);
- Germany, (DIN 51731).

European standard for biomass fuel is in preparation by European Committee for Standardization

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EXCEPTS FROM STANDARDS

	AUSTRIA ONORM M 7135	**GERMANY DIN 51731**
Unit denisty	>=1,0kg/dm3	1-1,4 kg/dm3
Water content	**<=12%**	**<=12%**
Ash content	**<=0,5%** (rel. to dry matter)	**<=1,5%**
Lower calorific value	>= 18 MJ/kg (rel to dry matter)	17,5-19,5 MJ/kg (water and ash free)
N	<=0,3%	<=0,3%
CL	< 0,02%	<=0,03%
Impurities	Only from uncontaminated wood	
Binding agents	Forbidden	

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ENERGY STATISTICS

Solid fuel production (wood pellets)

- Canada 3,6 PJ
- Denmark 2,2 PJ
- Finland 1,8 PJ

Present use of woodfuel in WB countries

- Albania 0,3 PJ
- Bosnia and Herzegovina 0,5 PJ
- Croatia 0,9 PJ
- Republic Macedonia 0,5 PJ

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WOOD FUEL USE AND TRADE

- In Europe 23% of wood removals is used for energy purposes in 2002.
- Share of fuel wood in total energy supply
  - Europe - 1,2%.
  - Sweden and Finland - 12-18%
  - Worldwide 5% of total primary energy supply and 34,8% of total renewable sources supply

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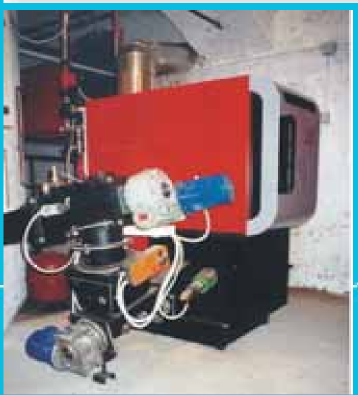
Pellet boilers and stoves

- Pellets are used in special pellets boilers and stoves:
  - combustion is of high quality,
  - environmental emissions are low,
  - fuel charging is fully automatic,
  - ash removal is easy,
  - technical complexity and investment costs are lower in comparison with woodchip boilers.



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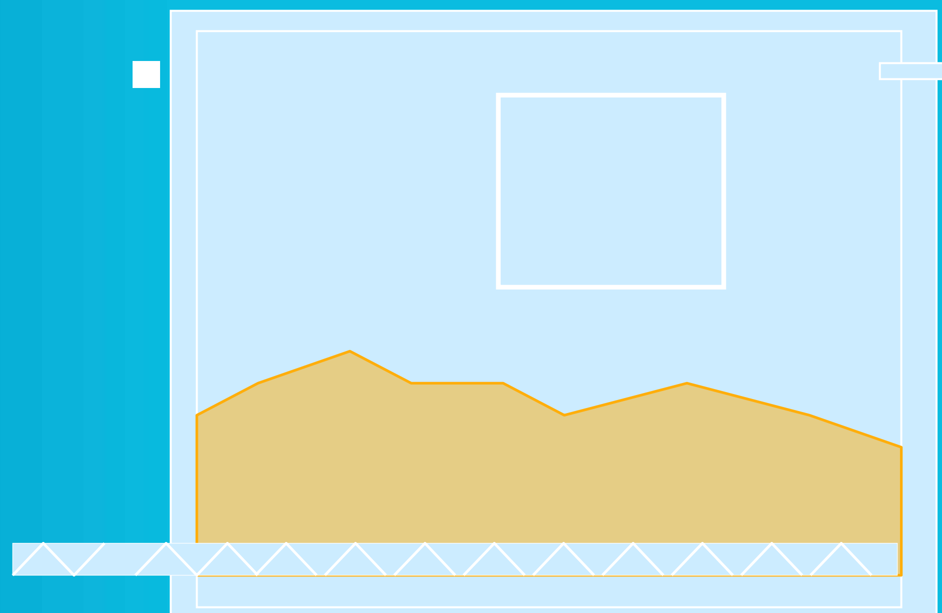
Distribution

- by truck-tank
- in small 15 kg bags
- in big bags (ca 1 t)

STORAGE

- In volume 3 times the volume of fuel oil storage
- Pellets conveyor
- Fines/dust proof
- Various solutions



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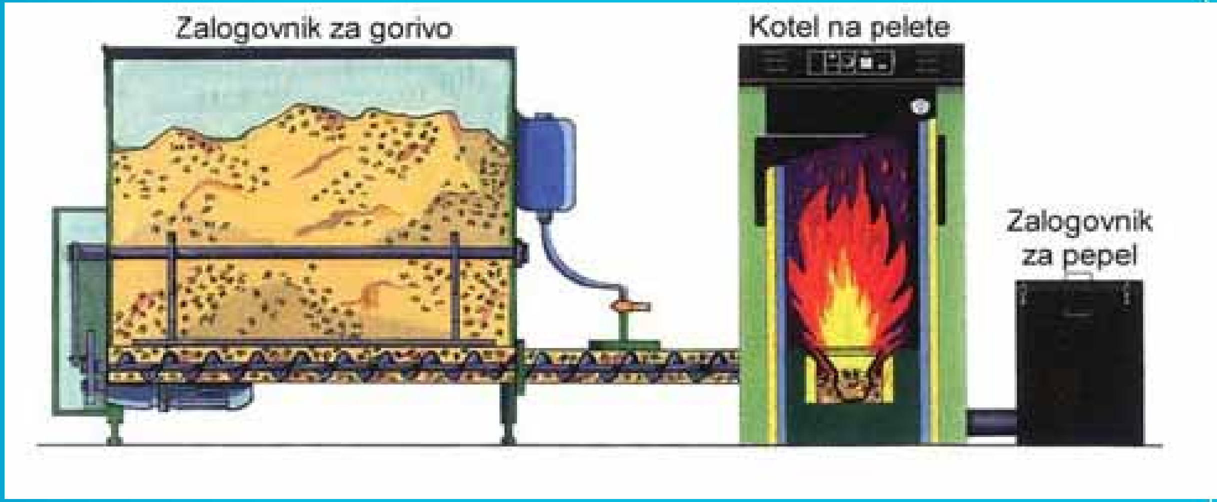
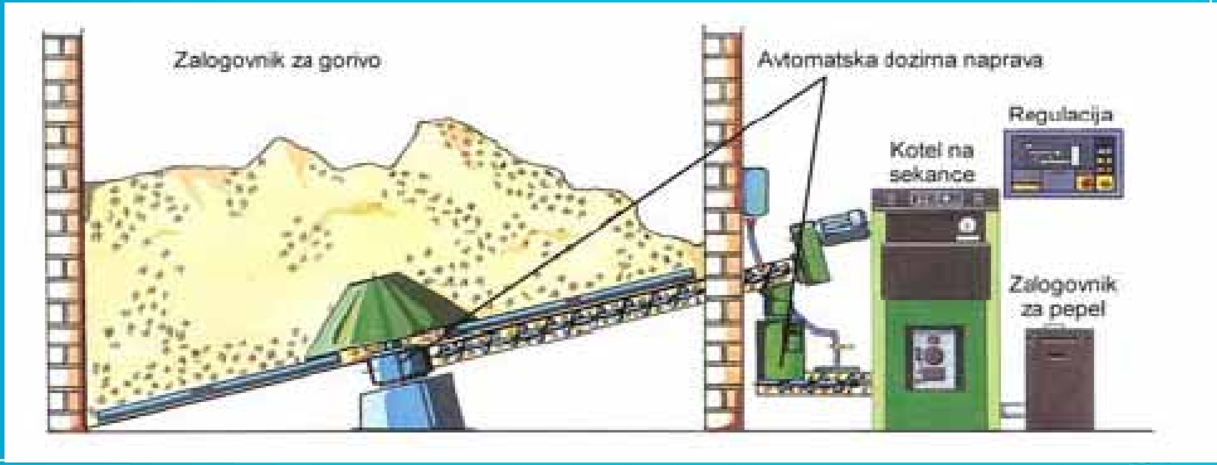
Wood pellet heating

Single familly house:

- storage
- water based central heating system
- Bulk material delivery in tanker and pneumatic filling of storage





RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

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HEATING SYSTEMS

- Small to medium scale district heating
- Micro networks
- Central heating for individual houses
- Central heating for single family houses
- Stoves and fireplaces

- Possibility of combined heat and power

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HEATING SYSTEMS CHARACTERSITCS

- Better technologies achieve efficiency over 90%,
- Electric ignition which enables automation,
- Capacity control systems to modulate output (100% to 20%),
- Small machines are tipically with manual de-ash as standard.
- A lambda oxigen monitoring sensor in the exhaust gas flue to modify the combustion profile of the machine.
- Technical solutions remain similar and in some cases universal at different manufacturers.

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ECONOMIC ASPECTS OF HOME HEATING WITH PELLETS

- Investment costs (capital costs)
  - approx 7500 EUR for 15 kW boiler
  - approx 4000 EUR for 15 kW stove
- Labour costs
  - near zero for domestic heating
- Maintenance costs
  - low, but higher than with gas oro oil boilers
- Pellets costs:
  - approx 120 EUR/t; 25 EUR/MWh

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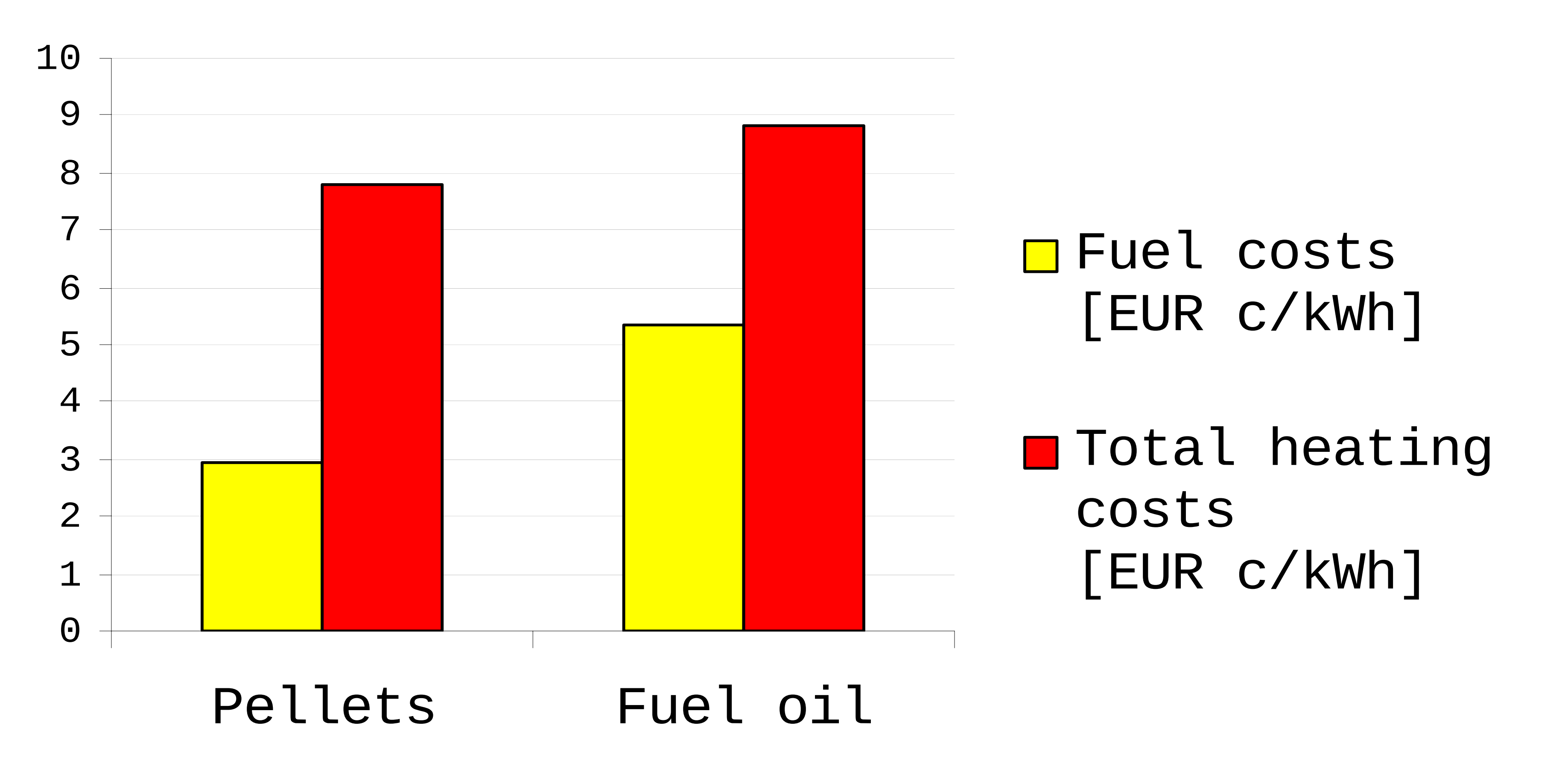
COMPARISSON OF HEATING COSTS



MAIN ENVIRONMENTAL CHARACTERISTICS

- CO2 neutral (zero CO2 emissions)

  Carbon dioxide (CO2) which was absorbed from the air while the plant was growing, is released back into the air when the fuel is burned.

- Waste: low quanities of ash (0,5-0,75%).

  A way for ash disposal is needed. Ashes might have high heavy metal contents.

COMPARISON OF EMISSIONS IN FLUE GASES

	CO mg/m3	NOx mg/m3	Particles (dust) mg/m3
Boiler with lambda control (log wood)	240	150	35
Automatic boiler (wood chips)	154	131	49
Pellet boiler	97	114	16

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Opportunities for the Western Balkans

- usage of pellets:
  - heating
  - combined heat and power production
  - other?
- pellet production
- production of boilers and stoves

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Yugo run by biomass

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Wood pellet fired Micro CHP

Istrabenz energetski sistemi
Borut Del Fabbro

Sixth Framework Programme, DG Research, International Cooperation
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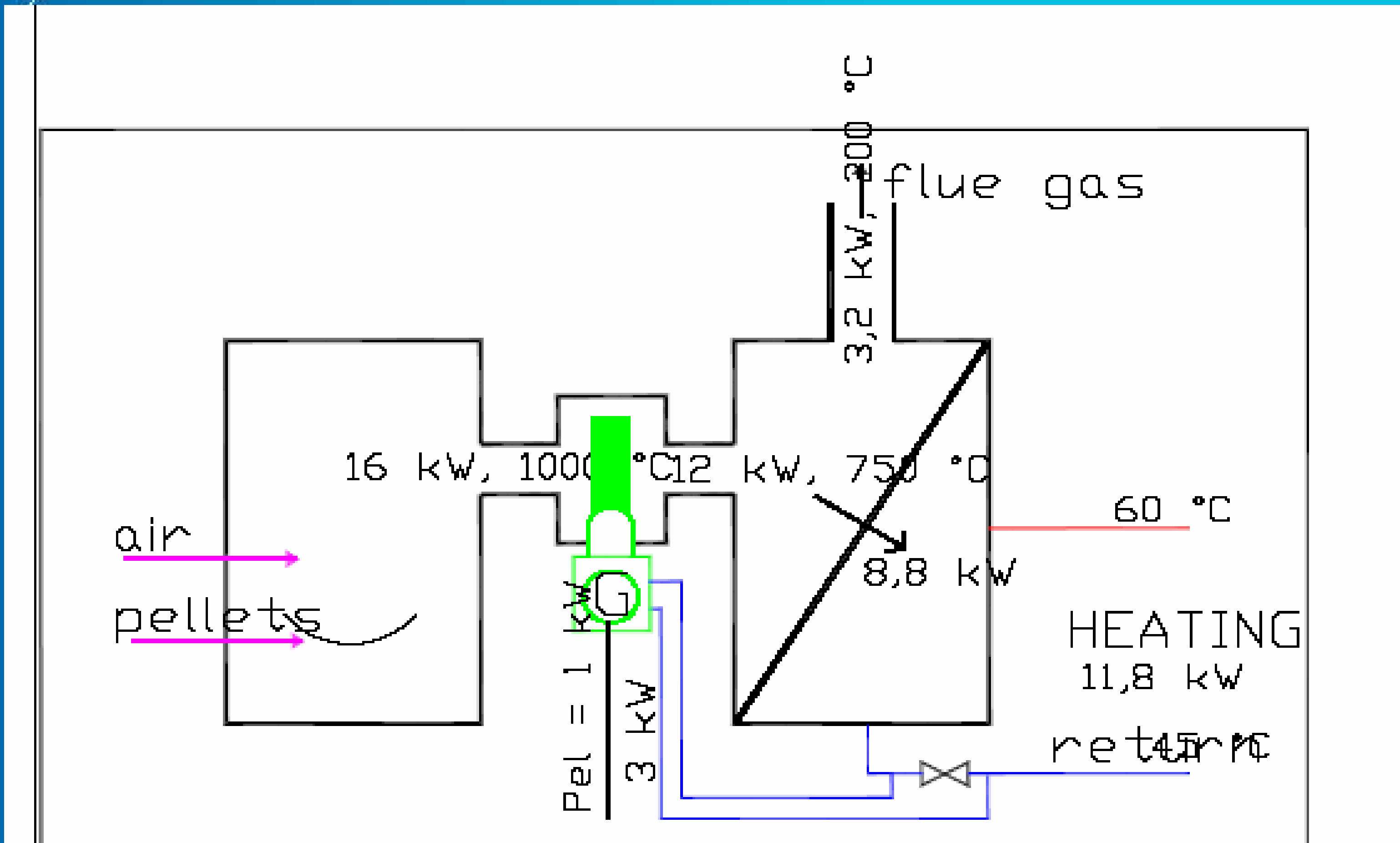
Why a micro CHP?

- Own source of electricity
  - in case of electricity insuficiency
- Better energy efficiency of the whole system
- Better energy supply in isolated areas
- Environmental impact

Basic description

- micro < 100 kW
- wood pellet boiler equipped with a stirling engine
- stirling engine
  - external combustion
  - any thermal source can be used
- beginnings/efforts of comercialisation

Energy flow



electricity

ca. 6 %

heat

74-85 %

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Advantages of pellets

- biomass
  - environmentally friendly
- standardized product
  - **low water content** – high burning tempertaures
  - lower storage costs
  - automatic manipulation, comfort(feeding, ignition etc.)
- local sources
- low price and price stability
  - 150 – 220 €/t
  - 0,03 – 0,05 €/kWh

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Contract: INCO-CT-2004-509205

Boiler selection

- possibility of fitting the stirling engine
- high temperature of the flue gases = efficiency of stirling engine ($\eta=1-T_L/T_h$)
  - can be as high as 1.100 °C
  - in small boilers usually between 800 and 950°C
  - high T is achiveable with pellets
  - not easiliy with other biomass –water content is problematic

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Electricity generation in isolated systems

- CHP operation modes:
  - Thermal load following
    - requires electricity storage or grid connection
  - Electrical load following
    - requires heat storage
    - additional regulation
  - Cost minimisation/revenue maximisation
    - keep it simple

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Stirling engine

Picture courtesy of ENERGIEBIG

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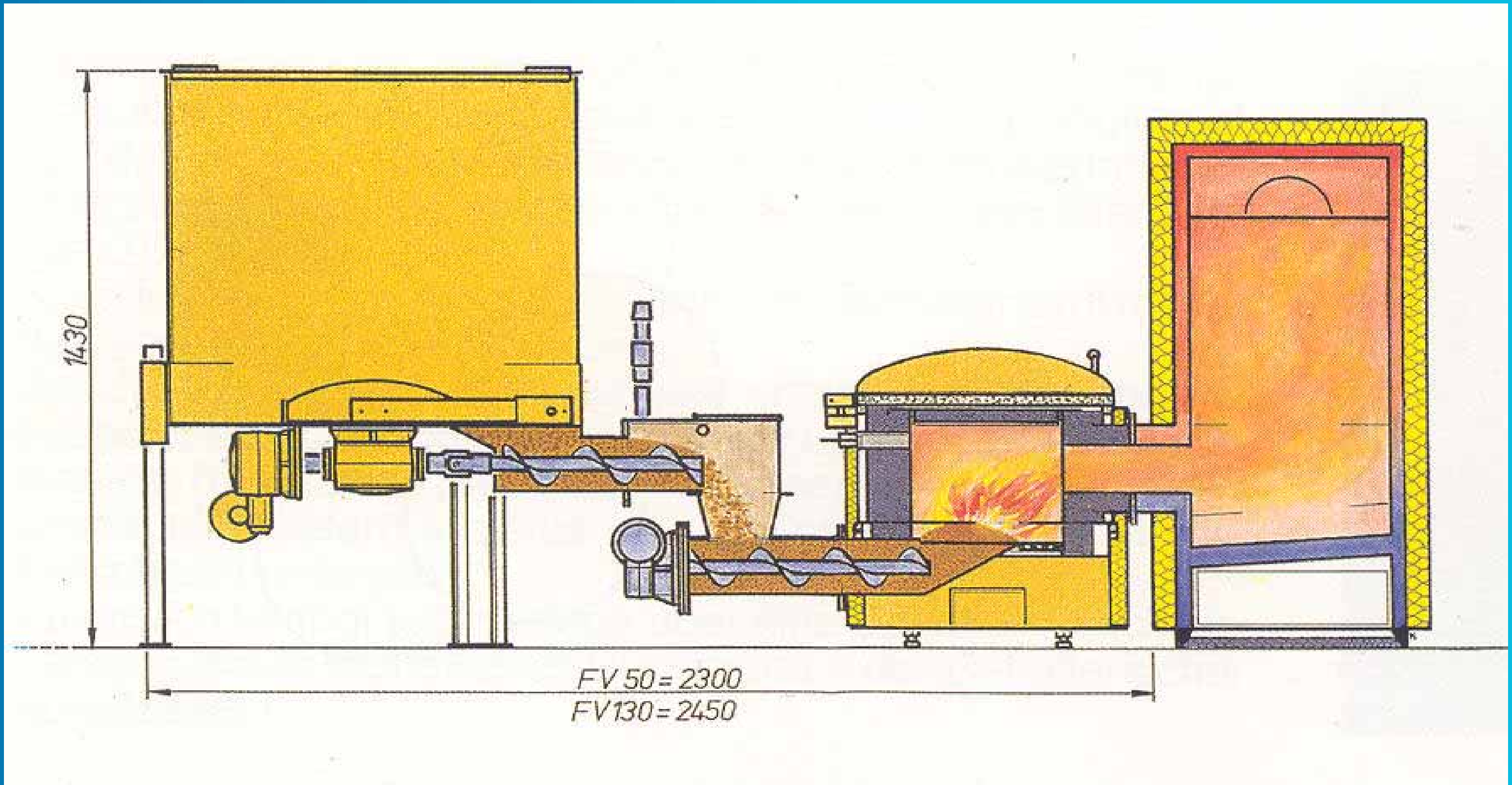
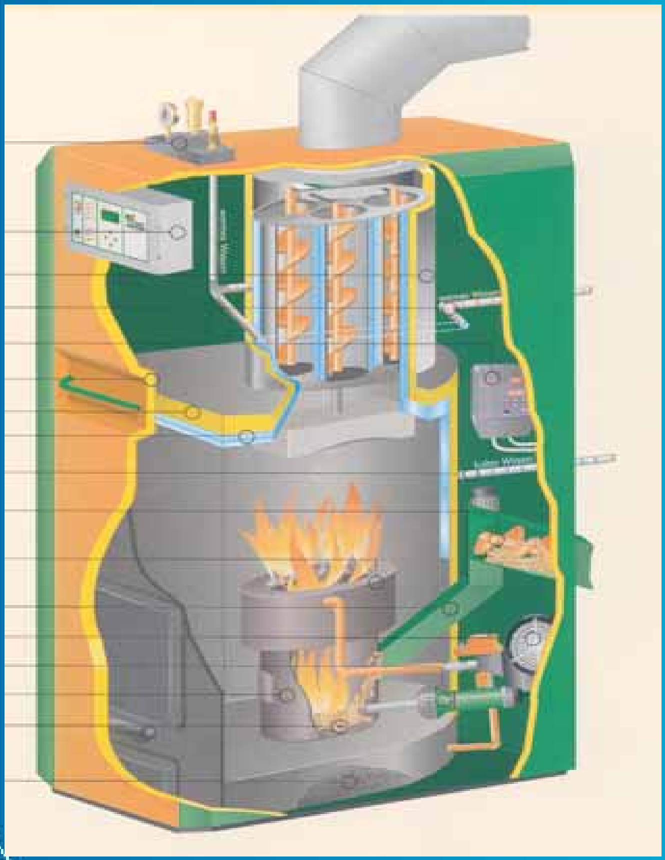
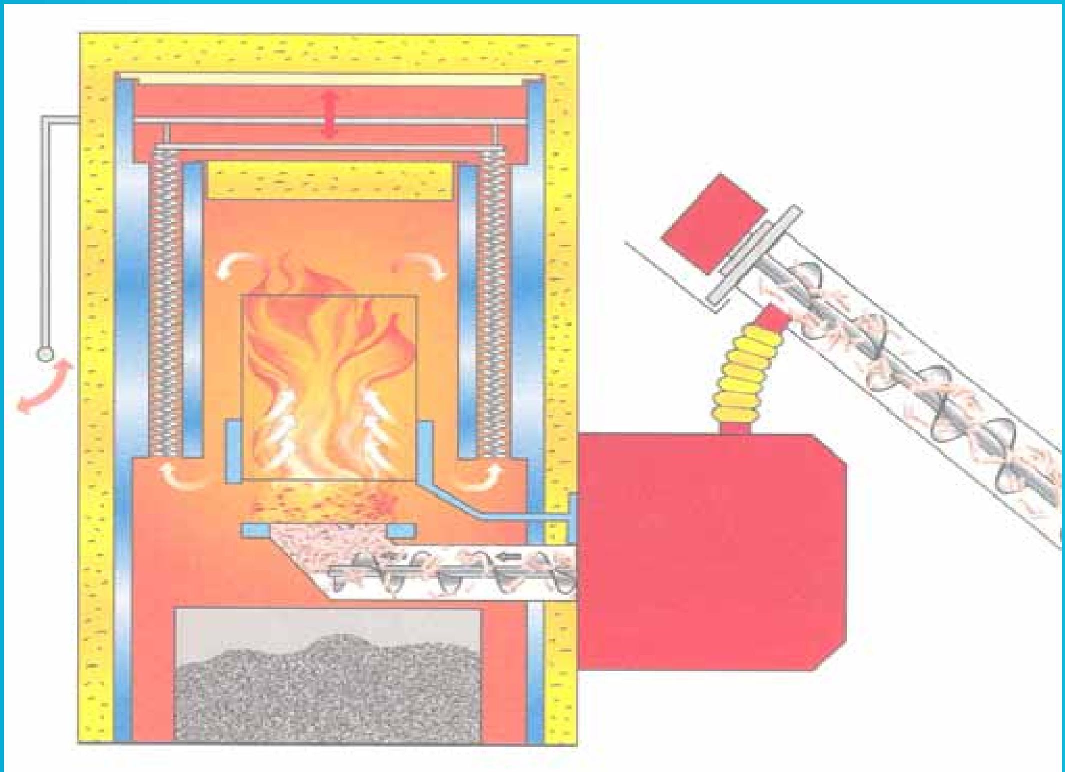
Stirling engine mounting (1)



Stirling engine mounting (2)





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Energy balance

- Example:
  - large familiy house:
    - 16 kW primary heat power installed
    - 37.000 kWh heat / year
      - radiator heating 1000-1500 full operating hours / year
      - floor heating 2000-2500 full operating hours / year
  - 1 kW of electric power installed as a stirling engine
    - 2.200 kWh electricity / year

Economics

- Investment costs
  - stirling engine with all instalations necesary: 2000 €
- Maintenance costs
  - 100 € per year
- Electricity generation
  - 2,2 MWh per year

Full costs analysis

	per year	per generated kWh el.
capital costs (5% pa, 15 years)	193 €	0,09 €
manteinance costs	100 €	0,05 €
fuel costs	73 €	0,03 €
	366 €	0,17 €

Electricity price

		per kWh
breakeven price of el.		0,17 €
feed in tariffs	Bosnia and Herzegovina	0,04 €
	Slovenia	0,07 €
	Austria	0,17 €

Wood chip fired ORC-plant for CHP-production for rural village

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Technical University of Sofia, Bulgaria

Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

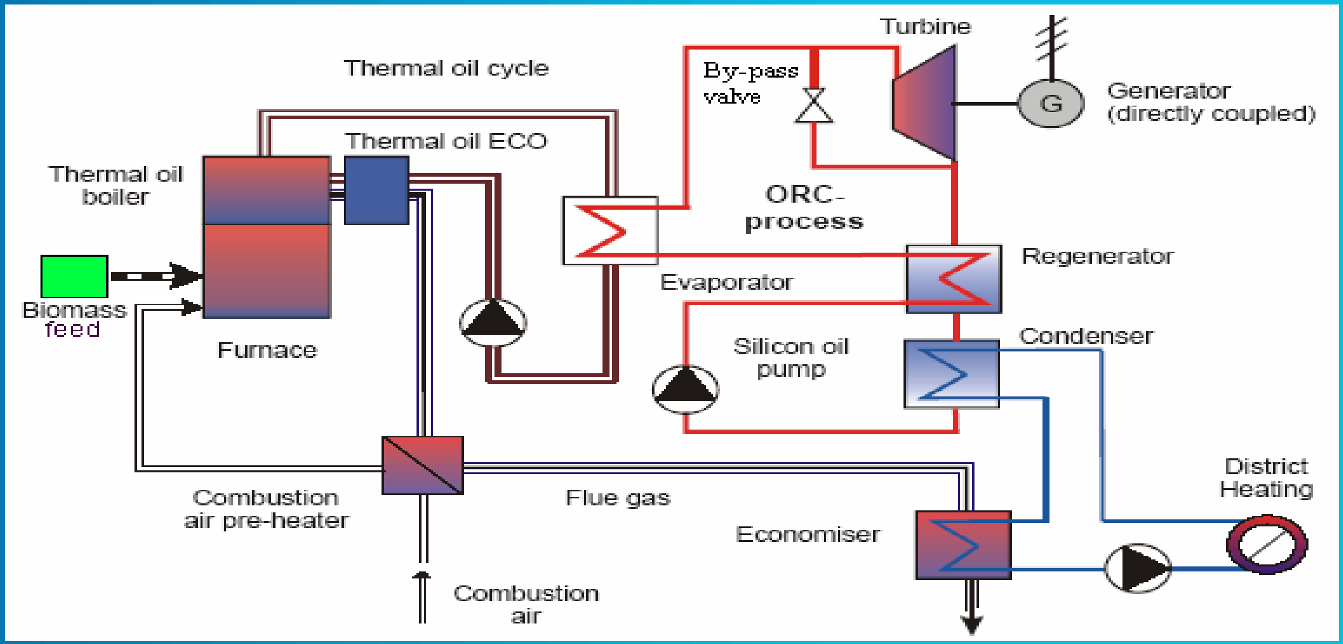
Biomass is an important renewable energy source largely available in West Balkan Countries

- It is possible nowadays electricity to be generated from biomass (bark, industrial wood chips and forest wood chips)
- Steam turbine Rankine cycle – feasible for large plants (above 5000 KW)
- ORC is emerging and feasible technology for capacity range 400 – 1500 KW;
- Over 33td demonstration and commercial projects in Austria, Germany, Italy and Switzerland

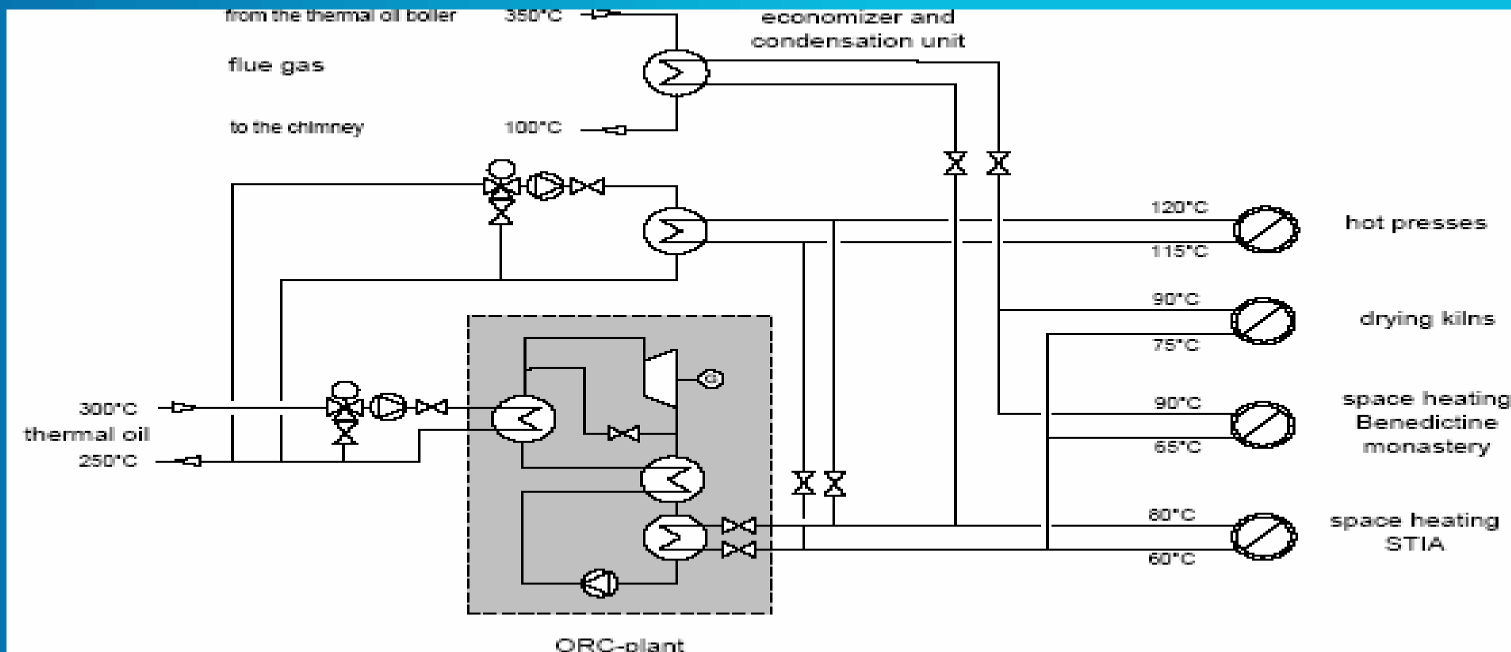
ORC – thermodynamic background

- **A Rankine cycle is usually known as a closed circuit steam turbine (water vapour) cycle;**
- **An "organic" Rankine cycle uses a heated chemical instead of steam;**
- **Chemicals used in the ORC include pentane or silicone oil.**
- **No danger of droplet erosion on turbine blades due to the favorable thermodynamic properties of the silicon oil**
- **The first ORC plants have been used to convert solar and geothermal heat into electricity almost fifty years ago**

The best reference case - ORC process in Lienz, Austria - sketch



ORC unit in wood processing plant – STIA, Admont diagram



ORC process – whole module fixed in a container – delivery stage in STIA-Admont

ORC process in Admont – two stage axial turbine

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ORC process – technical description

- **Utilization of an organic working medium instead of water**
- ***Organic Rankine Cycle* (ORC)**
- **The necessary energy is transferred from the biomass boiler to**
- **the evaporator of the ORC by a thermo-oil cycle under**
- **atmospheric conditions**
- ✓ **no pressurized boiler necessary, which decreases personal costs,**
- **no water treatment necessary**
- **An ORC process especially adapted for biomass CHP plants was developed in Italy (working medium: silicon oil)**
- **The implementation of ORC modules in existing biomass**
- **combustion plants is relatively easy**

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ORC process – ecological aspects

- **ORC plants are relatively silent (the highest noise emissions occur at the encapsulated generator and amount to 75 dBA in a distance of 1 m)**
- **Silicon oil is not toxic, not depleting the ozone layer, not explosive but is flammable with a flame point of 34°C**
- **The ORC cycle is completely closed (no losses of the working medium occur)**
- **The thermo-oil cycle demands higher security measures regarding leakage than water or steam cycles**

Technical data – ORC process, STIA-Admont

Thermal Power Input (Thermooil)	2,250 kW
Heating medium	Thermooil
Inlet temperature (at nominal load)	300°C
Outlet temperature (at nominal load)	250°C
Working medium	Silikon oil
Thermal Output (condenser)	1,800 kW
Cooling medium	Water
Inlet temperature (at nominal load)	60°C
Outlet temperature (at nominal load)	80°C
Net electric power (at nominal load)	400 kW
Electric efficiency (at nominal load)	17,7%

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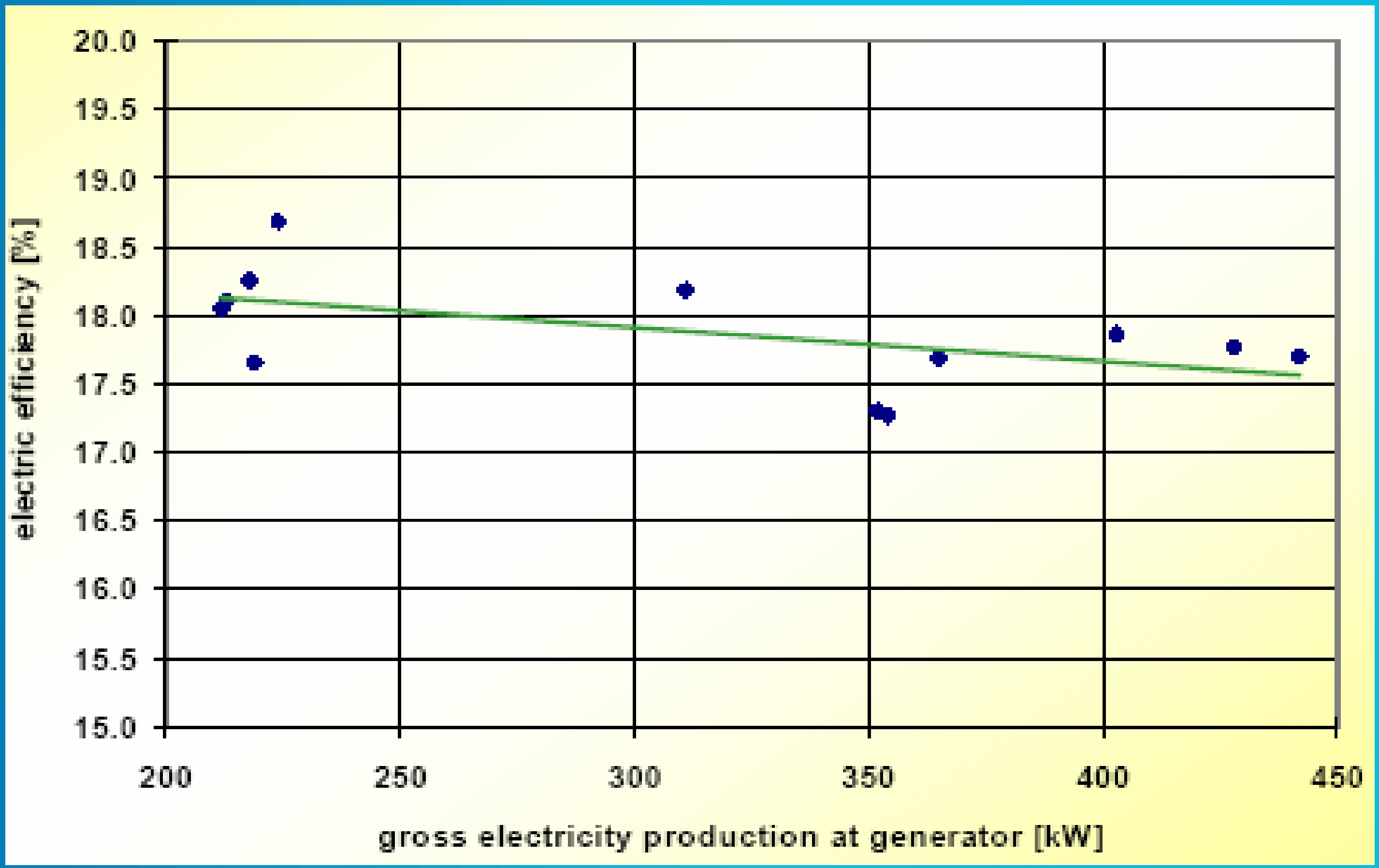
ORC plant in Admont - appropriate reference case for application in isolated region

- **The ORC plant Admont shows an excellent partial load behavior and is equipped with an automatic process control system**
- **The guiding value for heat controlled operation is the feed**
- **temperature of the water cycle at the condenser**
- **The operation of the ORC plant is fully automatic,**
- **no additional personal is required (just some man hours per week for regular checks)**
- **The ORC plant can be coupled to the electric grid within 5**
- **minutes (after having passed all security checks)**

Electric efficiency vs. Gross electric power – ORC process Admont/Austria



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ORC process-technological evaluation

- **Advantages**
- **Excellent partial load behavior**
- **Mature technology**
- **Atmospherically operated boiler reduces personal costs**
- **High degree of automation**
- **Low maintenance costs**

- **Weak points**
- **Relatively high investment costs (single supplier yet)**
- **Low experiences of biomass based ORC plants available**
- **Thermo-oil cycle necessary**

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ORC plants installed in rural areas

Country	ORC units in operation	ORC units under construction	Total number of ORC units
Austria	4	1	5
Germany	2	3	5
Total number of ORC units	6	4	10
Total ORC plants capacity	5170 KW_{el}	5100 KW_{el}	10270 KW_{el}

Conclusions

- **Power plants based on Organic Rankine Cycle are very promising solution for biomass co-generation in woody and agriculture remote areas.**
- **The advantages of this technology in terms of high availability, low maintenance costs, completely automatic and unmanned operation and high electric efficiency have been confirmed in practice.**
- **Typical applications are co-generative district heating systems and co-generation in wood manufacturing industries, where this technology is experiencing the fast growing number of installations**

VIRTUAL BALKAN POWER CENTRE

RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

Absorption cooling system based on the wood waste

Suad Halilčević, Izudin Kapetanović,
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Faculty of Electrical Engineering

Sixth Framework Programme, DG Research, International Cooperation
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Basic information on wood waste

- Biomass is organic material which has stored sunlight in the form of chemical energy. Biomass fuels include:
- wood,
- straw,
- manure,
- sugar cane, and
- - many other byproducts from a variety of agricultural processes.

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Wood history

- In the past, wood was the primary fuel for heating and cooking,
- in homes and businesses, and was used for steam in industries, trains, and boats.

- 1900 ethanol as a product of biomass fermentation was competing with gasoline to be the fuel for cars. 1984 the Burlington Electric in Vermont, USA, built a 50-MW wood-fired plant with electricity production as the primary purpose.
- In USA, due to 1990, the electricity generating capacity from biomass (not including municipal solid waste) reached 6 GW.

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Europe and RES

- Because of the basic energy situation in Europe and owing to climatic change, the European countries lunched a new energy strategy in which the RES has the important place.
- The Europian Commission target is 12% of total energy consumpted in 2010 to be satisfied from RES.
- About 16 GW is proposed in EU of biomass energy based facilities to be on in energy network by the 2050.

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Basic information on wood waste

- Biomass can be converted into energy by simple combustion, by co-firing with other fuels or through some intermediate process such as gasification (anaerobic digestion to produce methane or fermentation to produce ethanol is suited only for non lignocellulosic materials).
- The energy produced can be electricity, heat or both (combined heat and power, or CHP).

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Basic information on wood waste

- The advantage of utilising heat as well as or instead of electricity is the marked improvement of conversion efficiency – electrical generation has a typical efficiency of around 30%, but if heat is used efficiencies can rise to more than 85%.
- The main driving factor, which influences the wood-based biomass using, is the kWh price of electricity and MJ of distributed heat in the market.

Table 2: The costs of electricity production for some of the energy sources (eurocents/kWh)

Source	Cost of production	Extern cost (political-economical costs)
Coal	2,9-3	0,9-12,5
Gas	2,25-3	0,9-3,7
Nuclear	3-5,75	0,18-0,55
Good wind	5,5	0,045-0,24
Optimal wind	3,75	0,045-0,24
Wood waste	3	0,08

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Technology	Size	euro/kW installed
Biomass heating	> 1 MWth	105
Biomass heating	> 300 kWth	150
Biomass heating	< 300 kWth	300
Gas fired combined cycle of gas and steam turbine	150 MWe	600
Gas fired combined heat and power - CHP	750 kW – 1 MW	900 - 1050
Pulverized Coal Power	600 MWe	1500
Steam turbine Biomass Power	5 MWe – 40 MWe	2100 - 2700
Biomass power	5 MWe – 40 MWe	2700

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Biomass using

- The simplest way to use biomass as an energy source is heat generation.
- Typically up to 90% of the Net Caloric Value of the fuel can be recovered as heat.
- Most of the non-combustible part of the fuel as primarily minerals, leaves the combustion chamber as bottom ash. Finer particles are conveyed out of the combustor and removed in the gas cleaning stage as fly ash.
- Heat-only applications for biomass are constrained to locations where biomass fuel is available and a market for the heat exists, such as we proposed here in this report.

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Number of examples of successful biomass applying world-wide

- **Wood from forest management seems to be a particularly suitable fuel for heat and cool fluid producing plants.**
- **For example, a 460-kW boiler (small-scale wood fuelled heat facility) supply by heat 55 houses in Scotland. That boiler uses wood chips and by-product from a nearby sawmills.**

Number of examples of successful biomass applying world-wide

- **In Northern Ireland one company has 4 sawmills and 2 pallet factories. It produces 50.000 tonnes of pellets per year.**

- **This company uses surplus of sawdust and woodchip from the mills to fire a 15- MW boiler to produce 2,7 MW of electricity and heat to dry further wood and heat the entire facilty.**

Number of examples of successful biomass applying world-wide

- **In UK the Forestry Commission has calculated that about 3,1 million tonnes of dried wood-derived fuel could currently be available.**
- **This includes forestry materials, sawmill co-product, municipal arisings and energy crops (without straw). This is equivalent to 440 MW of electricity.**
- **The same amount of fuel could also produce 1400 MW of heat (assuming 85% total efficiency).**

Situation in Bosnia and Herzegovina

- **Although there are no reliable statistical data for Bosnia and Herzegovina, it is possible to mention certain estimates.**
- **For instance, based on the data of the international institutions, there are approximately 2.273,000 hectares of forest region in BiH, with app 110m³/ha.**
- **The data is presented in the FAO (Food and Agriculture Organization of the United Nations) report, Forestry Department from July 2003.**

Situation in B&H

- Owing to rich source of wood raw materials a thriving wood-processing industry has developed, with leading representation of the basic phase of wood processing (sawn wood, veneer and boards, parquet, soft-wood flooring strips, paneling and similar).

- The centres of the development of the wood-industry of the Tuzla Canton are the following companies: »Šipad-Konjuh« Živinice and former »Sokolina« (»Drinjača« and»Starić« Kladanj).

Situation in B&H

- »Konjuh« has the most developed production process, including all stages from block-processing to finishing phase, with capacity of 50.000m³ round-wood per year.
- There are other about 30 minor wood-processing companies in the Canton area, among which there are 22 sawmills.

Situation in B&H

- Today, total timber mass of the Tuzla Canton is approximately 18.6 million m^3.
- In 1998 the total of 67.000m^3 of timber mass was processed.
- 72% of the entire wood production accounts for industrial wood and the entire mass of the industrial wood is used for the production of wood for mechanical processing.

Situation in B&H

- **This short review of wood production and its residuals (wood waste), then its conversion into heat and electricity have to be integrated so as the investment, efficiency and public acceptance are to be achieved.**
- **The introduction of biomass as a renewable energy in the B&H will not be easy without considerable planning and certain amount of investment by government and other financial funds.**

The most appropriate solution

- **One of the most appropriate solution to apply the biomass as energy source is combining of heat and power (electricity).**
- **For generation of electricity and heat, the plant requires a generator driven either by the combustion gases or by some other working fluid.**
- **In any case, the CHP facility requires consistent free-flowing fuel for automatic operation (sawdust pellets, willow chips, forestry residue).**

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Environmental prosperity

- **The important aspect of biomass materials as the energy sources is environmental implication.**
- **The emission of most concern pollutants is much lower with respect to plant fuelled with coal, gas or oil.**

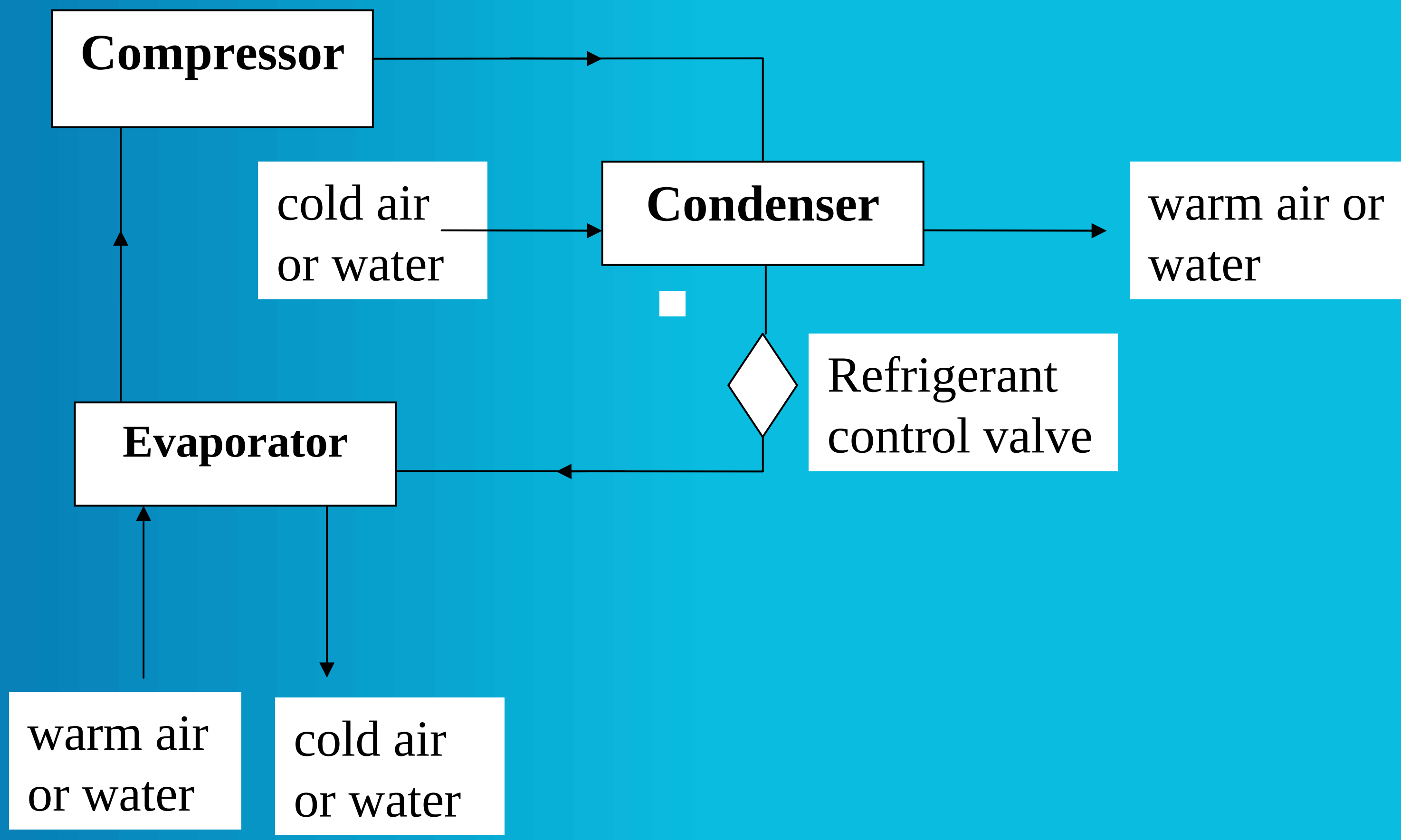
ABSORPTION COOLING MACHINES

- **Biomass wood chips or pellets combustors can be used as an equipment to provide requested input energy for cooling process.**

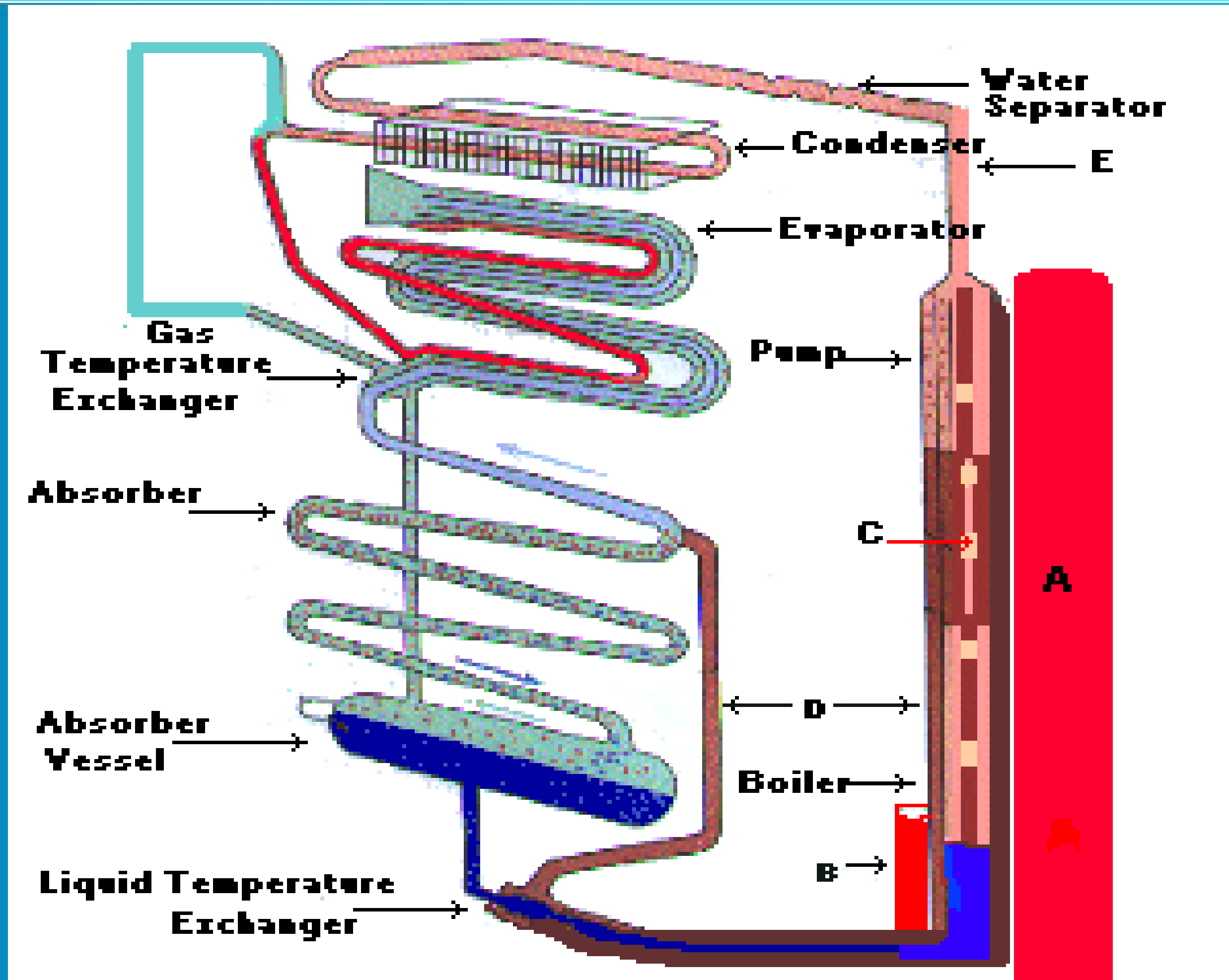
- **There are two ways for cooling process:**

- **absorption, and**
- **compression cooling systems,**

Compression cooling system



Continuous-cycle Absorption System



Continuous-cycle Absorbtion System

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ACS

- **As a working fluid, the ACS uses ammonia-water mixture.**
- **The good attribute of the working fluid based on the ammonia-water mixture is possibility of the multi-purpose application ranging from air conditioning to deep freezing.**

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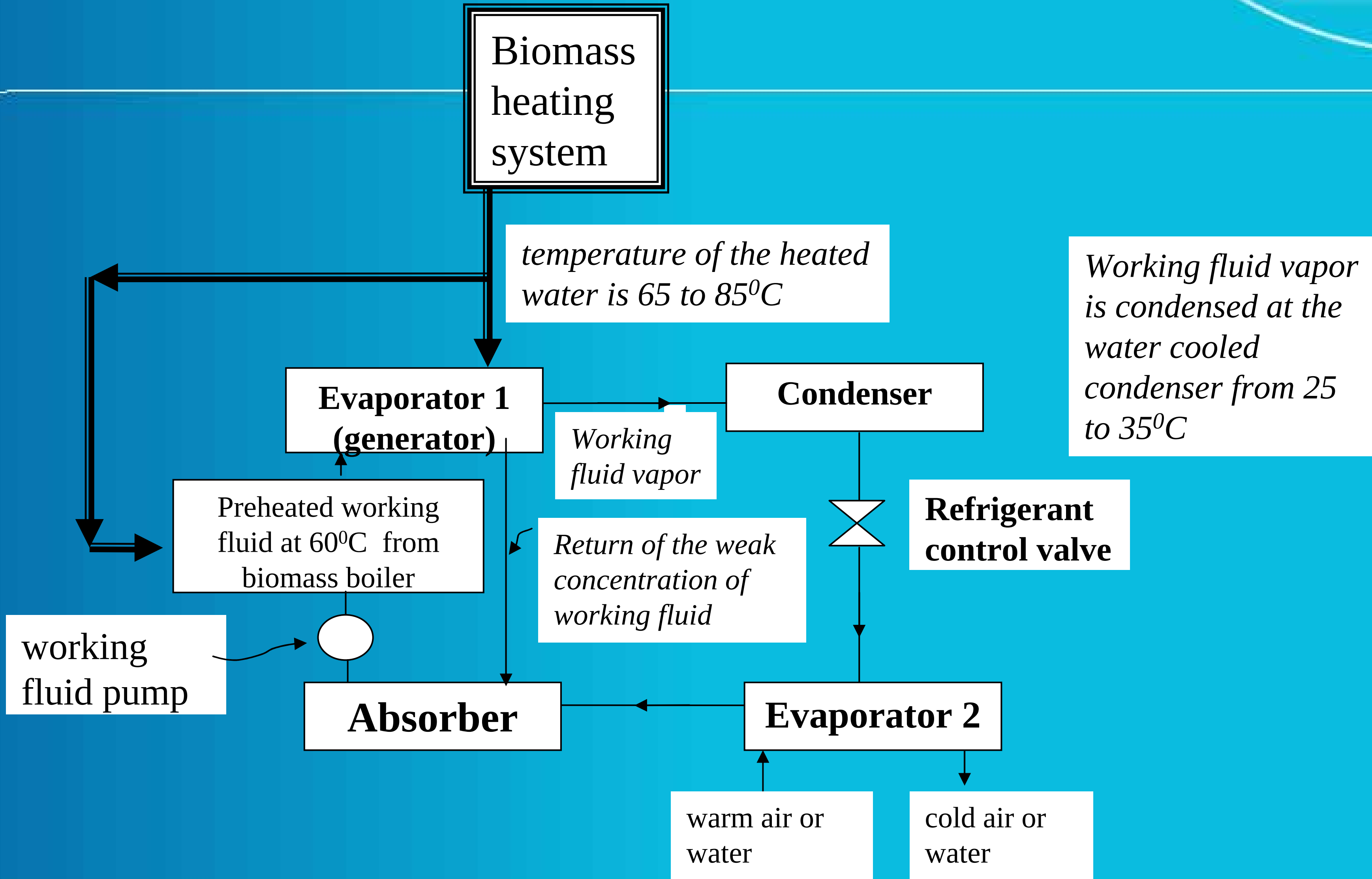
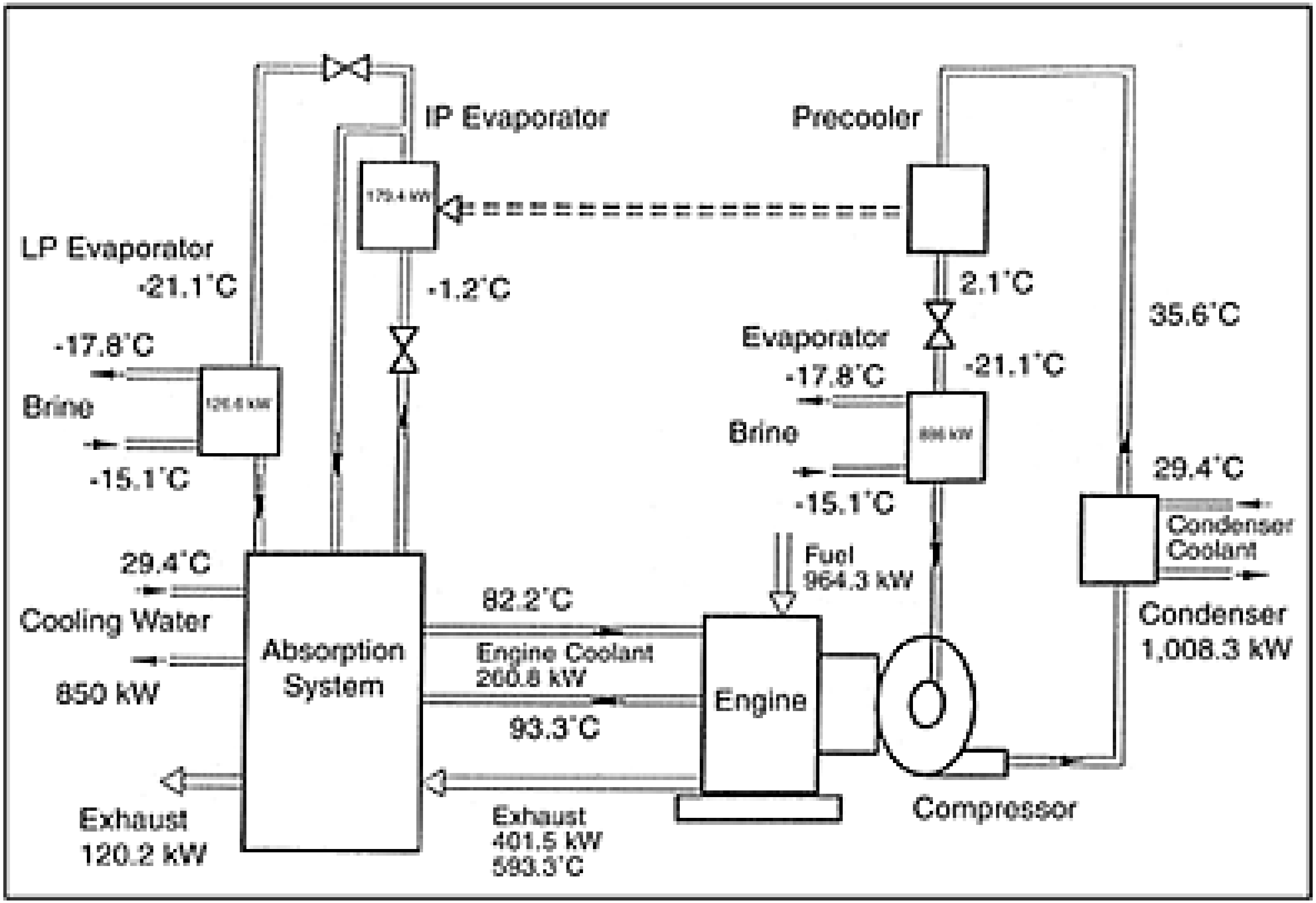
ACS

- **Depending on the temperature of the heated water produced in biomass boiler, one can apply ACS for**
- **air conditioning,**
- **cooling at -10^{0}C (temperature from biomass boiler should be amounted to 90^{0}C), and**
- **deep-freezing at -34^{0}C (temperature from biomass boiler should be amounted to 120^{0}C).**


Biomass heating system
temperature of the heated water is 65 to 85^{0}C
Working fluid vapor is condensed at the water cooled condenser from 25 to 35^{0}C
Evaporator 1 (generator)
Condenser
Working fluid vapor
Refrigerant control valve
Preheated working fluid at 60^{0}C from biomass boiler
Return of the weak concentration of working fluid
working fluid pump
Absorber
Evaporator 2
warm air or water
cold air or water



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PROPOSAL FOR ONE ABSORPTION-COOLING SYSTEM DRIVEN BY WOOD WASTE

- **In the northeast part of Bosnia and Herzegovina, there is a factory for fruit and vegetable processing plant.**
- **For own needs this factory uses a cooler of 300 kW.**
- **In the neighboring of this factory there is several sawmills that can provide about 1000 tons of wood-derived fuel per year.**
- **That includes, forestry materials, sawmill co-product, and straw. This is equivalent to 450 kW of heat (assuming 85% total efficiency).**

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Proposal

- This is a sufficient resource to initiate a biomass using for own needs.

▪

- It is very important that sufficient fuel can be sourced within a 30-km radius of this factory, which will keep transport distances to a minimum.

Proposal

- **The factory's cooler consumes electric power for about 100.000 euros/year for its operation.**
- **The investment cost of ACS accounted to 615.000 euros for refrigeration capacity of 300 kW.**
- **The investment cost of biomass 300 kW(th) boiler for annual heat production about 2.500.000 kWh is amounted to 50.000 euros.**
- **The total capital cost of ACS based on wood-waste as biomass is amounted to 665.000 euros.**

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Proposal

- **This means are provided by the credit from the bank. We can calculate the annual repayment of credit by means of the time value of money method, taking into account the 6% of interest rate over 20 years. This results into annual investment cost of 40.000 euros.**
- **The price of wood-derived fuel is amounted to 25 euros/ton (including transport).**
- **The biomass fuel cost is amounted to 25.000 euros/year.**

Proposal

- **Therefore, the total operating cost per year for considered ACS is amounted to 65.000 euros.**

- **This is about 1,5 time lesser than total annual running cost for current conventional cooling system based on vapor compression technique.**

CONCLUSION

- **The presented kind of refrigeration technology may not yet be mass-produced, but it is ready to tackle any large-scale systems on a project-by-project basis.**
- **Mid-capacity units, in the range of 50 to 100 tons, will be available in one to two years.**
- **Small capacity units, maybe 25 tons and smaller, won't be available for another three years or so.**

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CONCLUSION

- **There is very limited knowledge of absorption in the refrigeration community anymore.**
- **Engineers have to be cognizant of state-of-the-art absorption technology.**
- **There are only a few dozen places in the world where that knowledge currently exists.**

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CONCLUSION

- **In Bosnia and Herzegovina there are limited wood waste resources, but it doesn't mean that possibilities to develop and apply presented techniques and apparatus don't need to be used.**

- **However, due to fluctuations of oil and gas prices, environmental challenges, social reasons, keeping of the present fosil fuel based resources, the presented approach to solve cooling (and heating) needs is very acceptable.**

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Biomass fired Organic Rankine Cycle (ORC) - Power generation

TU-Sofia, Bulgaria –
– contribution to RES Guidelines, Tuzla

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Biomass fired ORC co-generative district heating plant in Lienz

Biomass is an important renewable energy source largely available in West Balkan Counties

- ➢ It is possible nowadays electricity to be generated from biomass (bark, industrial wood chips and forest wood chips)
- ✓ Steam turbine Rankine cycle – feasible for large plants (above 5000 KW)
- ✓ ORC is emerging and feasible technology for capacity range 500 – 1500 KW;
- ✓ Over 33^{td} demonstration and commercial projects in Austria, Germany, Italy and Switzerland

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ORC – thermodynamic background

- A Rankine cycle is usually known as a closed circuit steam turbine (water vapour) cycle;
- An "organic" Rankine cycle uses a heated chemical instead of steam;
- Chemicals used in the ORC include pentane or silicone oil.
- The first ORC plants have been used to convert solar and geothermal heat into electricity almost fifty years ago

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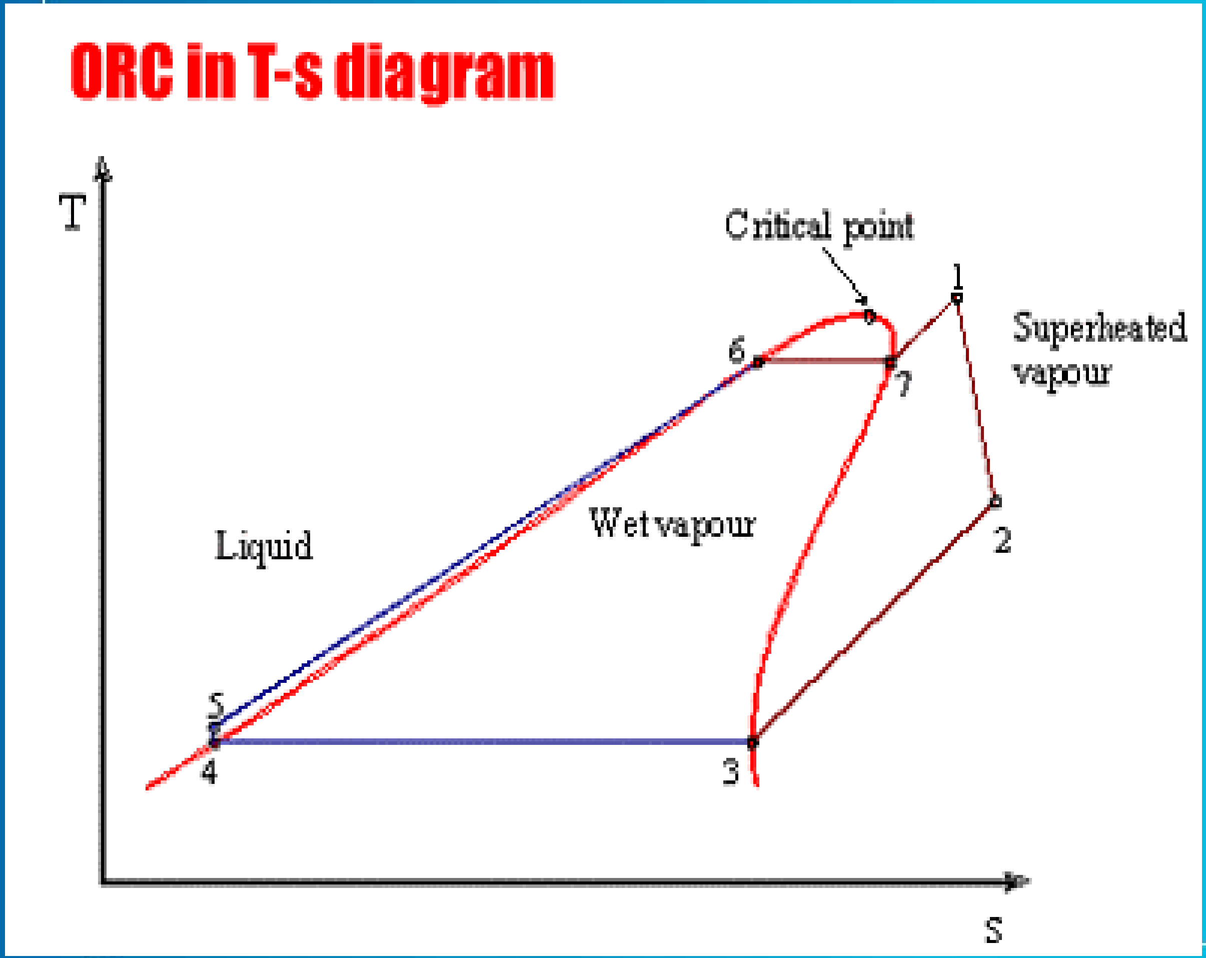
The selected working fluid for biomass fired ORC plants is silicone oil



- **1 -> 2** Expansions in ORC-turbine
- **2 -> 3** cooling/ regeneration
- **3 -> 4** Condensation
- **4 -> 5** Pressurization
- **5 -> 6** Heating
- **6 -> 7** Evaporation
- **7 -> 1** Superheating

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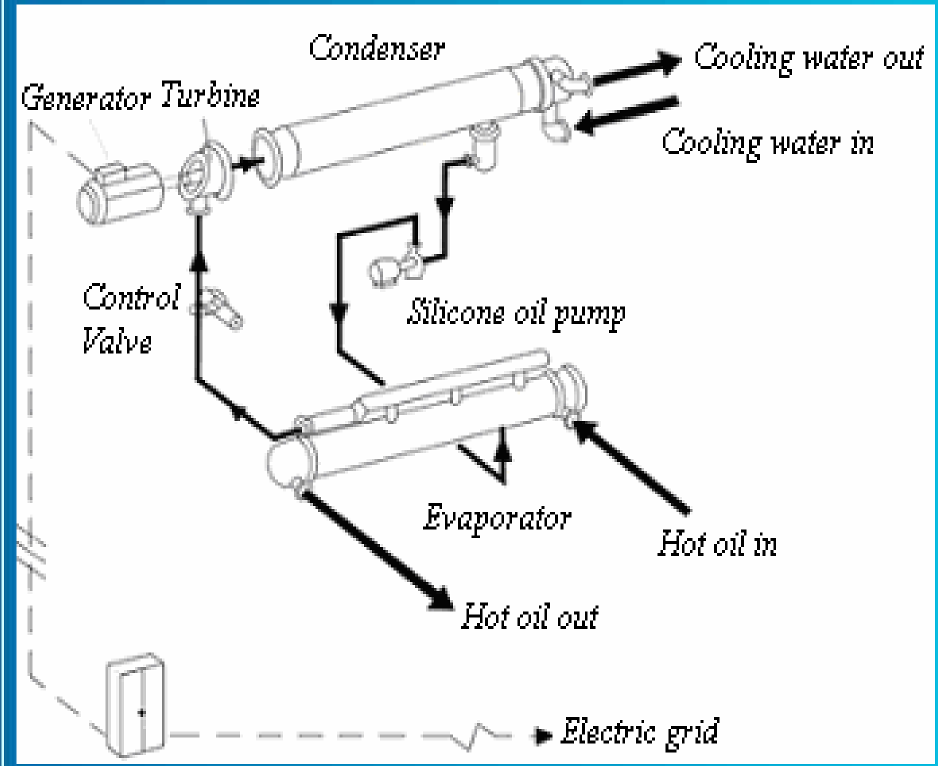
The ORC has several advantages over conventional steam plant technology for small and medium scale biomass fired power generation



- high cycle efficiency
- very high turbine efficiency (up to 85 percent)
- low mechanical stress of the turbine, due to the low peripheral speed
- low RPM of the turbine allowing the direct drive of the electric generator
- no erosion of blades, due to the absence of moisture
- long life
- no operator required

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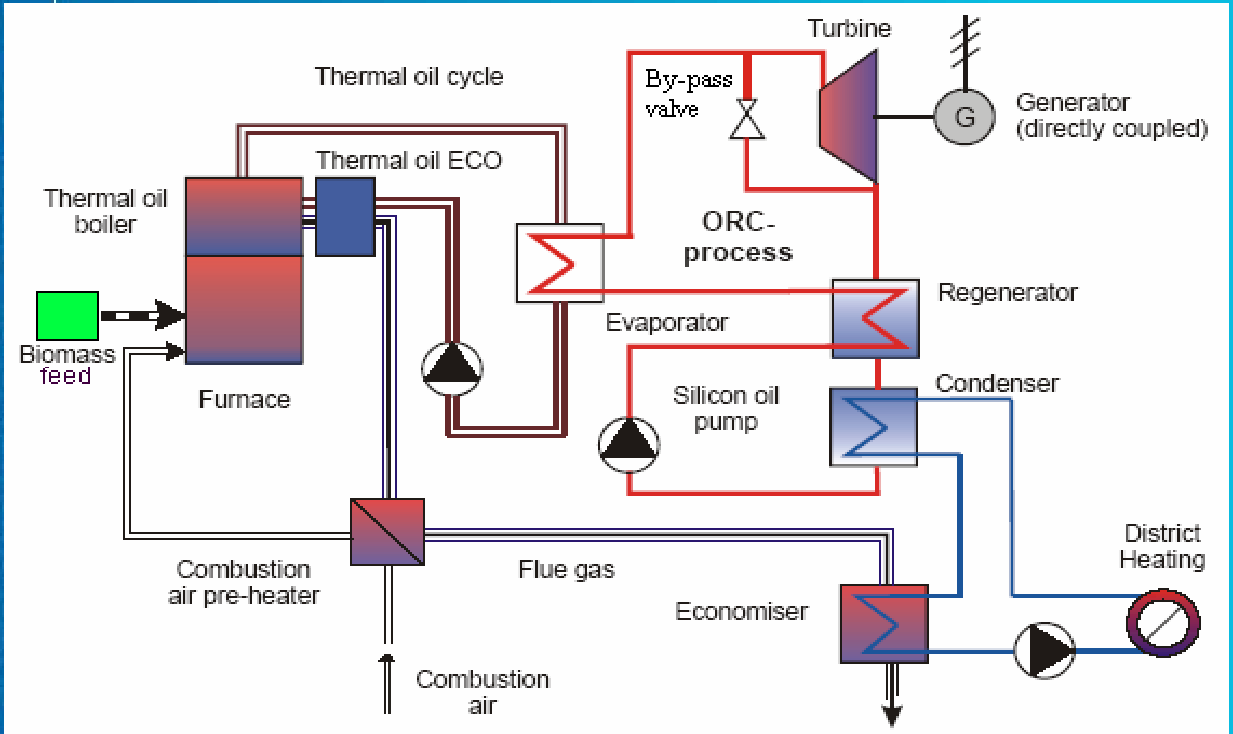
Biomass fired ORC plant basic design features



- Virgin wood is burned in thermal oil boiler;
- The heat is transferred from the boiler to the evaporator of the ORC unit by a thermo-oil circuit;
- Two stage axial turbine drives directly coupled generator;
- The condenser is cooled by district heating water;
- The ORC unit is heat controlled

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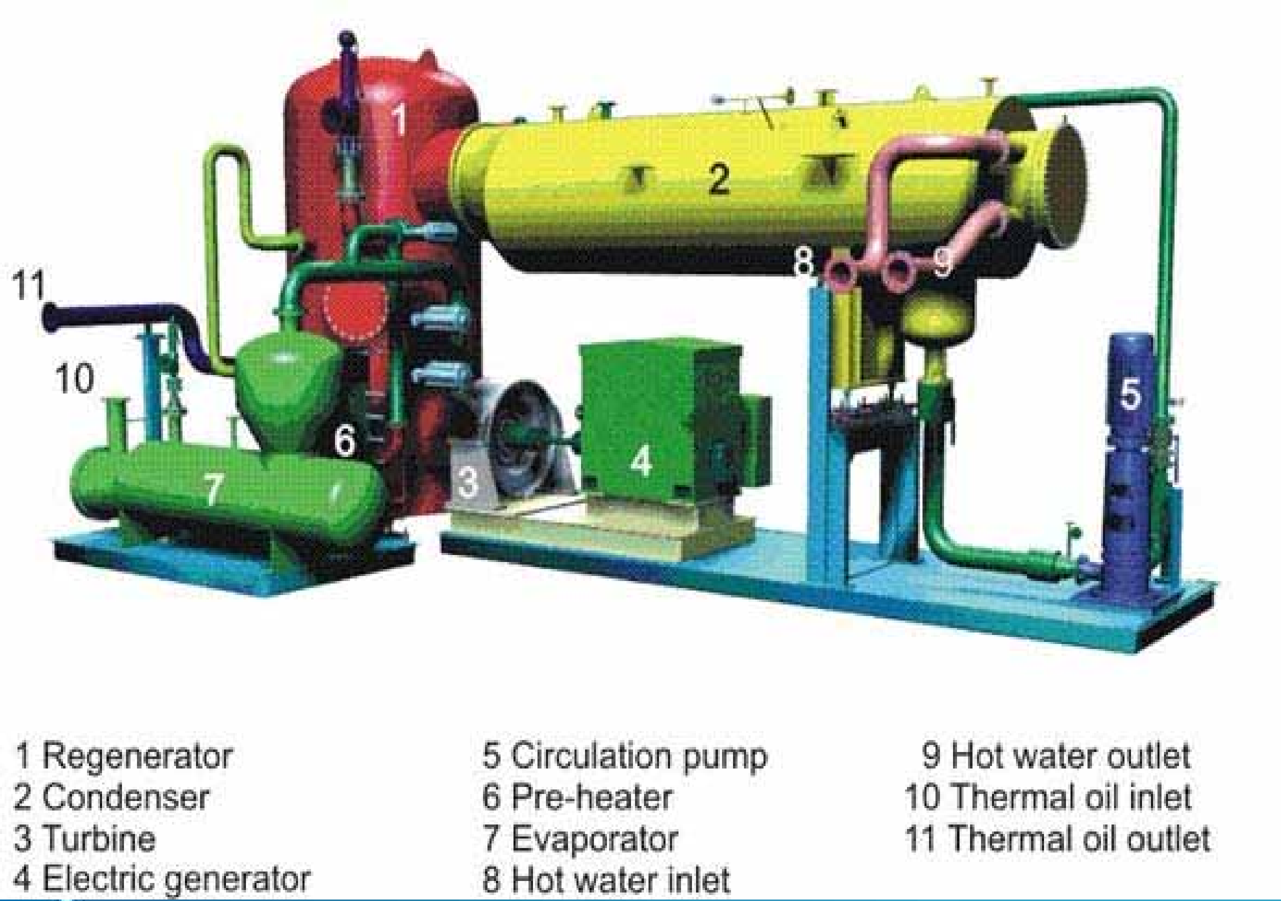
ORC process – whole module fixed in container

The ORC turbo-Generator (up to about 800 kW) consists of a single skid-mounted assembly, containing all the equipment required for the turbo-generator to be operated (i.e. heat exchangers, piping, working fluid feed pump, turbine, electric generator, control and switch-gear).

The biomass fired ORC units are manufactured only by Turboden)



Turboden s.r.l., Brescia - Italy

(http://www.turboden.it)

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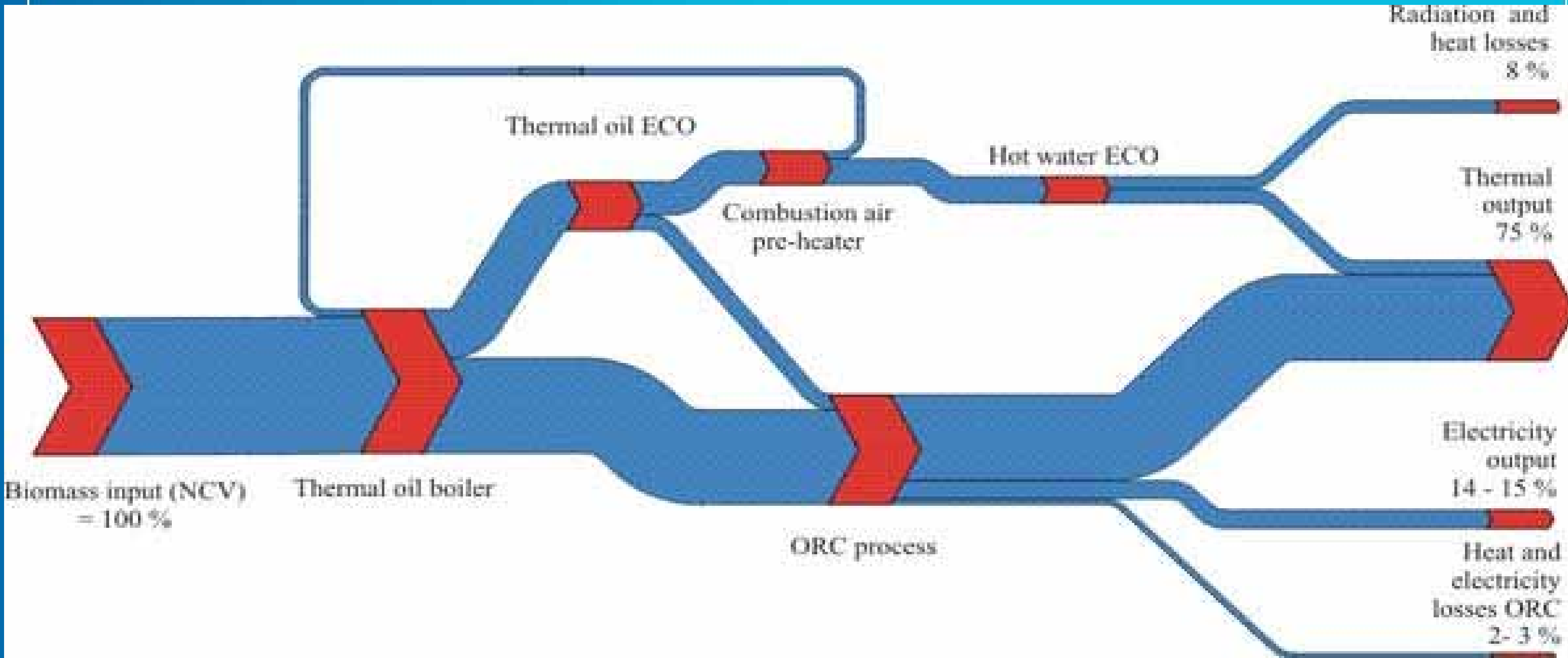
Energy balance of the biomass fired ORC-combined heat and power plant (Lienz case)



Biomass fired ORC plant - control and operation

- The ORC plant is equipped with an automatic process control system;
- no additional personal is required (just some man hours per week for regular checks)
- The guiding value for heat controlled operation is the feed temperature of the water cycle at the condenser;
- The ORC plant can be coupled to the electric grid within 5
- minutes

- Regarding constant thermal oil feed temperature the biomass-fired boiler is more difficult to control;
- a newly developed Fuzzy Logic control system for biomass CHP plants has been installed;
- thermal oil boiler operated at atmospheric conditions no steam boiler operator is needed and the steam boilers law is not applied

ORC- technology development

After several successful demonstration projects biomass fired ORC process is already mature technology

Country	ORC units in operation	ORC units under construc.	Total number of ORC units
Austria	6	11	17
Czech Republic	0	1	1
Italy	2	1	3
Germany	3	7	10
Switzerland	2	0	2
Total number of ORC units	13	20	33
Total ORC plants capacity	12050 KW_{el}	21500 KW_{el}	33550 KW_{el}

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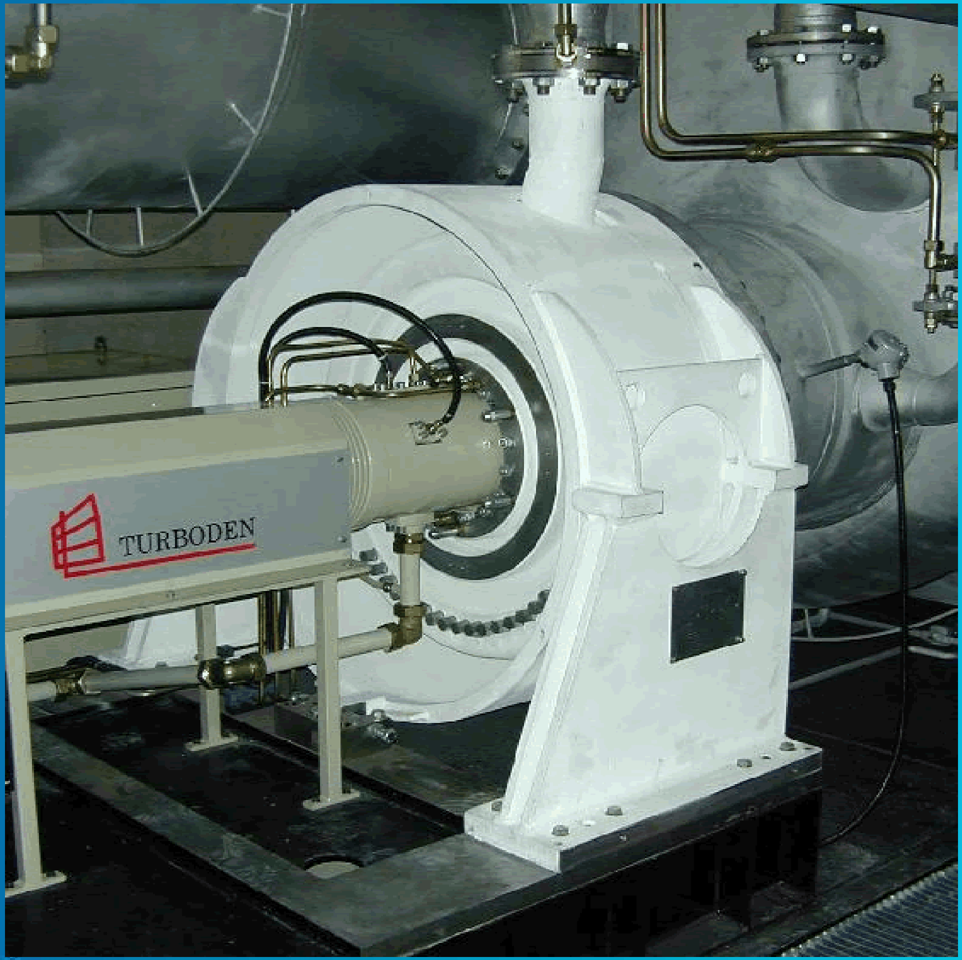
ORC demonstration projects in Austria

- The first ORC technology demonstration project funded by the European Union is located in Admont, Austria. This is biomass CHP plant fed by saw dust.The plant has 450 KW ORC unit. Hot water produced at the ORC condenser is used for wood drying and for district heating;
- The next demonstration project is a biomass CHP plant based on an ORC cycle and a newly developed Fuzzy Logic control system - Stadtwärme Lienz. This plant has 1100 KW ORC unit.. The water heated by the ORC condenser (from 60°C to 80 °C) feeds the Lienz district heating circuit.
- The latest demonstration project is a biomass CHP plant based on an ORC cycle and absorption chillier for power generation and cooling, fired with 100% waste wood. This is Austrian national funded project located at BIOSTROM, Fussach site, Vorarlberg. The plant has the following technical data: Nominal electric capacity: 1,100 kW; Nominal thermal capacities: 6.2 MW (thermal oil boiler + thermal oil ECO) +1.0 MW (pressurised hot water economiser) Nominal chilling capacity - absorption chiller: 2.4 MW, Start of operation: 2002.

Biomass CHP Plant Admont – 2-stage axial flow turbine (ORC-process)



Biomass CHP plant with absorption chiller Fussach

– in front of waste wood treatment facility with integrated Fe and non Fe metal separation

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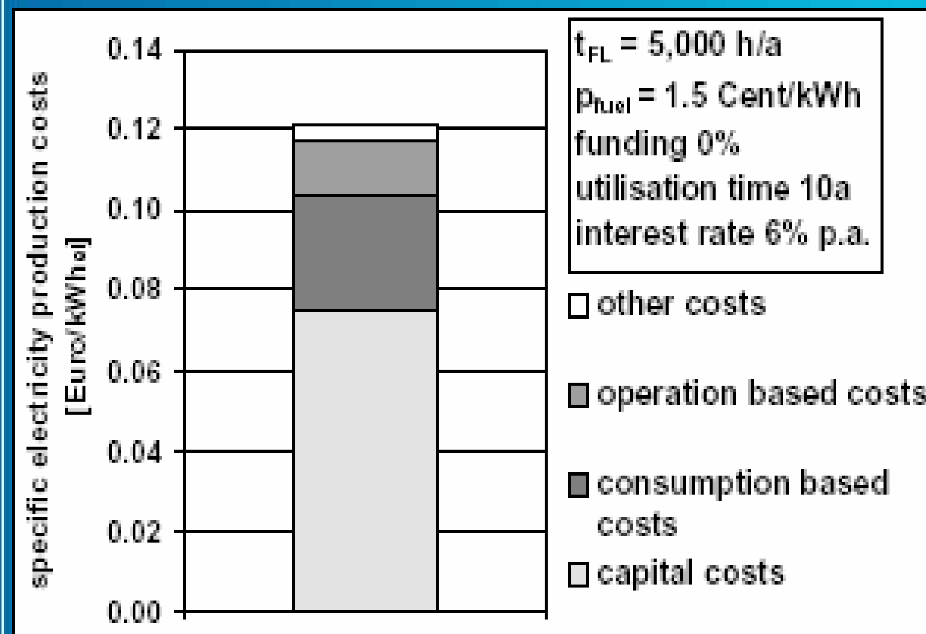
The ORC plant in Fussach has some important innovations like:

- Waste wood treatment with metal and non-metal separation;
- Low-NOx waste wood furnace with CFD optimised geometry;
- Thermal oil boiler with separate radiative and convective sections and an automatic cleaning system;
- Highly efficient fibrous filter with integrated dry sorption;
- Production of electricity from waste wood;

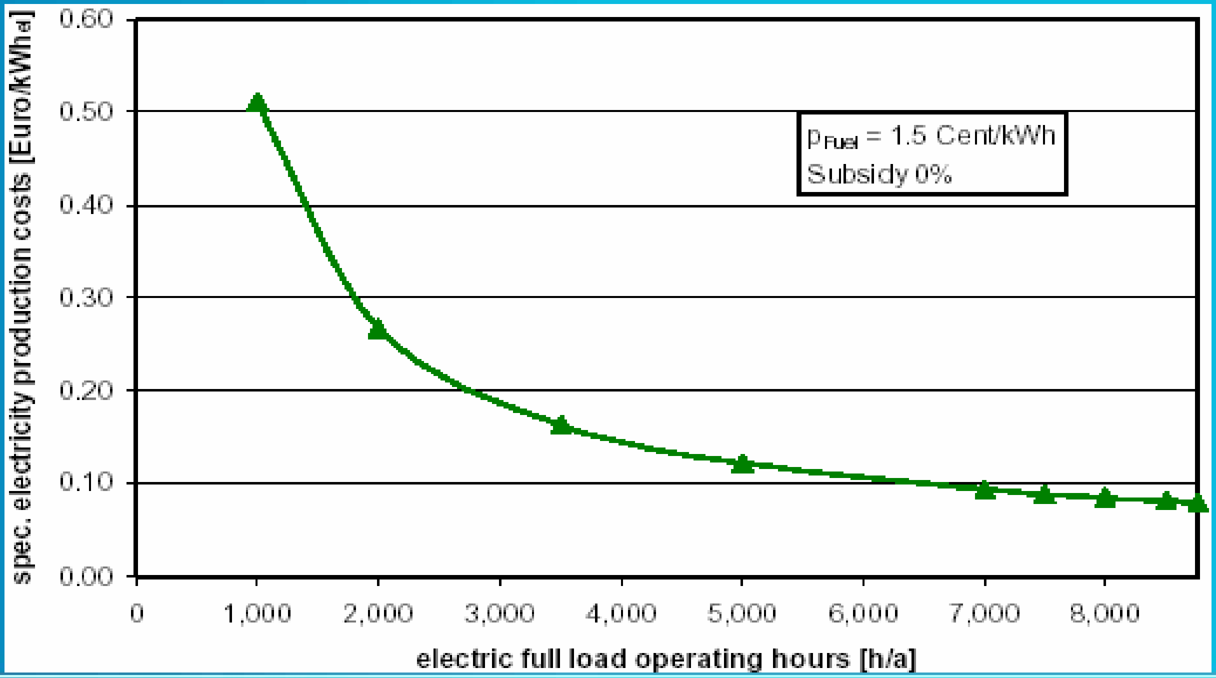
Biomass fired ORC Plant – Economic aspects



- ➢ Electricity production cost (Lienz case)
- ✓ The capital costs are based on additional investment costs, and consider only surplus investment costs of ORC plant in comparison to a conventional biomass fired plant with a hot water boiler and the same thermal output
- ✓ The average fuel price is set at 15 Euro/MWh.;
- ✓ The capacity utilization of the ORC plant is set at 5000 h/a;

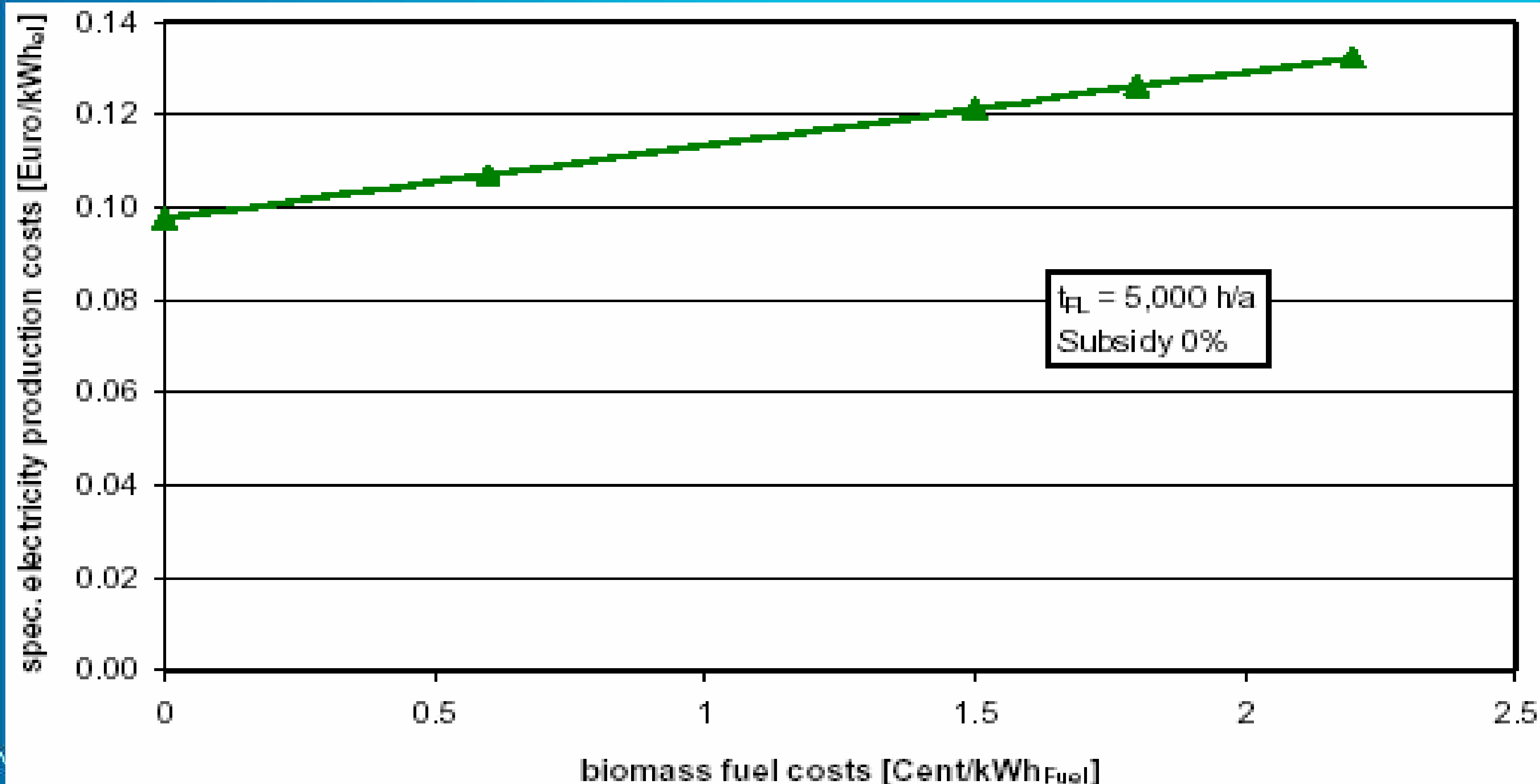
Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

ORC plant - specific power generation costs versus capacity utilisation factor (full-load operating hours) (Lienz case)



Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

Specific power generation costs versus the biomass fuel **costs (Lienz case)**



Environmental aspects

- The ORC cycle does not cause any solid, liquid or gaseous emissions, since it is completely closed;
- Silicone oil is not toxic not depleting the ozone layer, not explosive but is flammable
- The combustion of biomass fuels (bark, wood chips and saw dust) implies the production of residues, the ashes
- The mixture of bottom ash and cyclone ash representing about 90% of the total ash produced, can be defined as usable ash, because the mixture of these two ash fractions have got very low;
- the usable ash from biomass fired ORC-power generation plants can be used as a soil amending and fertilising agent for agriculture and forest soils as well as for compost production.

Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

Conclusions- biomass fired ORC power generation plants are now entering the market

- **Advantages**
  - **Excellent partial load behavior**
  - **Mature technology**
  - **Atmospherically operated boiler reduces personal costs**
  - **High degree of automation**
  - **Low maintenance costs**

- **Weak points**
  - **Relatively high investment costs (single manufacturer)**
  - **Low experiences of biomass based ORC plants available**
  - **Thermo-oil cycle necessary**

Renewable Energy Sources Technology, Economics and Policy Curriculum

Technology-Source Combination Module

Sun: photovoltaics &heating

Author:
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Bosna & Hercegovina

SUSTAINABLE ENERGY

We divide it into two major groups:

- Energy efficiency, and
- Renewable energy

ENERGY EFFICIENCY encompasses

- Demand-side management,
- Integrated resource planning,
- Generation, transmission, and distribution efficiency,
- End-use efficiency

RENEWABLE ENERGY includes

- Solar power,
- Biomass power
- Wind power,
- Hydro-electric generation,
- Goethermal power,
- Fuel cell,
- Hydrogen
- Tides

SUN

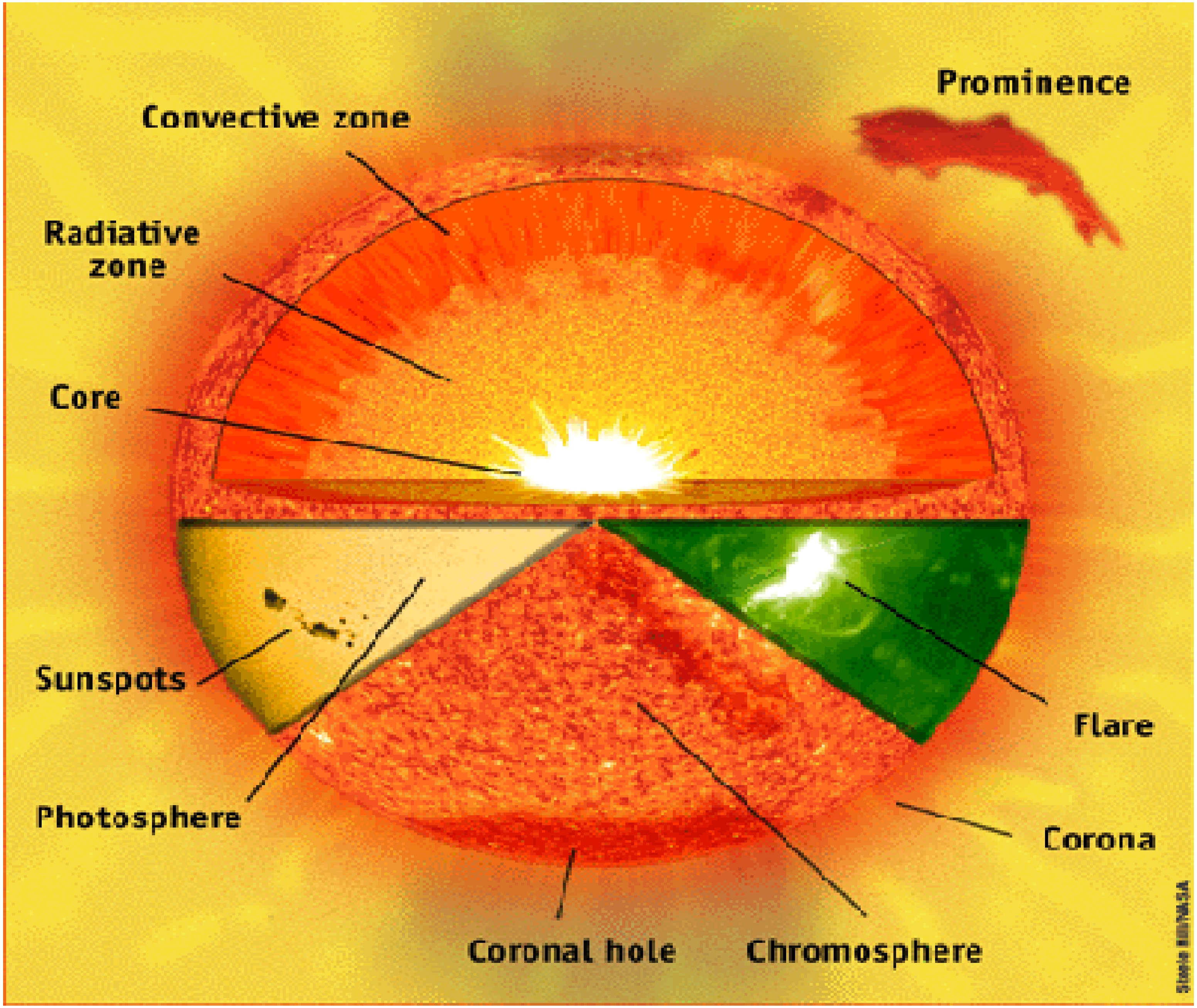
- The sun is made of gas and has no solid surface as Earth does. However, it still has a defined structure. The three major surface areas of the sun are shown in the upper half of the next figure:
- **Core**
- **Radiative Zone**
- **Convective Zone**

SUN

- The sun is a star, just like the other stars we see at night. The difference is distance -- the other stars we see are light years away, while our sun is only about 8 light minutes away (many thousands of times closer).
- Officially, the sun is classified as a G2 type star based on its temperature and the wavelengths or **spectrum** of light that it emits. The sun is an "average" star, merely one of billions of stars that orbit the center of our galaxy.

SUN

- The sun has "burned" for more than 4.5 billion years and will continue to do so for several billion more. It is a massive collection of gas, mostly hydrogen and helium. Because it is so massive, it has immense gravity, enough gravitational force to hold all of hydrogen and helium together (and to hold all of the planets in their orbits around the sun!).
- The sun does not "burn" like wood burns. Instead the sun is a gigantic nuclear reactor


Prominence
Convective zone
Radiative zone
Core
Sunspots
Photosphere
Flare
Corona
Coronal hole
Chromosphere

SUN

- Above the surface of the sun is its atmosphere, which consists of three parts as shown in the lower half of the previous figure:
- **Photosphere**
- **Chromosphere**
- **Corona** - extremely hot outermost layer extending outward from the chromosphere several million kilometers

SUN

- All of the major features of the sun can be explained by the nuclear reactions that make its energy, the magnetic fields that are caused by the movements of the gas, and the immense gravity.

Sun Facts

- **Average distance from Earth** = 150 million km
- **Radius** = 696.000 km
- **Mass** = 1.99 x 1030 kg (330.000 Earth masses)
- **Makeup (by mass)** = 74 percent hydrogen, 25 percent helium, 1 percent other elements
- **Average temperature** = 5,800 degrees Kelvin (surface), 15.5 million degrees Kelvin (core)
- **Average density** = 1.41 grams per cm3
- **Rotational period** = 25 days (center) to 35 days (poles)

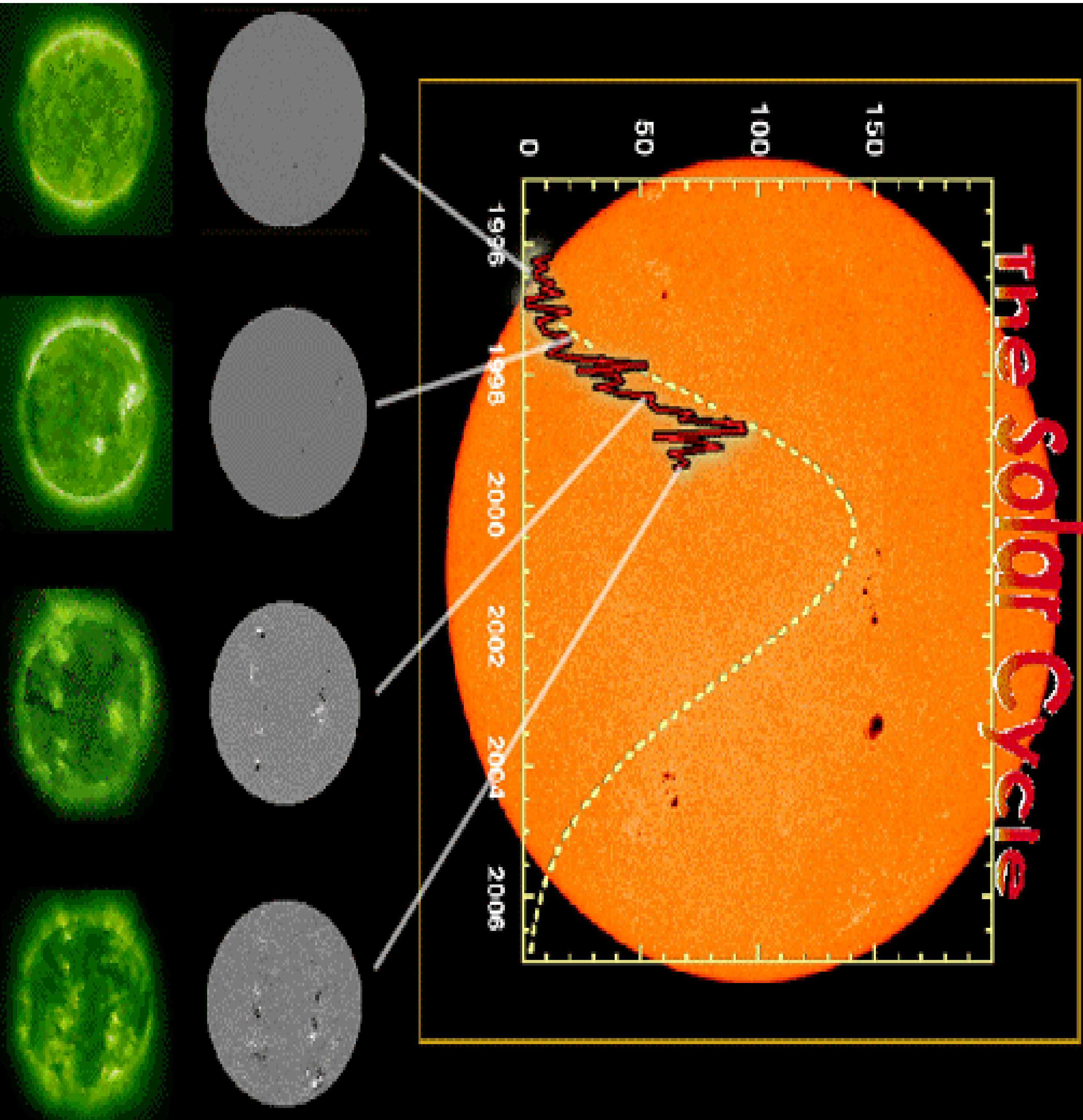
Sun Facts

- **Magnitude** = -26.8 (apparent), +4.8 (absolute) Apparent magnitude refers to a star's brightness in the sky from our vantage point on Earth. Absolute magnitude is the star's true brightness if all of the stars were the same distance from Earth. The lower the number, the brighter the star.

- **Distance from center of Milky Way** = 25,000 light-years

- **Orbital speed and period** = 230 kilometers per second and 200 million years

The sun's 11-year solar cycle as reflected by the number of sunspots recorded to date and projected (dotted line). Selected EIT 195 angstrom (green) and MDI magnetogram (gray) images are shown. In this cycle, the sun undergoes a period of activity (solar maximum) followed by a period of quiet (solar minimum). The rising level can be clearly seen in the comparison of EIT and MDI images.



Reactions on Sun

- The core starts from the center and extends to 25 percent of the sun's radius. Here, gravity pulls all of the mass inward and creates an intense pressure. The pressure is high enough to force atoms of hydrogen to come together in nuclear fusion reactions. Two atoms of hydrogen are combined to create helium-4 and energy in several steps:
- Two protons combine to form a deuterium (hydrogen atom with one neutron), a positron (similar to electron, but with a positive charge) and a neutrino
- A proton and a deuterium atom combine to form a helium-3 atom (two protons with one neutron) and a gamma ray.

- Two helium-3 atoms combine to form a helium-4 (two protons and two neutrons) and two protons.

Reactions on Sun

- These reactions account for 85 percent of the sun's energy. The remaining 15 percent comes from the following reactions:

- A helium-3 and a helium-4 combine to form a beryllium-7 (four protons and three neutrons) and a gamma ray.

- A beryllium-7 captures an electron to become lithium-7 (three protons and four neutrons) and a neutrino.

- The lithium-7 combines with a proton to form two helium-4 atoms.

Reactions on Sun

- The helium-4 atoms are less massive than the two hydrogen atoms that started the process, so the difference in mass was converted to energy as described by Einstein's theory of relativity (E=mc2). The energy is emitted in various forms of light:
- ultraviolet light,
- X-rays,
- visible light,
- infrared,
- Microwaves, and
- radio waves).

Reactions on Sun

- The sun also emits energized particles (neutrinos, protons) that make up the **solar wind**. This energy strikes Earth, where it warms the planet, drives our weather and provides energy for life. We are not harmed by most of the radiation or solar wind because the Earth's atmosphere protects us.

How much we get from the Sun

- On a bright, sunny day, the sun shines approximately 1,000 watts of energy per square meter of the planet's surface, and if we could collect all of that energy we could easily power our homes and offices for free.

PHOTOVOLTAICS

- Photovoltaics, as the word implies (photo = light, voltaic = electricity), convert sunlight directly into electricity. Once used almost exclusively in space, photovoltaics are used more and more in less exotic ways. They could even power your house.

- How do these devices work?

Photovoltaics

- Providing power for villages in developing countries is a fast-growing market for photovoltaics. The United Nations estimates that more than 2 million villages worldwide are without electric power for water supply, refrigeration, lighting, and other basic needs, and the cost of extending the utility grids is prohibitive, $23,000 to $46,000 per kilometer in 2000.

- A one kilowatt PV system* each month:
  - prevents 150 lbs. of coal from being mined
  - prevents 300 lbs. of CO_2 from entering the atmosphere
  - keeps 105 gallons of water from being consumed
  - keeps NO and SO_2 from being released into the environment

- * in Bosnia and Herzegovina, or an equivalent system that produces 150 kWh per month

Solar panels absorb energy to produce hydrogen at SunLine Transit Agency.

PHOTOVOLTAICS

- Photovoltaic (**PV**) cells are made of special materials called **semiconductors** such as silicon, which is currently the most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor.

- The energy knocks electrons loose, allowing them to flow freely. PV cells also all have one or more electric fields that act to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off to use externally.

- This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

Silicon

- Silicon has some special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells.
- The first two shells, those closest to the center, are completely full. The outer shell, however, is only half full, having only four electrons. A silicon atom will always look for ways to fill up its last shell (which would like to have eight electrons).
- To do this, it will share electrons with four of its neighbor silicon atoms. It's like every atom holds hands with its neighbors, except that in this case, each atom has four hands joined to four neighbors. That's what forms the **crystalline structure**, and that structure turns out to be important to this type of PV cell.

Silicon

- We've now described pure, crystalline silicon. Pure silicon is a poor conductor of electricity because none of its electrons are free to move about, as electrons are in good conductors such as copper. Instead, the electrons are all locked in the crystalline structure. The silicon in a solar cell is modified slightly so that it will work as a solar cell.

Silicon in Solar Cells

- A solar cell has silicon with **impurities** -- other atoms mixed in with the silicon atoms, changing the way things work a bit. We usually think of impurities as something undesirable, but in our case, our cell wouldn't work without them.
- These impurities are actually put there on purpose. Consider silicon with an atom of phosphorous here and there, maybe one for every million silicon atoms. Phosphorous has five electrons in its outer shell, not four. It still bonds with its silicon neighbor atoms, but in a sense, the phosphorous has one electron that doesn't have anyone to hold hands with. It doesn't form part of a bond, but there is a positive proton in the phosphorous nucleus holding it in place.

Silicon in Solar Cells

- In to pure silicon we drop the impurities – for example phosphorous
- It is **doping**, to get more free electrons, more free carriers
- when doped with phosphorous, the resulting silicon is called **N-type** ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon is.

Silicon in Solar Cells

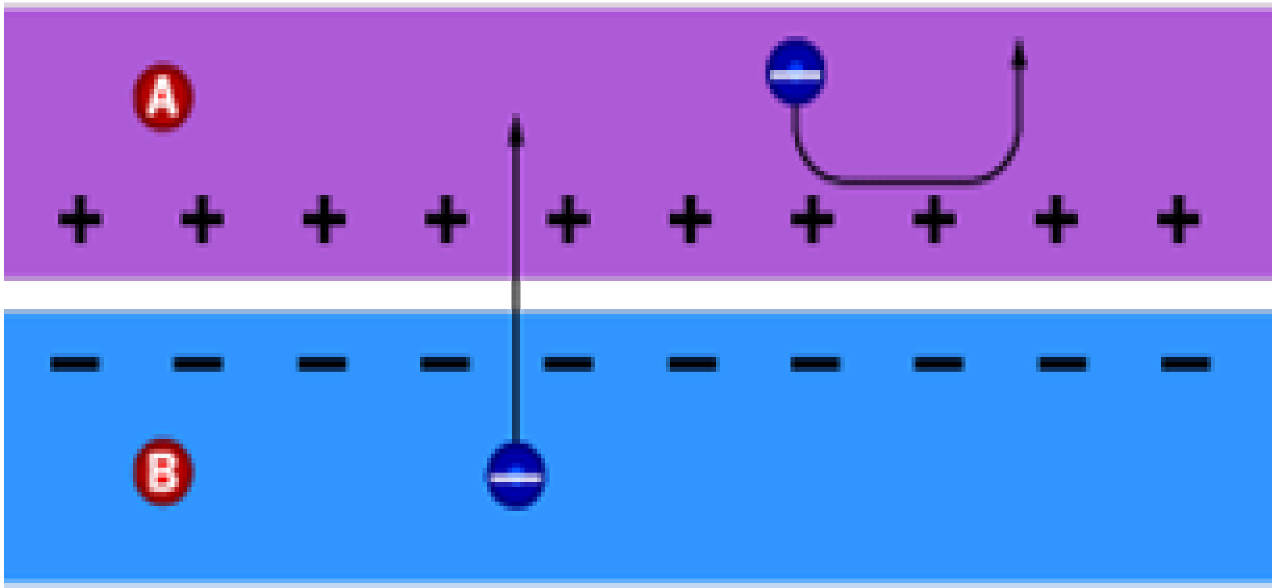
- Actually, only part of our solar cell is N-type.
- The other part is doped with boron, which has only three electrons in its outer shell instead of four, to become **P-type** silicon.
- Instead of having free electrons, P-type silicon ("p" for positive) has free holes. Holes really are just the absence of electrons, so they carry the opposite (positive) charge. They move around just like electrons do.

N-type Plus P-type Silicon

- The interesting part starts when you put N-type silicon together with P-type silicon.
- Every PV cell has at least one **electric field,** and this field forms when the N-type and P-type silicon are in contact.
- The free electrons in the N side, which have been looking all over for holes to fall into, see all the free holes on the P side, and there's a mad rush to fill them in.

N-type Plus P-type Silicon

- This electric field acts as a diode, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill -- electrons can easily go down the hill (to the N side), but can't climb it (to the P side).


A
B

When Light Hits the Cell

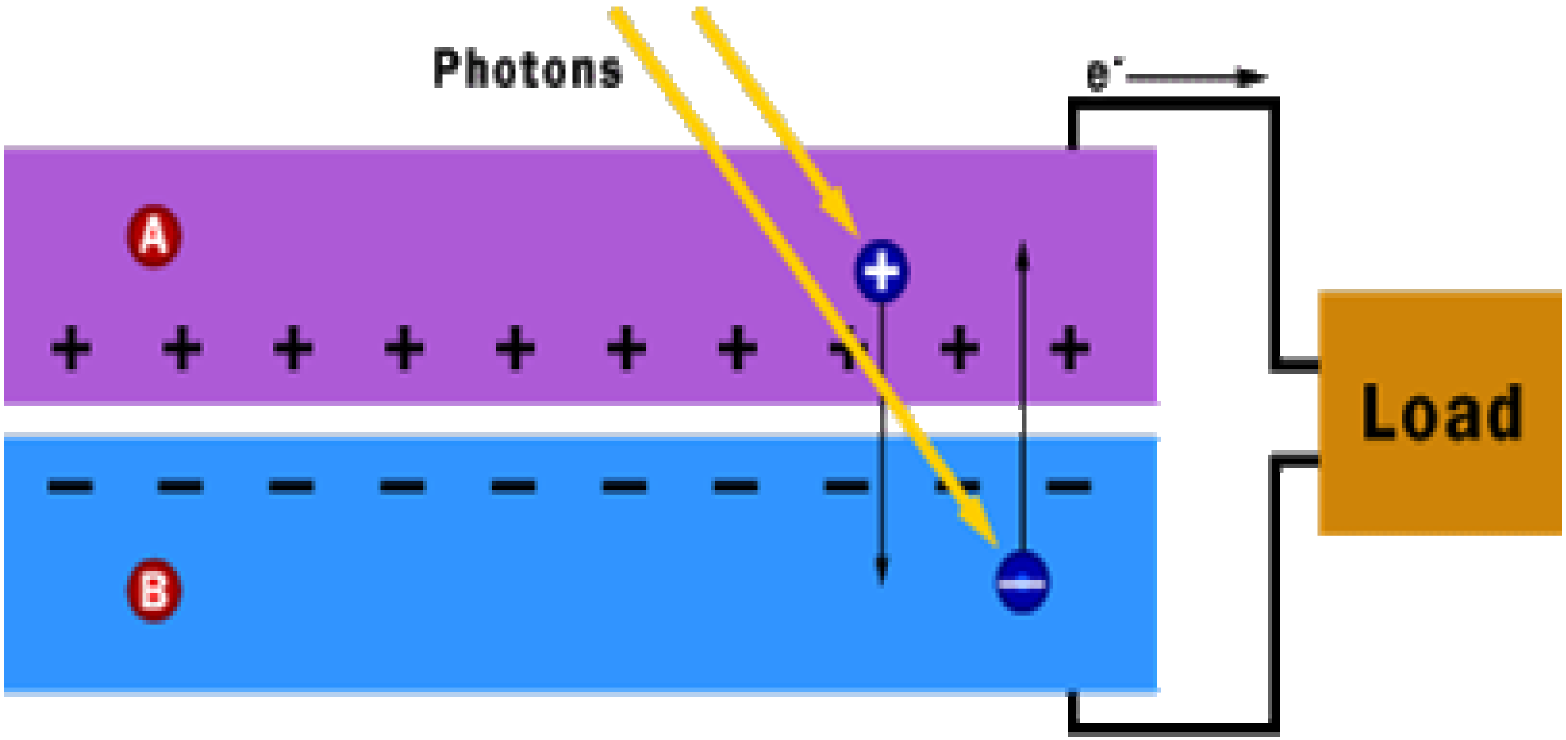
- When light, in the form of photons, hits our solar cell, its energy frees electron-hole pairs.

- Each photon with enough energy will normally free exactly one electron, and result in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if we provide an external current path, electrons will flow through the path to their original side (the P side) to unite with holes that the electric field sent there, doing work for us along the way.

When Light Hits the Cell

- The electron flow provides the **current**, and the cell's electric field causes a **voltage**. With both current and voltage, we have **power**, which is the product of the two.

When Light Hits the Cell



How much sunlight energy does our PV cell absorb?

- Unfortunately, the most that our simple cell could absorb is around 25 percent, and more likely is **15 percent or less**.

Energy Loss

- Visible light is only part of the electromagnetic spectrum. Electromagnetic radiation is not monochromatic -- it is made up of a range of different wavelengths, and therefore energy levels.

Energy Loss

- Light can be separated into different wavelengths, and we can see them in the form of a rainbow. Since the light that hits our cell has photons of a wide range of energies, it turns out that some of them won't have enough energy to form an electron-hole pair. They'll simply pass through the cell as if it were transparent. Still other photons have too much energy. Only a certain amount of energy, measured in electron volts (eV) and defined by our cell material (about 1.1 eV for crystalline silicon), is required to knock an electron loose.

Energy Loss

- We call this the **band gap energy** of a material. If a photon has more energy than the required amount, then the extra energy is lost (unless a photon has twice the required energy, and can create more than one electron-hole pair, but this effect is not significant). These two effects alone account for the loss of around 70 percent of the radiation energy incident on our cell.

Energy Loss

- Why can't we choose a material with a really low band gap, so we can use more of the photons? Unfortunately, our band gap also determines the strength (voltage) of our electric field, and if it's too low, then what we make up in extra current (by absorbing more photons), we lose by having a small voltage. Remember that power is voltage times current. The optimal band gap, balancing these two effects, is around **1.4 eV** for a cell made from a single material.

Energy Loss

- We have other losses as well. Our electrons have to flow from one side of the cell to the other through an external circuit. We can cover the bottom with a metal, allowing for good conduction, but if we completely cover the top, then photons can't get through the opaque conductor and we lose all of our current (in some cells, transparent conductors are used on the top surface, but not in all). If we put our contacts only at the sides of our cell, then the electrons have to travel an extremely long distance (for an electron) to reach the contacts. Remember, silicon is a semiconductor -- it's not nearly as good as a metal for transporting current.

Energy Loss

- Its internal resistance (called **series resistance**) is fairly high, and high resistance means high losses. To minimize these losses, our cell is covered by a metallic contact grid that shortens the distance that electrons have to travel while covering only a small part of the cell surface. Even so, some photons are blocked by the grid, which can't be too small or else its own resistance will be too high.

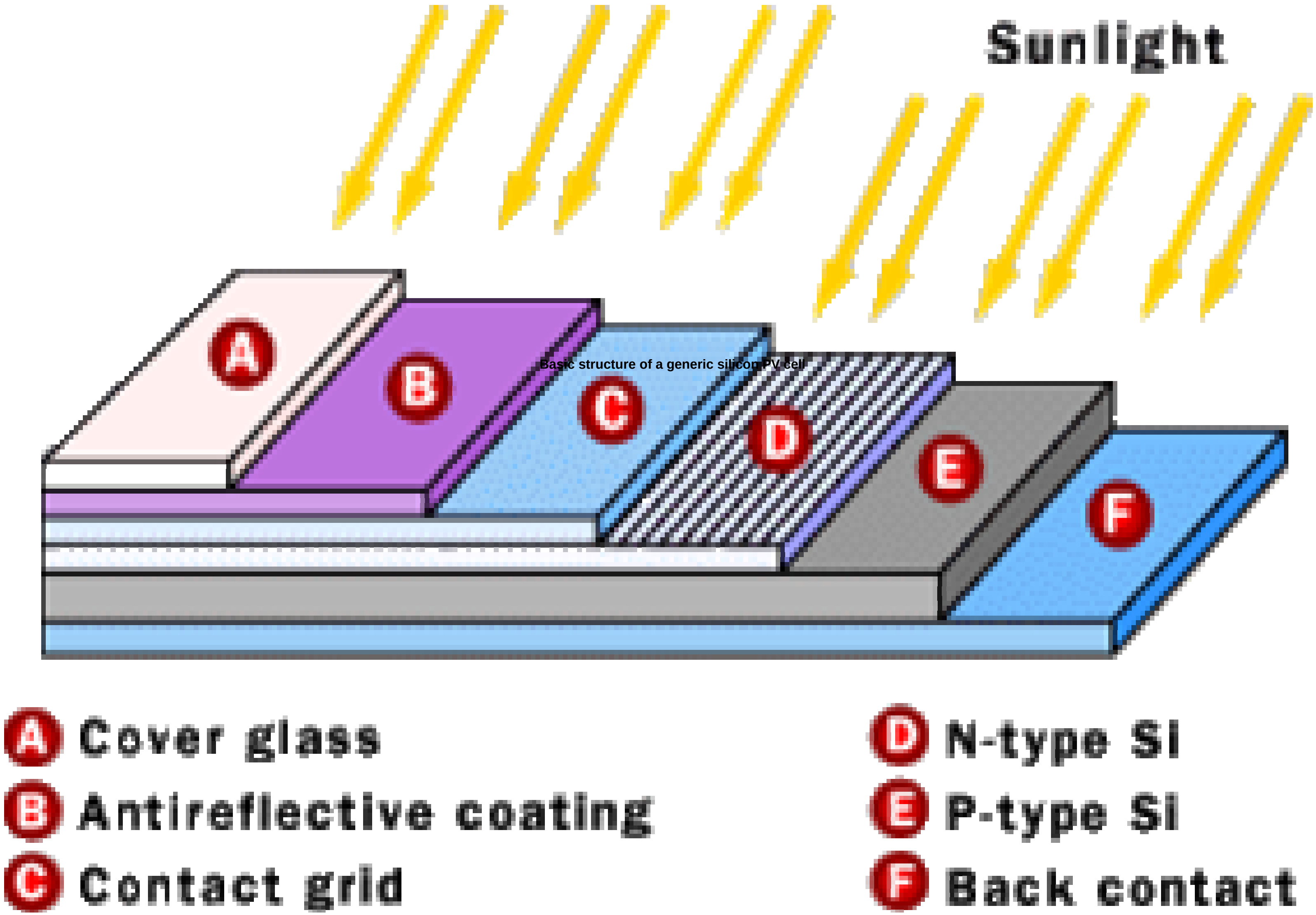
Finishing the Cell

- There are a few more steps left before we can really use our cell. Silicon happens to be a very shiny material, which means that it is very reflective. Photons that are reflected can't be used by the cell. For that reason, an **antireflective coating** is applied to the top of the cell to reduce reflection losses to less than 5 percent.

Finishing the Cell

- The final step is the **glass cover plate** that protects the cell from the elements. PV modules are made by connecting several cells (usually 36) in series and parallel to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with a glass cover and positive and negative terminals on the back.

Finishing the Cell



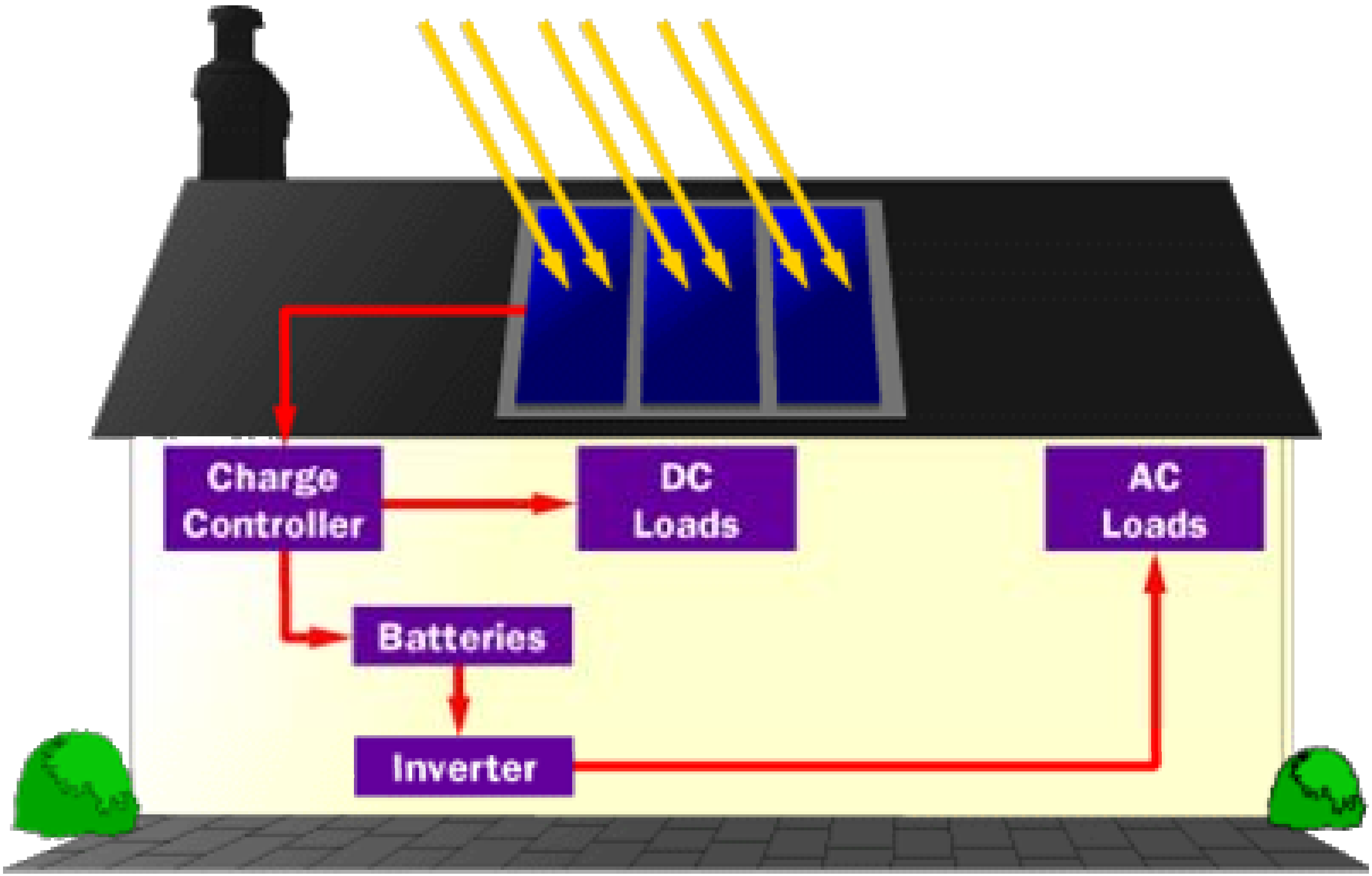
Other materials

- Amorphous silicon, which has no crystalline structure, is also used, again in an attempt to reduce production costs. Other materials used include gallium arsenide, copper indium diselenide and cadmium telluride. Since different materials have different band gaps, they seem to be "tuned" to different wavelengths, or photons of different energies.

Other materials

- One way **efficiency** has been improved is to use two or more layers of different materials with different band gaps. The higher band gap material is on the surface, absorbing high-energy photons while allowing lower-energy photons to be absorbed by the lower band gap material beneath. This technique can result in much higher efficiencies. Such cells, called **multi-junction cells**, can have more than one electric field.

Powering a House



Powering a House

- Throw in the mounting hardware, wiring, junction boxes, grounding equipment, overcurrent protection, DC and AC disconnects and other accessories and you have yourself a system.
- Electrical codes must be followed (there's a section in the National Electrical Code just for PV), and it's highly recommended that the installation be done by a licensed electrician who has experience with PV systems. Once installed, a PV system requires very little maintenance (especially if no batteries are used), and
- It will provide electricity cleanly and quietly for 20 years or more.

Costs

- Currently, an installed PV system will cost somewhere around 8 **euros per peak Watt**.

Costs

- Small home, and it is estimated that its 3.6-kW PV system covers about half of the total electricity needs (this system doesn't use batteries -- it's connected to the grid). Even so, at 8 euros per Watt, this installed system would cost you around 28.000 euros.

Possibilities

- 6.5 cm^2 of solar cells can generate about 70 milliwatts of electricity, and that it might be able to do this for about five hours a day on average (depending on latitude, average rainfall and other environmental factors).
- An 4,047 m^2, size solar panel in an hour, can produce about 440,000 watt-hours of electricity. In a five-hour day, it can produce 2.2-million watt-hours, and in a year it can produce about 800-million watt-hours of electricity.

How many solar cells would I need in order to provide all of the electricity that my house needs?

- The solar panel contains 4 cells, and each of them can produce 0.45 volts and 100 milliamps, or 45 milliwatts. With these solar cells you can generate 45 milliwatts in 6.45 square cm. For the sake of discussion, let's assume that a panel can generate 70 milliwatts per 6.45 square cm. To calculate how many square cm of solar panel you need for a house, you need to know:
- How much power the house consumes on average
- Where the house is located (so you can calculate mean solar days, average rainfall, etc.). This question is impossible to answer unless you have a specific location in mind. We'll assume that on an average day the solar panels generate their maximum power for 5 hours.

Calculation

- A "typical home" in Europe can use either electricity or gas to provide heat -- heat for the house, the hot water, the clothes dryer and the stove/oven. If you were to power a house with solar electricity, you would certainly use gas appliances because solar electricity is so expensive. This means that what you would be powering with solar electricity are things like **the refrigerator, the lights, the computer, the TV, stereo equipment, motors in things like furnace fans and the washer, etc**. Let's say that all of those things average out to 600 watts on average. Over the course of 24 hours, you need 600 watts * 24 hours = 14,400 watt-hours per day.

Calculation

- From our calculations and assumptions above, we know that a solar panel can generate 70 milliwatts per 6.45 square cm * 5 hours = 350 milliwatt hours per day. Therefore you need about 5.18 meters square. That would cost around 12.500 euros right now. Then, because the sun only shines part of the time, you would need to purchase a battery bank, an inverter, etc., and that often doubles the cost of the installation.

Conclusion

- The thing to remember, however, is that 100 watts per hour purchased from the power grid would only cost about 18 eurocents a day right now, or app. 68 euros a year. That's why you don't see many solar houses unless they are in very remote locations. When it only costs about 68 euros a year to purchase power from the grid, it is hard to justify spending thousands of dollars on a solar system.

Ways to use the Sun energy

- Passiv

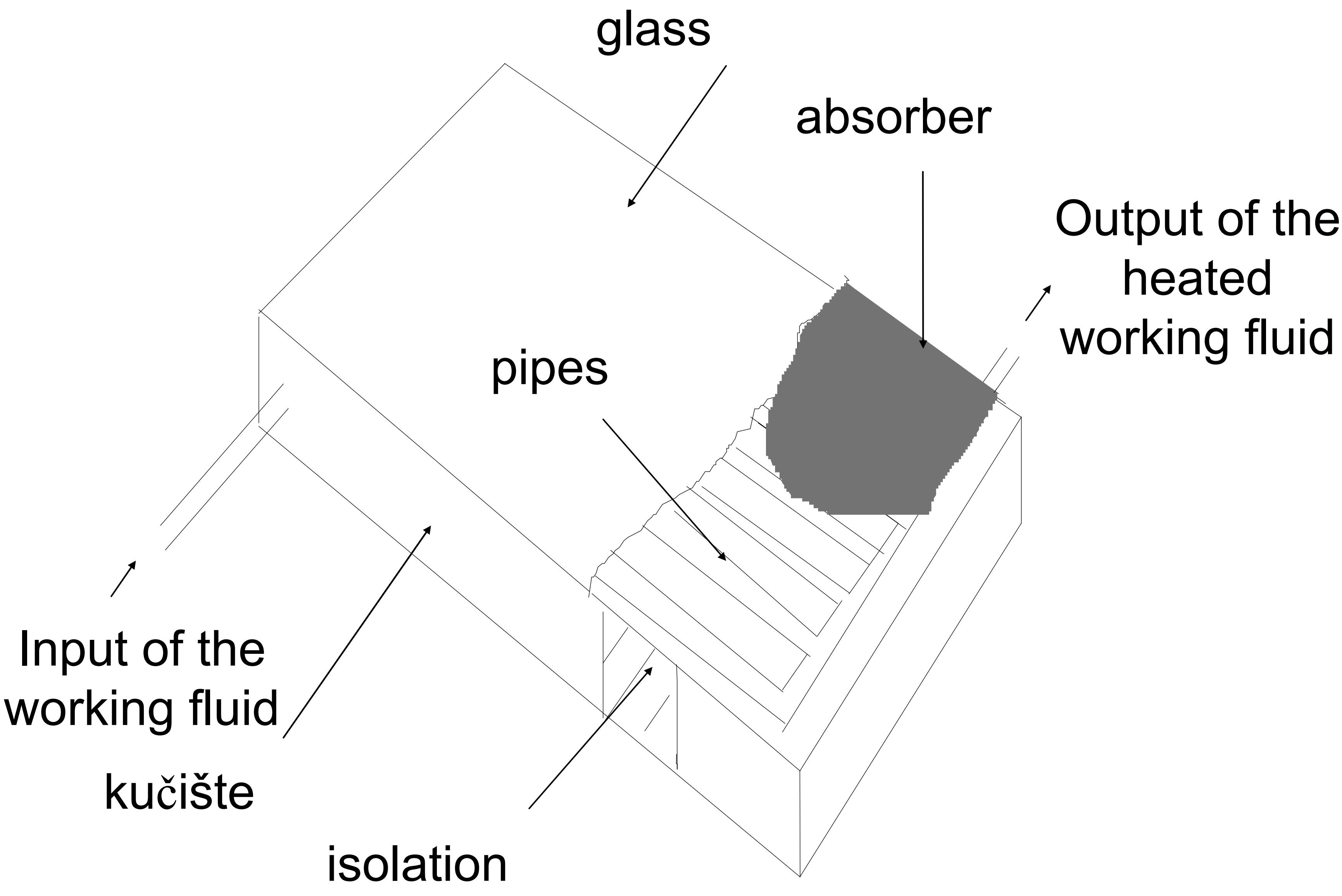
Thousands of years ago, the Anasazi Indians in Colorado incorporated passive solar design in their cliff dwellings.

This home's passive solar design features direct gain heating and clerestory windows for daylighting.

Heat solar collector (HSC)
The equipment intended to transform the solar energy in to the heat energy

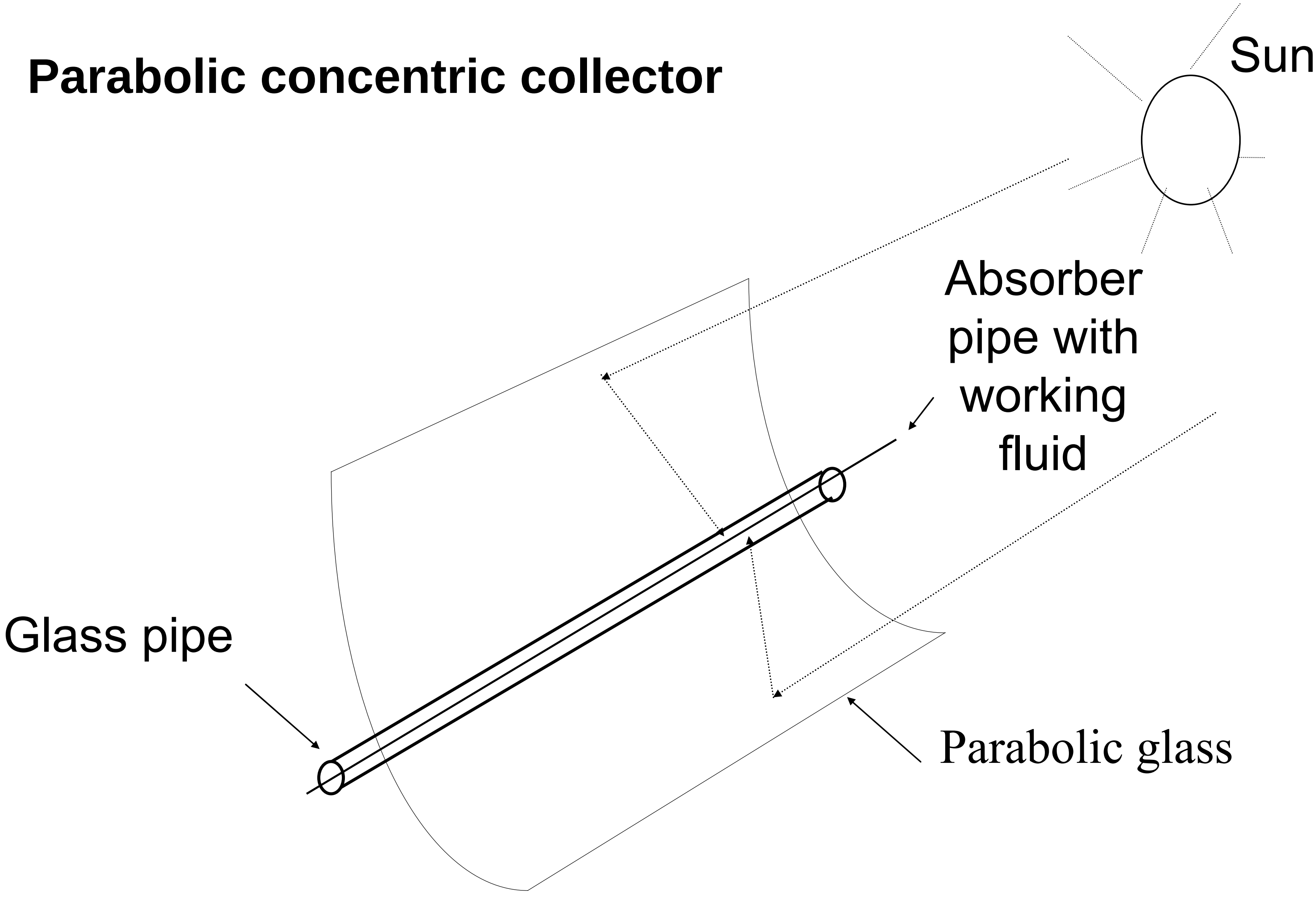
- There are three types of the HSC:
  a) flat collector,
  b) selective collector, and
  c) concentric collector.

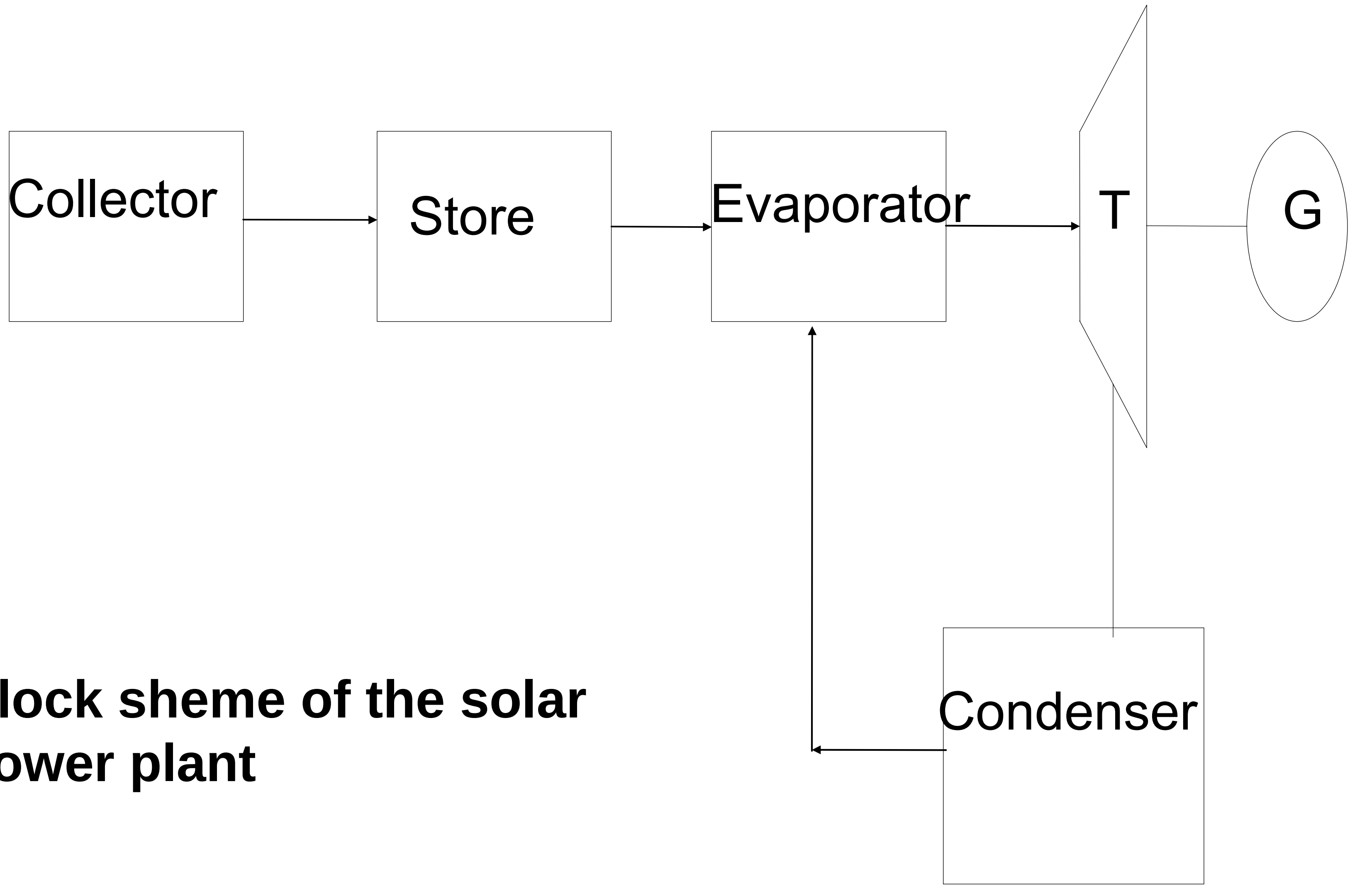
Flat solar heat collector



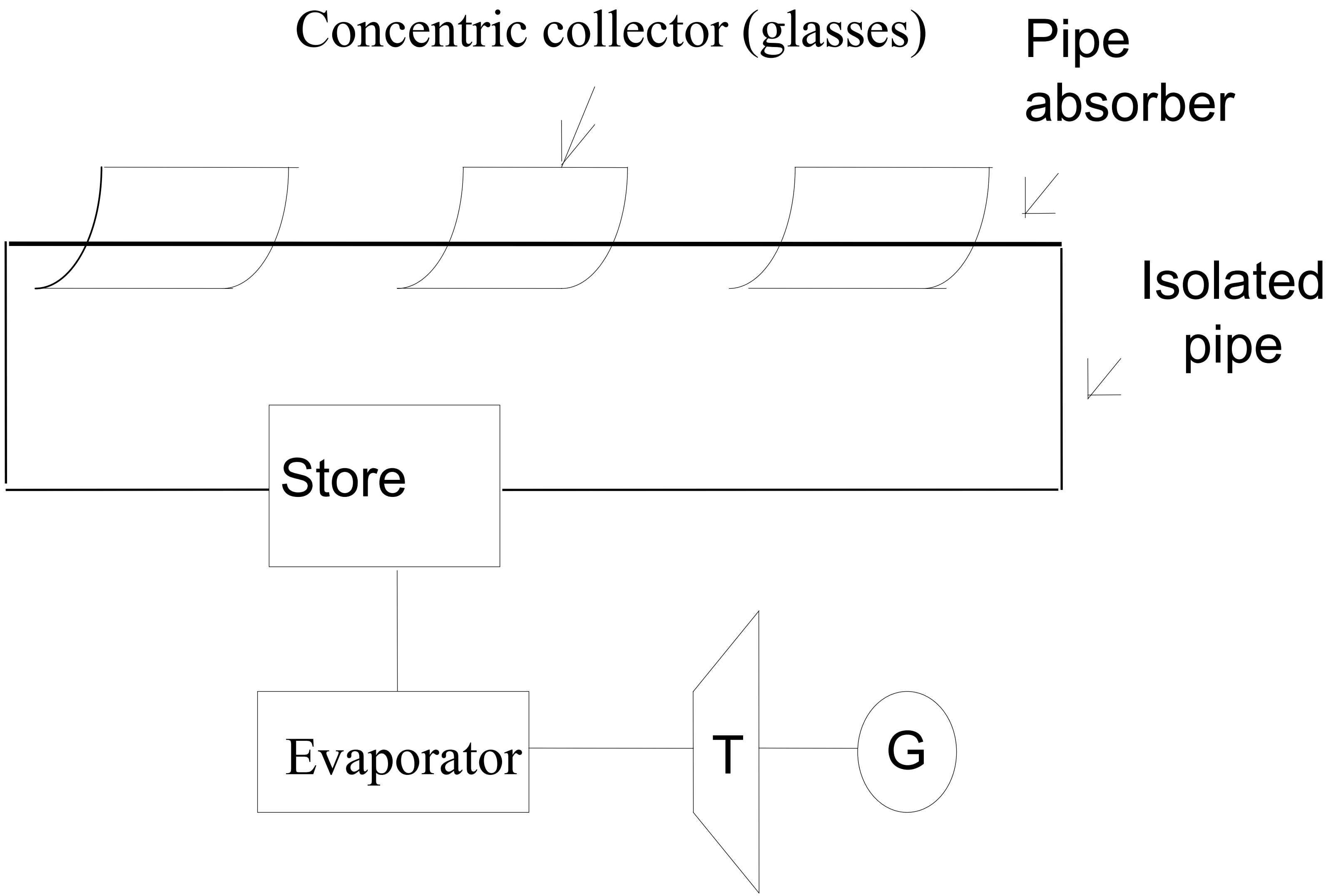
The solar hot water system on this roof in Sarasota, Florida, can provide 40% to 50% of a family's hot water needs.

Parabolic concentric collector





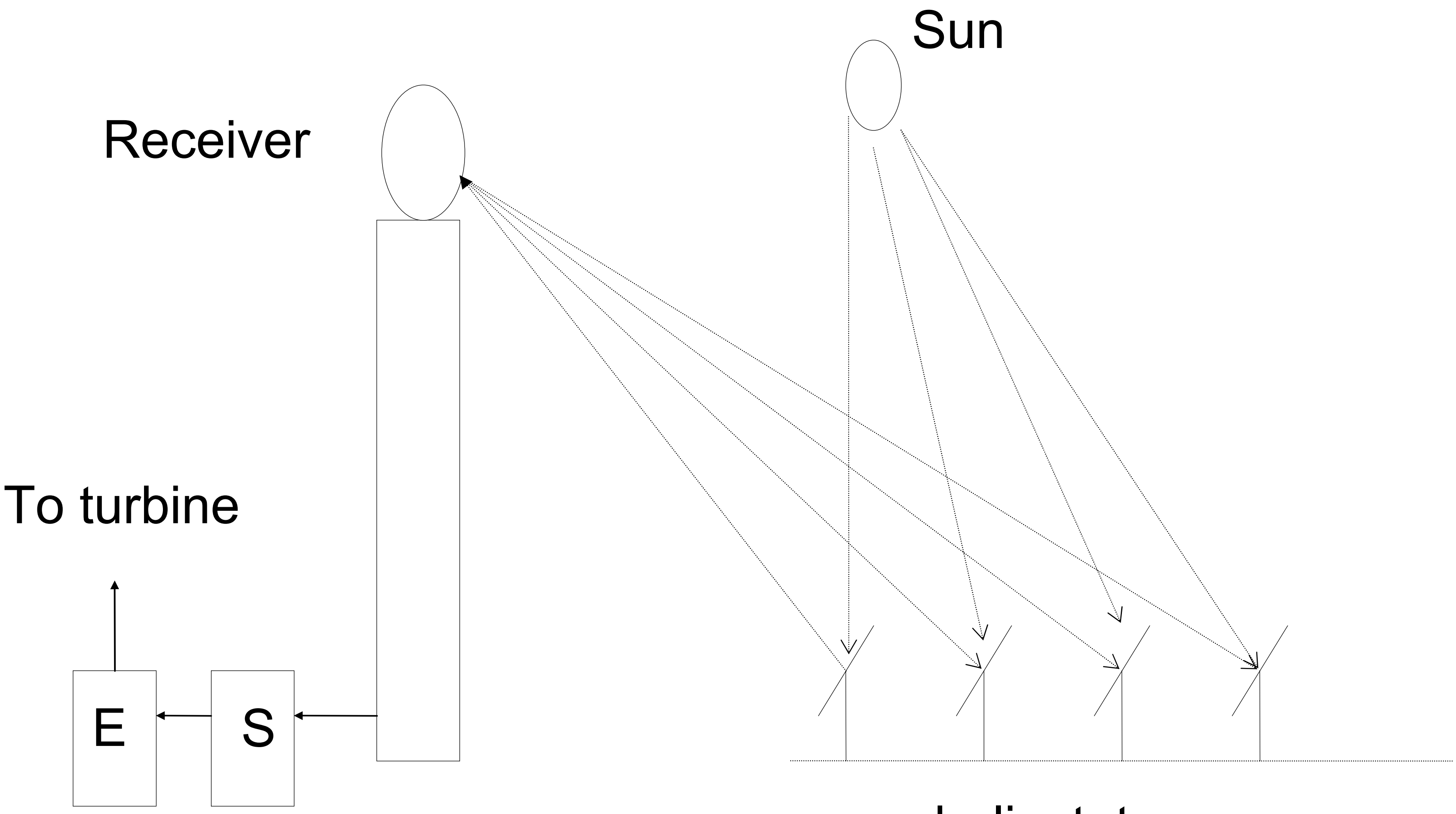
Block sheme of the solar power plant



Solar Power Plant with the Distributed Collectors

A 25-kilowatt Dish Stirling System catches its last rays of light at the end of the day.

Solar Power Plant with the Central Receiver



S - Store
E - Evaporator

There are several ways to store the solar energy :

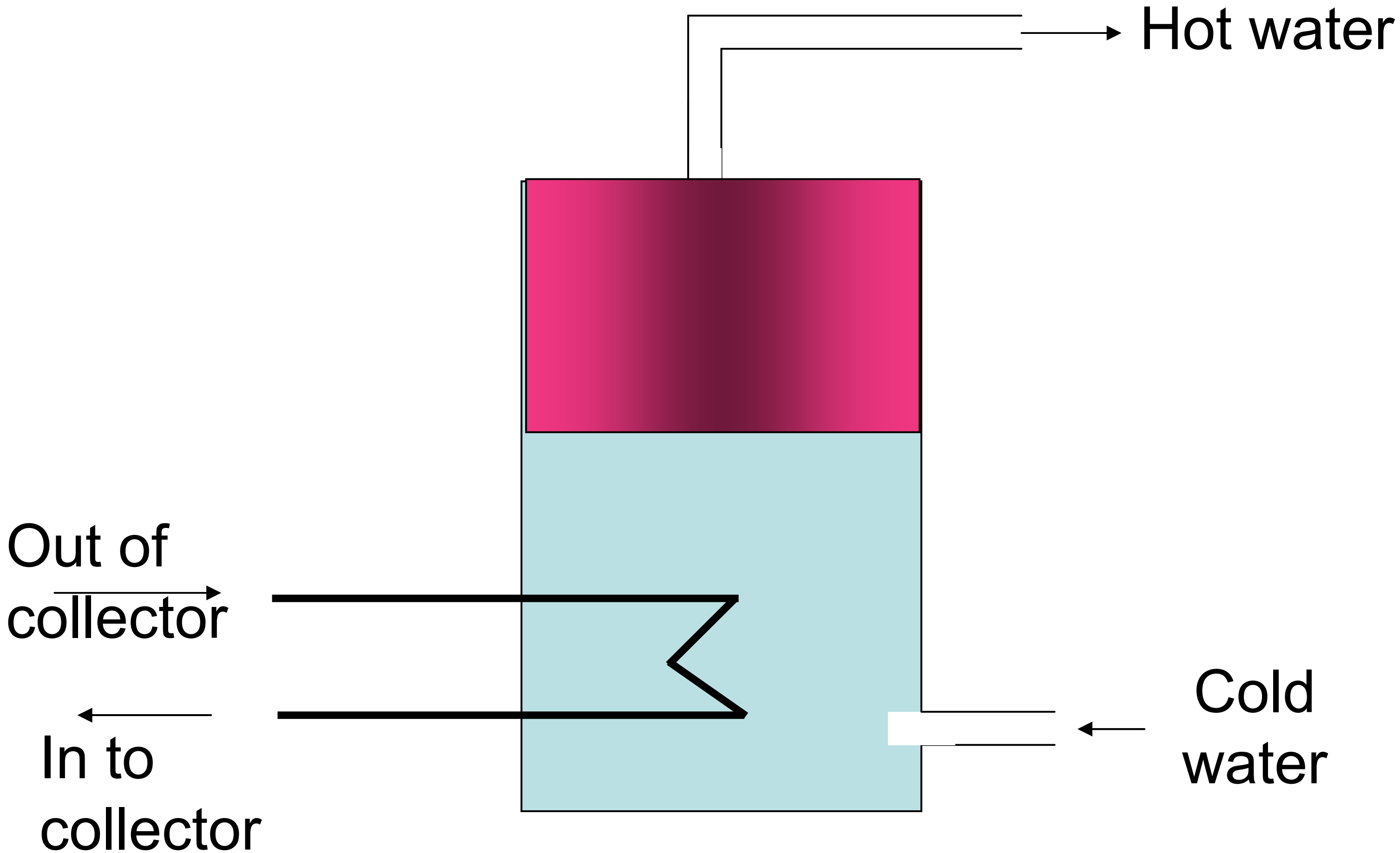
- heating (by heating the specifical materials, and by using the latent heat),
- chemical (reverse chemical reaction),
- thermo-chemical (heat capacity of the isolated volumes of water and land),
- mechanical (fly weel).

1 Storing by means of the heated materials

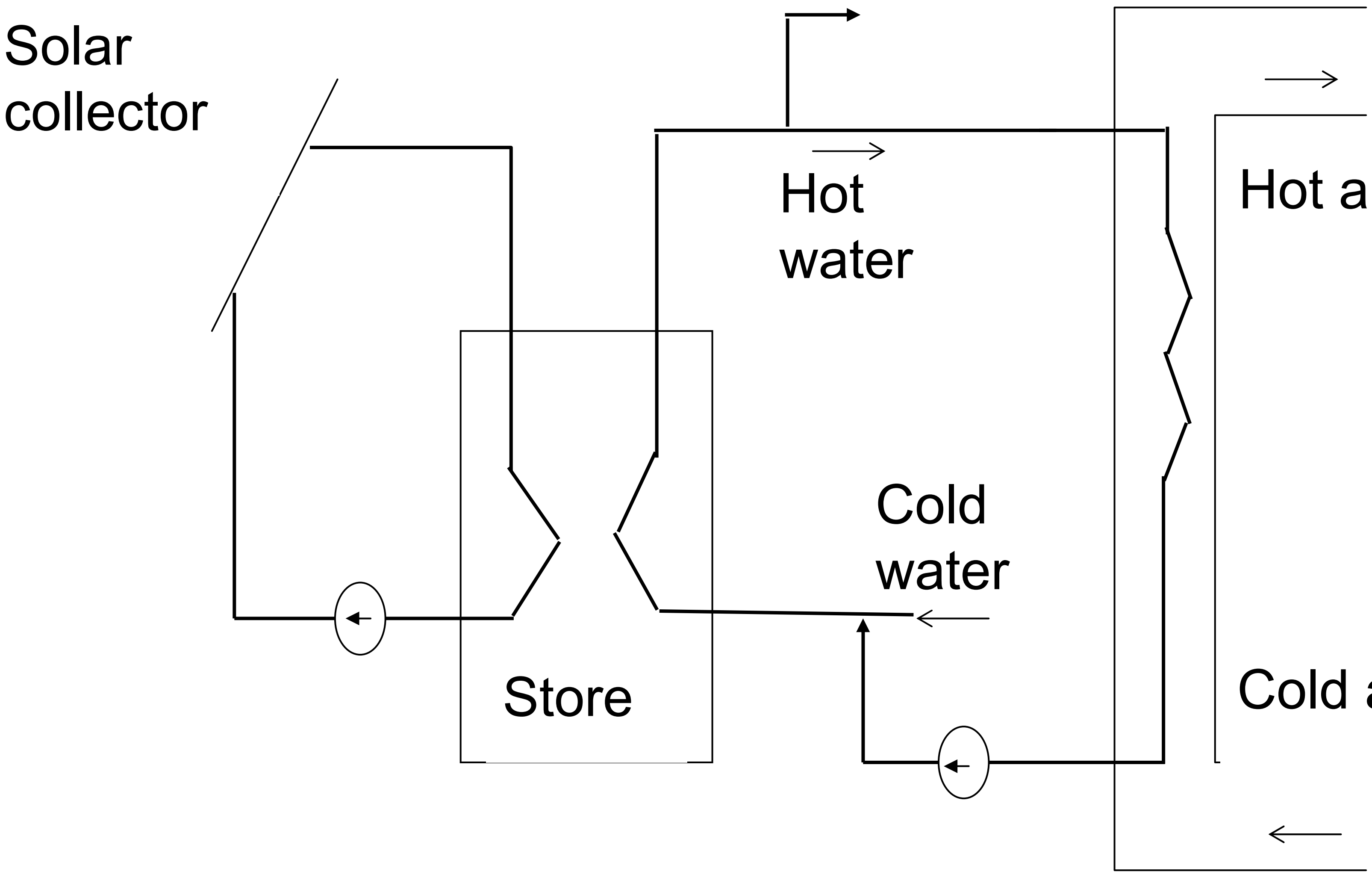
- gustoća (kg/m3),
- specific heat capacity (kJ/kgK),
- volumen heat capacity (J/m3K), and
- conducting (W/mK).

$$V = \frac{Q}{c \cdot \varphi \cdot \Delta T} \; (m^3)$$

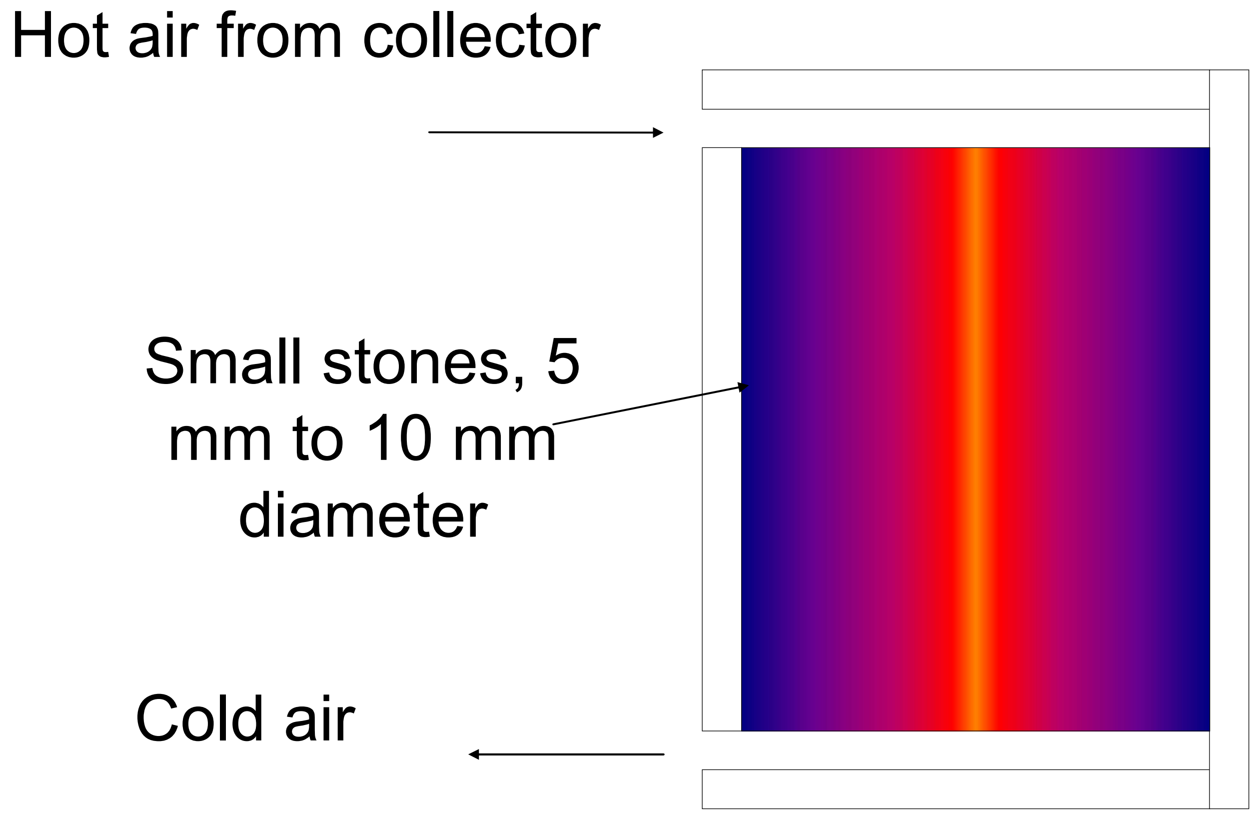
Needed volumen of materials to store the heat Q



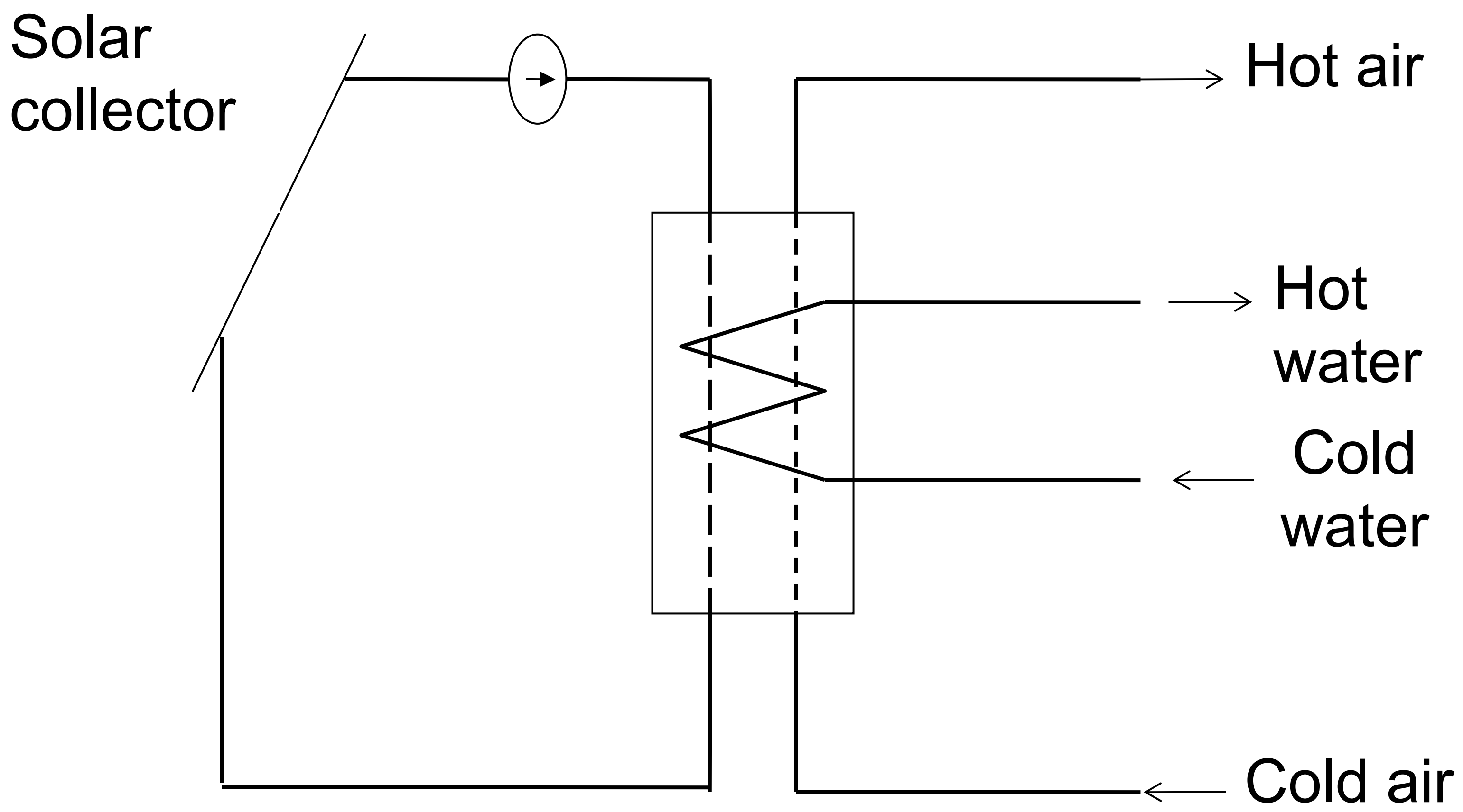
Water Reservoar for the Storing of Sun Energy



Principal Scheme of Cogenerative Solar System



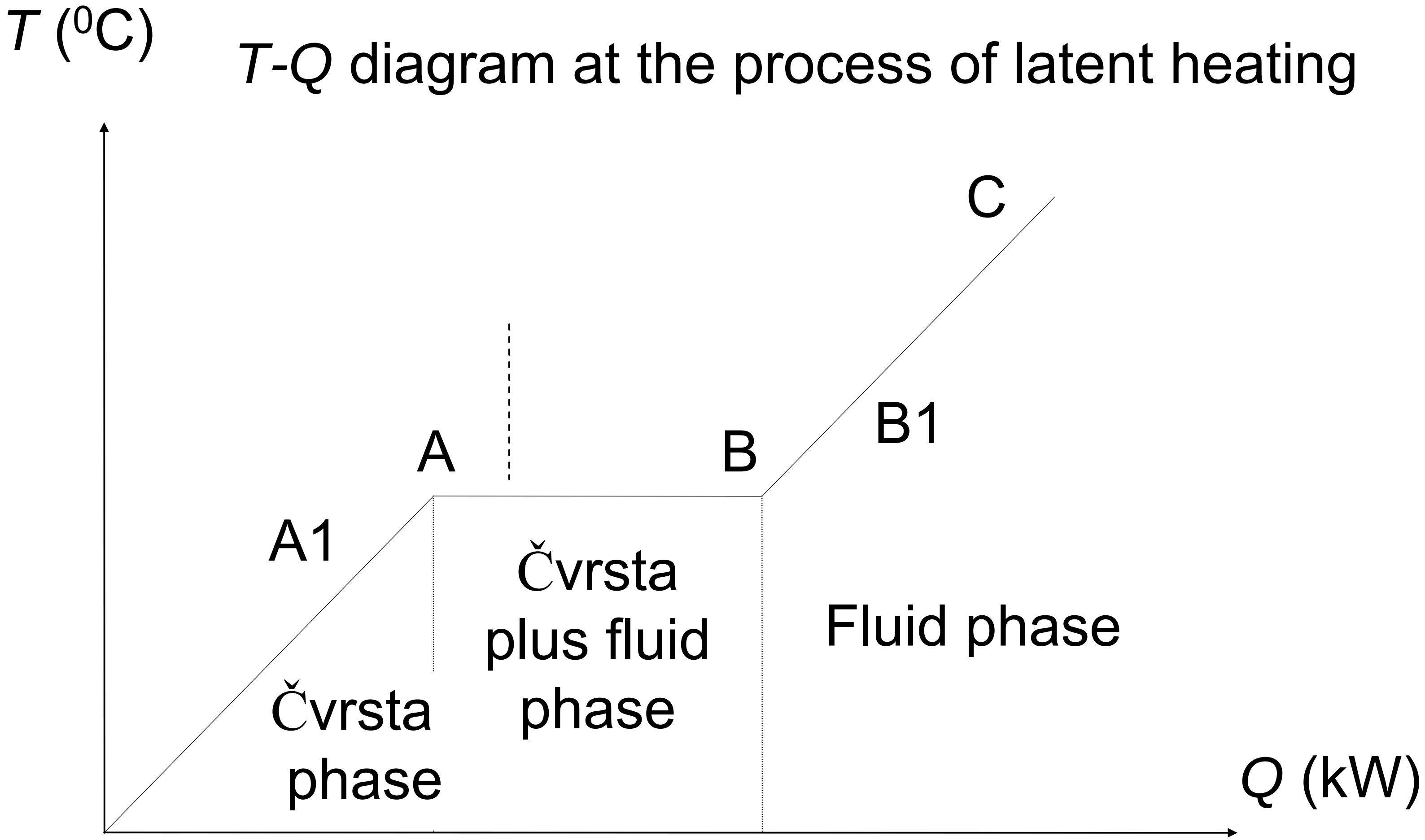
Heat store with the stones as a store medium



Cogenerativ system for air and water heating with the stone heat store

2 Energy of Sun stored by means of the latent heat

T-Q diagram at the process of latent heating



The total amount of heat Q which is delivered to some material into well defined temperature interval :

$$Q = m\int_{T_{A1}}^{T_{A2}} c_1\,dT + mL + \int_{T_B}^{T_{B1}} c_2\,dT$$

m - material mass (kg),
c1 - specific heat capacity of the čvrstog state of material (kJ/kgK),
c2 - specific heat capacity of the fluid state of material (kJ/kgK),and
L – specific heat of transition, i.e. the heat necessary to transfer the stone state of material in to fluid state (kJ/kg).

Appropriate materials for latent heating

- Parafin, and
- Glauber's salt ($Na_2SO_410H_2O$).

For example:

To store 1 MJ of energy, in to temperature range of 20 ^{0}C, we need 3,1 kg Glauber salt.

For the same process, we need 12 kg of water or 60 kg of stones.

3 The Sun Energy storing by means of the reverse chemical reactions

- To melt one amount of salt we need the heat;
- To take out the heat stored into the melted salt we need the process of cooling – in that way we take the heat out
- For these processes the appropriate materials are sulphur acid - H2SO4, kalium-nitrogen salt - KNO3, sodium-nitrogen salt - NaNO3, sodium-sulfpur salt - Na2SO4

Past projects have included a 20 kilowatt building integrated photovoltaic system in Woody Creek, Colorado. The entire roof of a barn was covered in PV roof shingles.

Energy Facts

- **Energy Consumption**

Though accounting for only 5 percent of the world's population, Americans consume 26 percent of the world's energy. *(American Almanac)*

In 1997, U.S. residents consumed an average of 12,133 kilowatt-hours of electricity each, almost nine times greater than the average for the rest of the world. *(Grist Magazine)*

Worldwide, some 2 billion people are currently without electricity. *(U.S. Department of Energy)*

Total U.S. residential energy consumption is projected to increase 17 percent from 1995 - 2015. *(U.S. Energy Information Administration)*

- World energy consumption is expected to increase 40% to 50% by the year 2010, and the global mix of fuels--renewables (18%), nuclear (4%), and fossil (78%)--is projected to remain substantially the same as today; thus global carbon dioxide emissions would also increase 50% to 60%.

- Among industrialized and developing countries, Canada consumes per capita the most energy in the world, the United Sates ranks second, and Italy consumes the least among industrialized countries.

- Developing countries use 30% of global energy. Rapid population growth, combined with economic growth, will rapidly increase that percentage in the next 10 years.

- The World Bank estimates that investments of $1 trillion will be needed in this decade and upwards of $4 trillion during the next 30 years to meet developing countries' electricity needs alone.

- America uses about 15 times more energy per person than does the typical developing country.

- **Residential appliances**, including **heating and cooling equipment and water heaters**, consume **90% of all energy** used in the U.S. residential sector.

- The United States spends about $440 billion annually for energy. Energy costs U.S. consumers $200 billion and U.S. manufacturers $100 billion annually.

Global Warming

- Worldwide, 1995 was the warmest year since global temperatures were first kept in 1856. This supports the near consensus among climatologists that emissions of carbon dioxide and other gases are causing global warming. *(Chivilan and Epstein,* Boston Globe*)*

- On average, 16 million tons of carbon dioxide are emitted into the atmosphere every 24 hours by human use worldwide. *(U.S. Department of Energy)*

- Carbon emissions in North America reached 1,760 million metric tons in 1998, a 38 percent increase since 1970. They are expected to grow another 31 percent, to 2,314 million metric tons, by the year 2020.

- The United States is the world's largest single emitter of carbon dioxide, accounting for 23 percent of energy-related carbon emissions worldwide. *(U.S. Department of Energy)*

- An average of 23,000 pounds of carbon dioxide are emitted annually in each American home. *(U.S. Environmental Protection Agency)*

- The transportation sector consumed 35% of the nation's energy in 1990; this sector is 97% dependent on petroleum.

- Fossil fuels are depleted at a rate that is 100,000 times faster than they are formed.

Estimated electrical energy for 100.000 householders equipped with heat-solar collectors and photo-voltage panels is about 2000 GWh

- Reduction of NO_x for 4000 tons and SO_2 for 6000 tons

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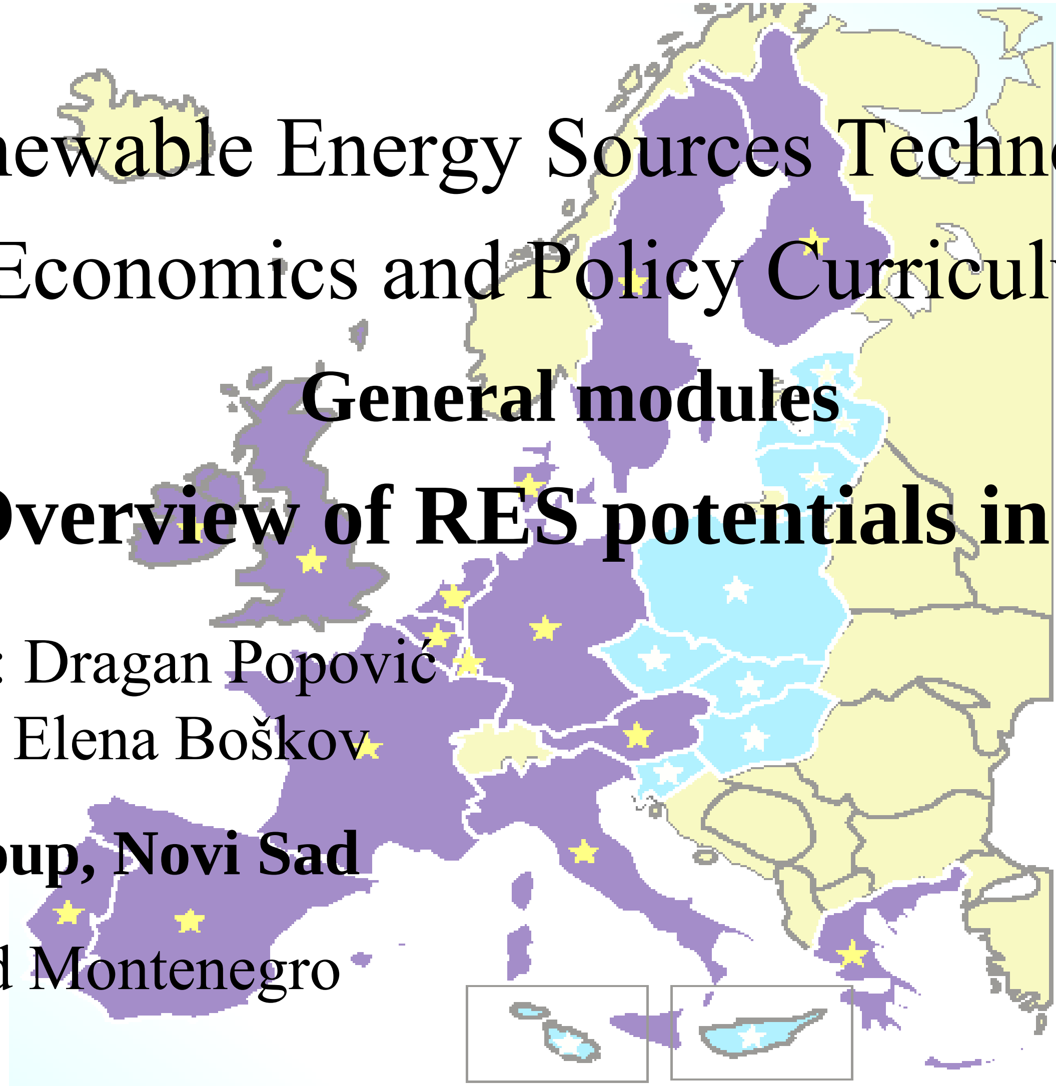

Renewable Energy Sources Technology, Economics and Policy Curriculum

General modules

Overview of RES potentials in EU

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Introduction

- Natural flows of renewable resources are immense in comparison with global energy use, this holds both from a theoretical and technical perspective
- However the level of their future use will primarily depend on the economic performance of technologies utilizing these flows
- analysis of renewable energy potentials performs detailed investigations in theoretical, physical, technological, environmental and economic aspects

Historical development of electricity generation from RES

- Electricity produced by renewable energy sources in the EU-15 countries amounted to 363 TWh in 2002, corresponding to a share of 13.4% of gross electricity consumption. The relevant figures for the EU-10 are 17.7 TWh and 5.6%, respectively.

- Wind energy is the RES-E source with the highest yearly growth rates of about 38% in electricity production over the last ten years. Especially in EU-15 countries, wind energy is predominant in recent portfolios of ‘new’ RES, whilst biomass is prominently represented in some of the new member states.

Methodology for the assessment of potentials

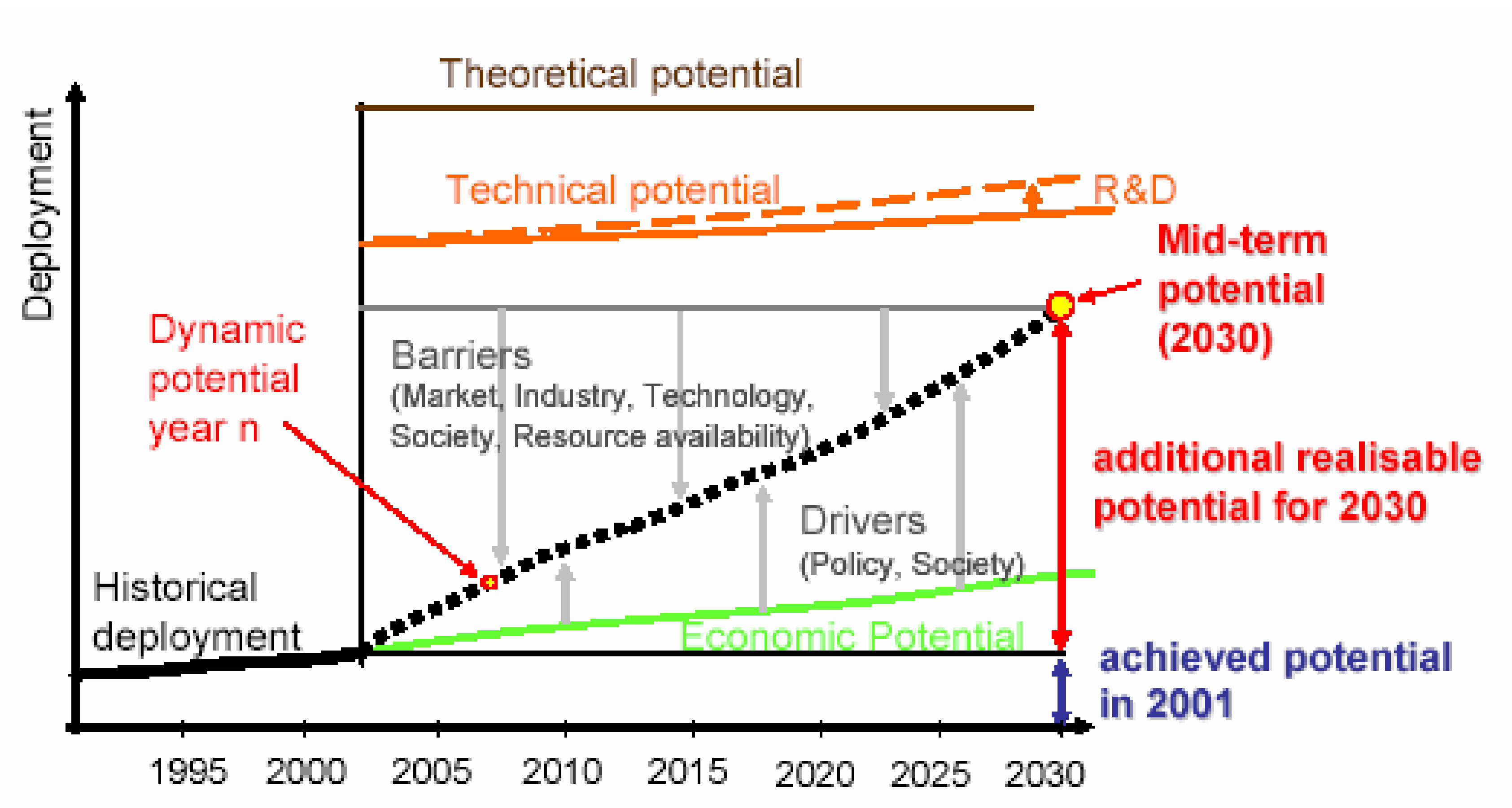
Definition of potential terms

***Theoretical potential*: general physical parameters have to be taken into account; the upper limit of what can be produced from a certain energy resource from a theoretical point-of-view, of course, based on current scientific knowledge;**

***Technical potential*: technical boundary conditions are considered; dynamic context**

***Realizable potential*: the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active, general parameters are taken into account.**

***Mid-term potential*: equal to the realizable potential in the year 2030.**


Theoretical potential
Technical potential
R&D
Mid-term potential (2030)
Deployment
Dynamic potential year n
Barriers
(Market, Industry, Technology, Society, Resource availability)
additional realisable potential for 2030
Drivers
(Policy, Society)
Historical deployment
Economic Potential
achieved potential in 2001
1995
2000
2005
2010
2015
2020
2025
2030

More on approaches

- In most cases a **'top-down'** approach seems suitable (e.g. for wind energy, photovoltaics)
- First step: the technical potential for one technology in one country for 2030 has to be derived by determining the total useable energy flow of a technology
- Second step: the midterm potential for the year 2030 is determined by taking into consideration the technical feasibility, social acceptance, planning aspects, growth rate of industry / market and market distortions
- The additional mid-term potential is determined by the mid-term potential minus existing penetration plus decommissioning of existing plants.

- For a few technologies, a **'bottom-up'** approach would be the preferable option (e.g. for geothermal electricity), i.e. by looking at every single site (or band) where energy production seems possible and by considering various barriers and drivers in a dynamic context, the additional mid-term potential is derived. The accumulated value of each single band yields in the additional potential.

Photovoltaics

-Energy source characterized by a large potential, which can be realized from a technical point-of-view. The recommended approach for the assessment of the (additional) realizable mid-term potential is based on the following categorization of PV plant:

- PV on roofs (building integrated),
- PV on facades (building integration),
-PV on fields (no building integration).

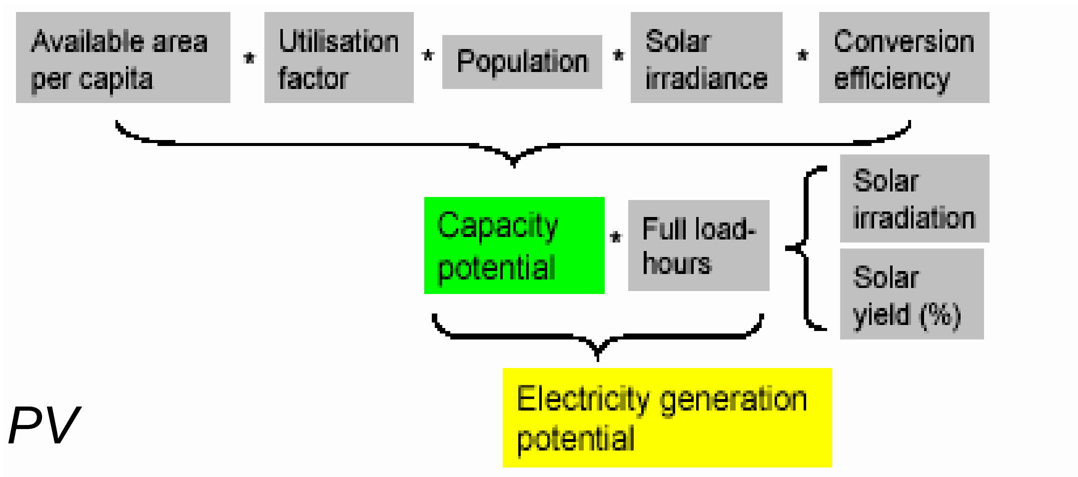
Economic aspects are the main obstacles to tapping this potential.

Annual Solar Energy Potential

Region	Minimum Exajoules	Maximum Exajoules
North America	181	7,410
Latin America and Caribbean	112	3,385
Western Europe	**25**	**914**
Central and Eastern Europe	**4**	**154**
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	371	9,528
Pacific Asia	41	994
South Asia	38	1,339
Centrally planned Asia	115	4,135
Pacific OECD	72	2,263
TOTAL	**1,575**	**49,837**

Note: The minimum and maximum reflect different assumptions on annual clear sky irradiance, annual average sky clearance, and available land area.

1. Assessment of the *capacity potential*:
- *building integrated PV*



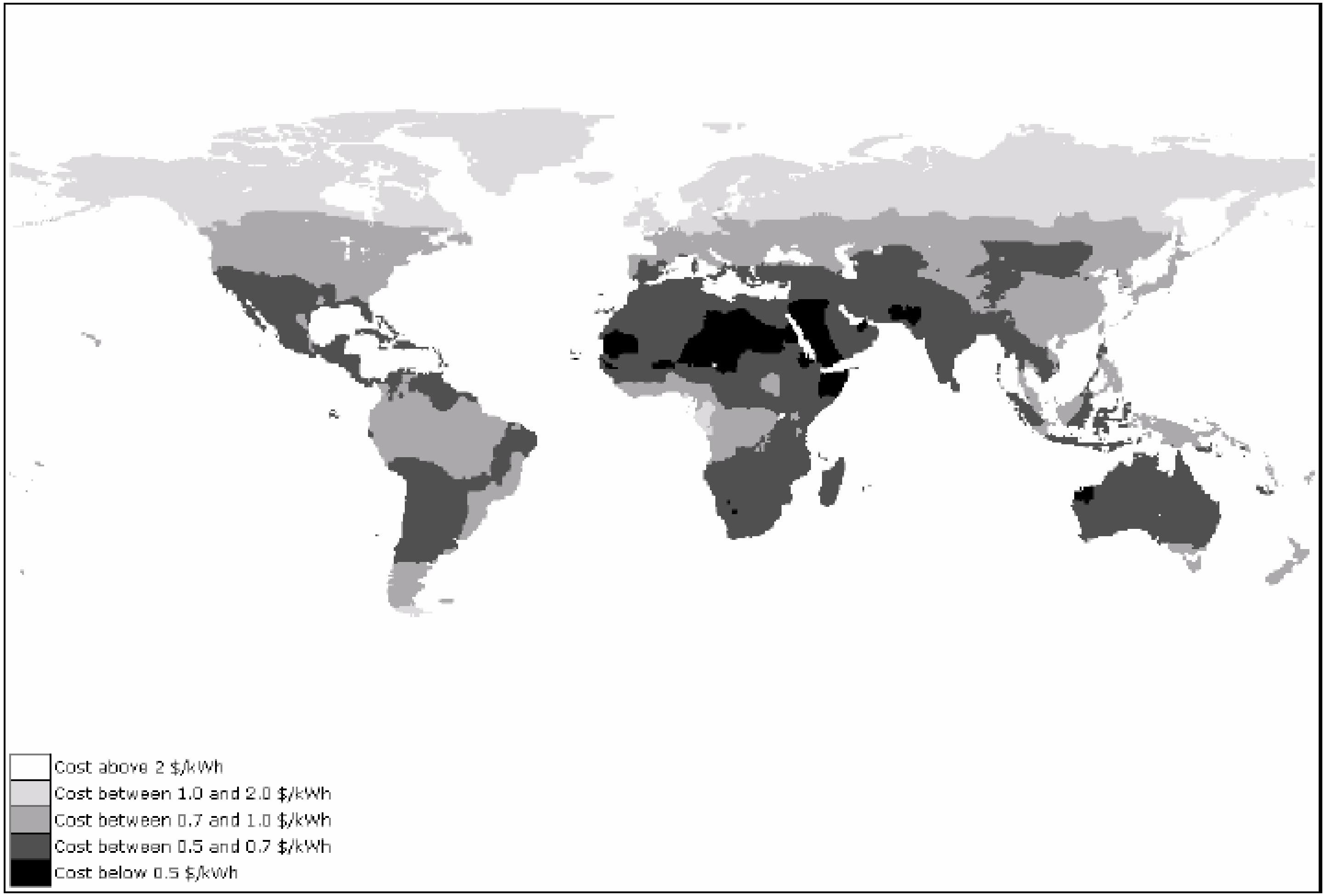
- *non-building integrated PV*

2. Total *primary energy potential* = equal to the electricity generation potential;

3. maximum achievable potential of electricity from PV is limited to 8% of expected gross electricity consumption in 2020

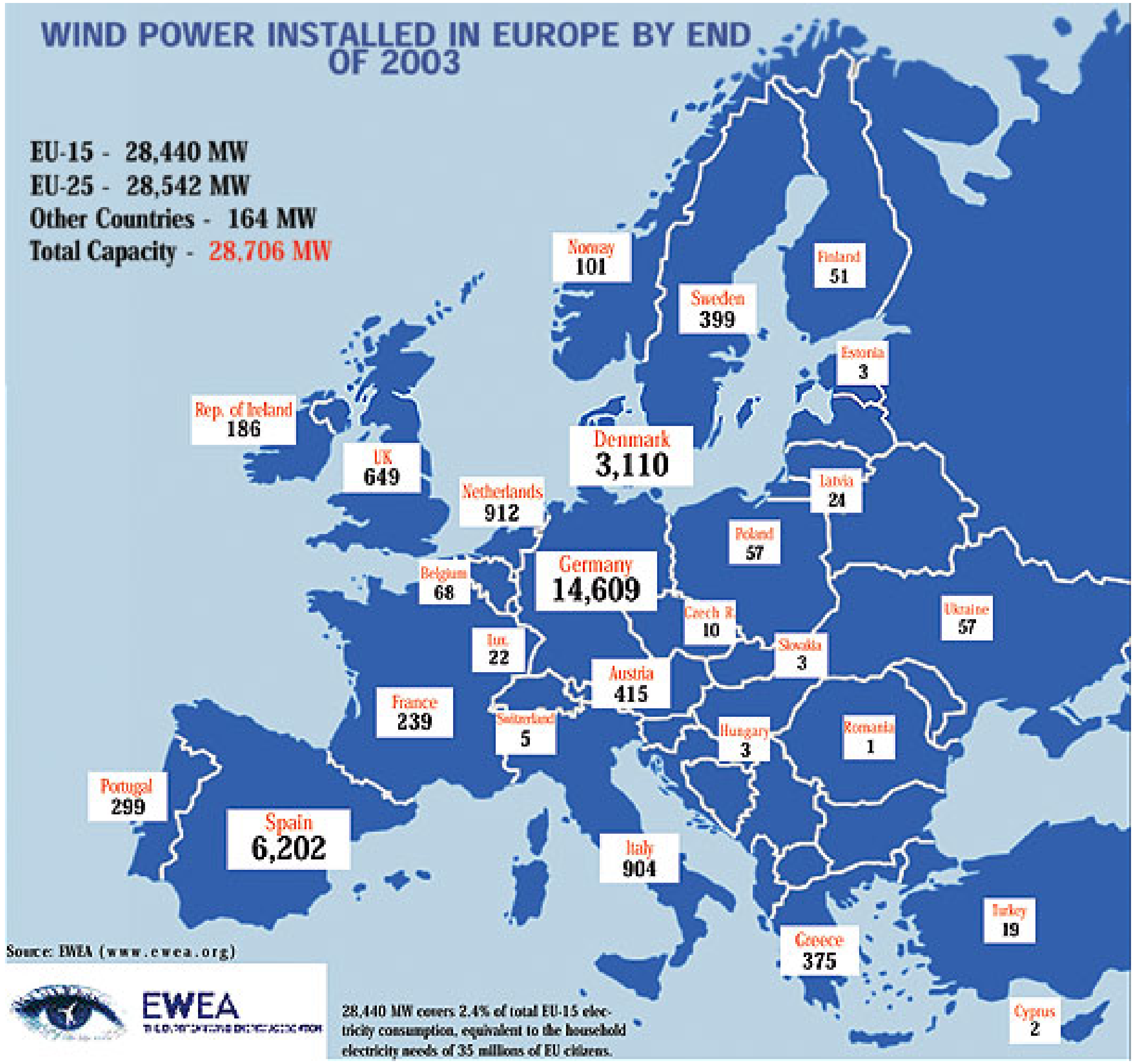
4. mid-term potential is calculated by subtraction of the already achieved potential

Geographical Distribution of Present Costs for Solar Electricity



Wind energy

- **important factors include the percentage of land exposed to the wind resource and land-use and environmental restrictions**
- **amount of potential electricity that can be generated is dependent on several factors, including the spacing between wind turbines, the assumed efficiency of the machines, the turbine hub height, and the estimated energy losses**
- **electricity production from grid-connected wind turbines has been growing at an impressive rate of about 30 percent per year**
- **gradual growth in the unit size of commercial machines, from 30 kilowatts of generating capacity in the 1970s (rotor diameter 10 meters) to 5 megawatts (110 to 120 meters diameter) and more at present**


WIND POWER INSTALLED IN EUROPE BY END OF 2003
EU-15 - 28,440 MW
EU-25 - 28,542 MW
Other Countries - 164 MW
Total Capacity - 28,706 MW
Norway 101
Finland 51
Sweden 399
Estonia 3
Rep. of Ireland 186
UK 649
Denmark 3,110
Netherlands 912
Latvia 24
Poland 57
Belgium 68
Germany 14,609
Czech R. 10
Ukraine 57
Lux. 22
Slovakia 3
Austria 415
France 239
Switzerland 5
Hungary 3
Romania 1
Portugal 299
Spain 6,202
Italy 904
Turkey 19
Greece 375
Cyprus 2
Source: EWEA (www.ewea.org)
EWEA
28,440 MW covers 2.4% of total EU-15 electricity consumption, equivalent to the household electricity needs of 35 millions of EU citizens.

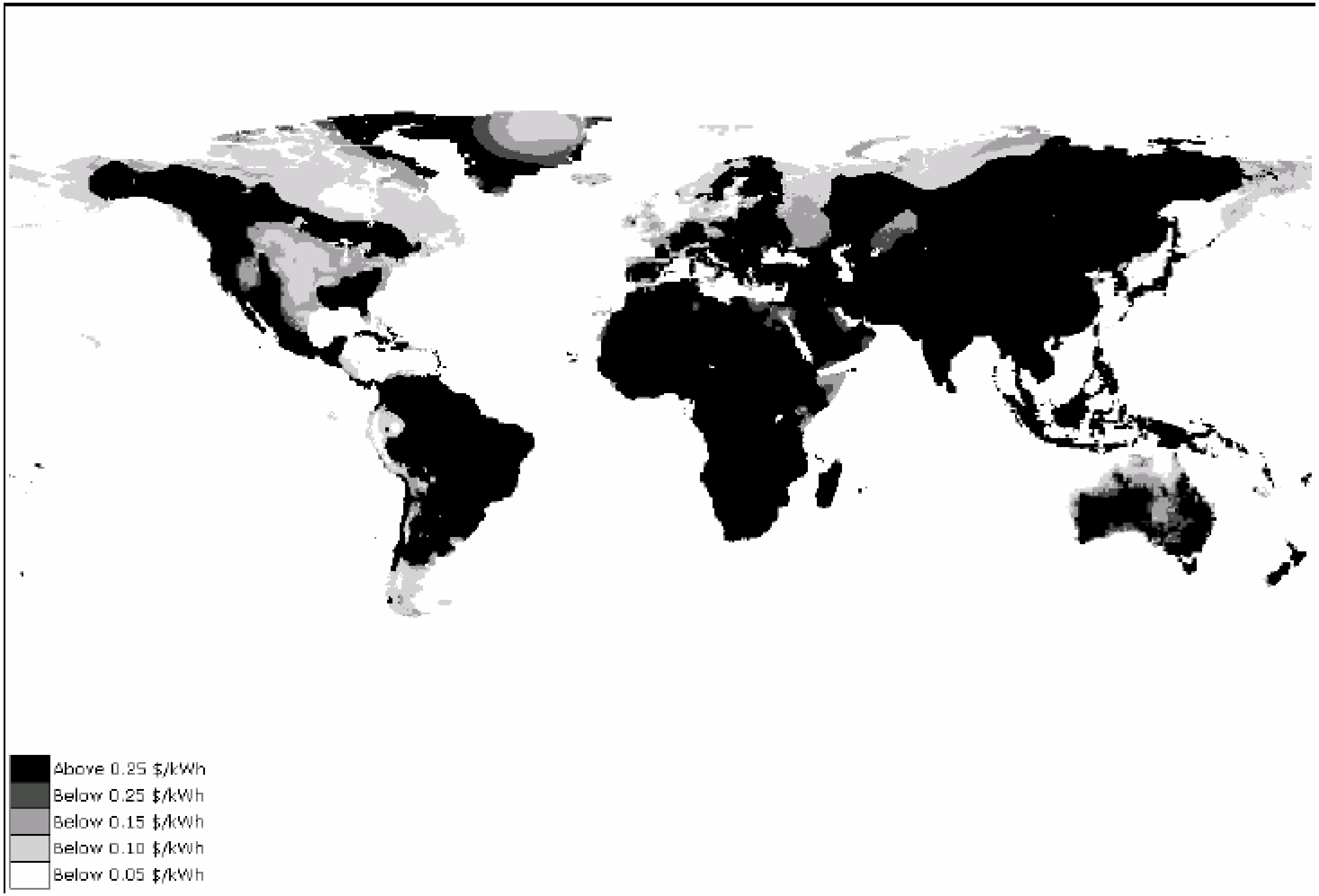
Wind offshore:

- overall technical potential for offshore wind energy seems to be huge in parts of Europe, especially in the North Sea
- realizable potentials: keeping in mind important ‘constrain indicators’ like e.g. ‘percentage of wind power on total electricity consumption’, ‘wind power (capacity) potential per capita’
- economic data: Area classes

Wind onshore:

- technical potential for on-shore wind energy is high in various EU countries, namely France, UK – but several barriers have to be overcome, e.g. public acceptance, power grid constraints
- realizable potential: wind maps can be applied to the define areas characterized by certain ‘wind characteristics’
- electricity potential: calculations are based by appliance of a power curve for a common on-site turbine in size of 2 MW

Geographical Distribution of Present Costs for Wind Electricity



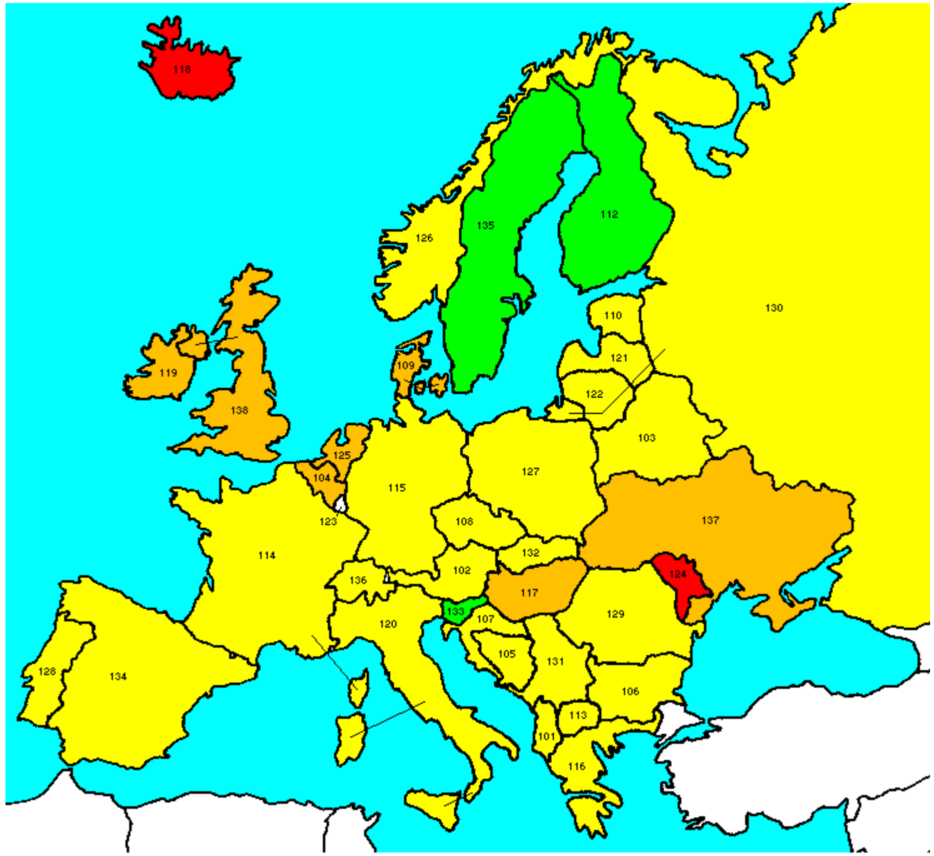
Biomass

•The present biomass contribution to the total world energy needs approaches 14 % (50 EJ/y on a total contribution of 406 EJ/y) and is essentially based on agro-forestry residues and natural forest

•An issue of availability but sustainable management, conversion, and delivery to the market in the form of modern and affordable energy services

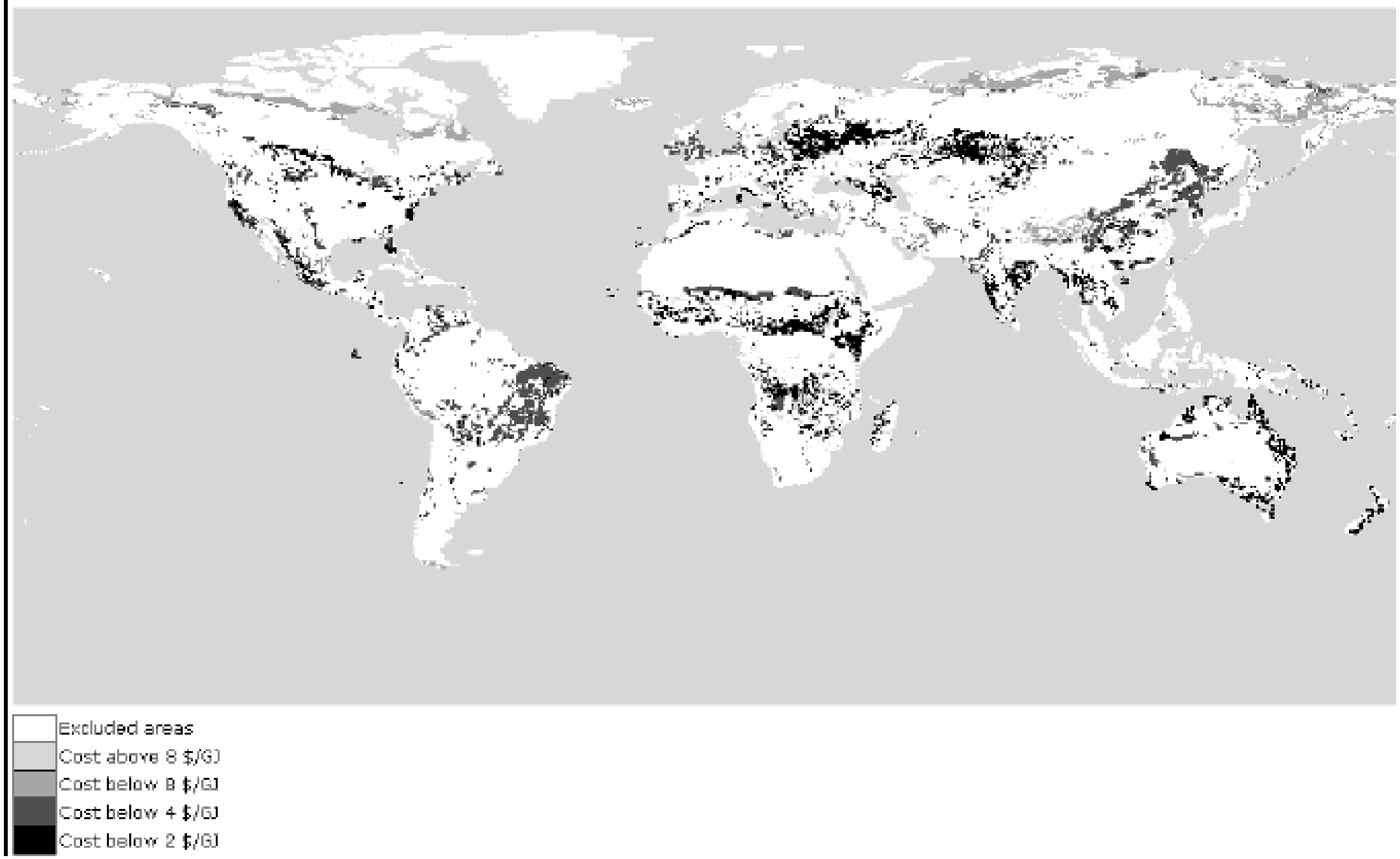
- Gaseous Biomass: Biogas, Landfill gas, Sewage gas
- Solid biomass: Forestry products, Agricultural products, residues
- Benefit: storage
- Key technical challenges to be overcome in order for bio based industrial products to be cost-competitive are finding new technology and reducing the cost of technology for converting biomass into desired bio based industrial products

Productive forest area in relation to the total area of the country



>50%
25...50%
10...25%
<10%

Geographical Distribution of Present Costs for Biomass Energy



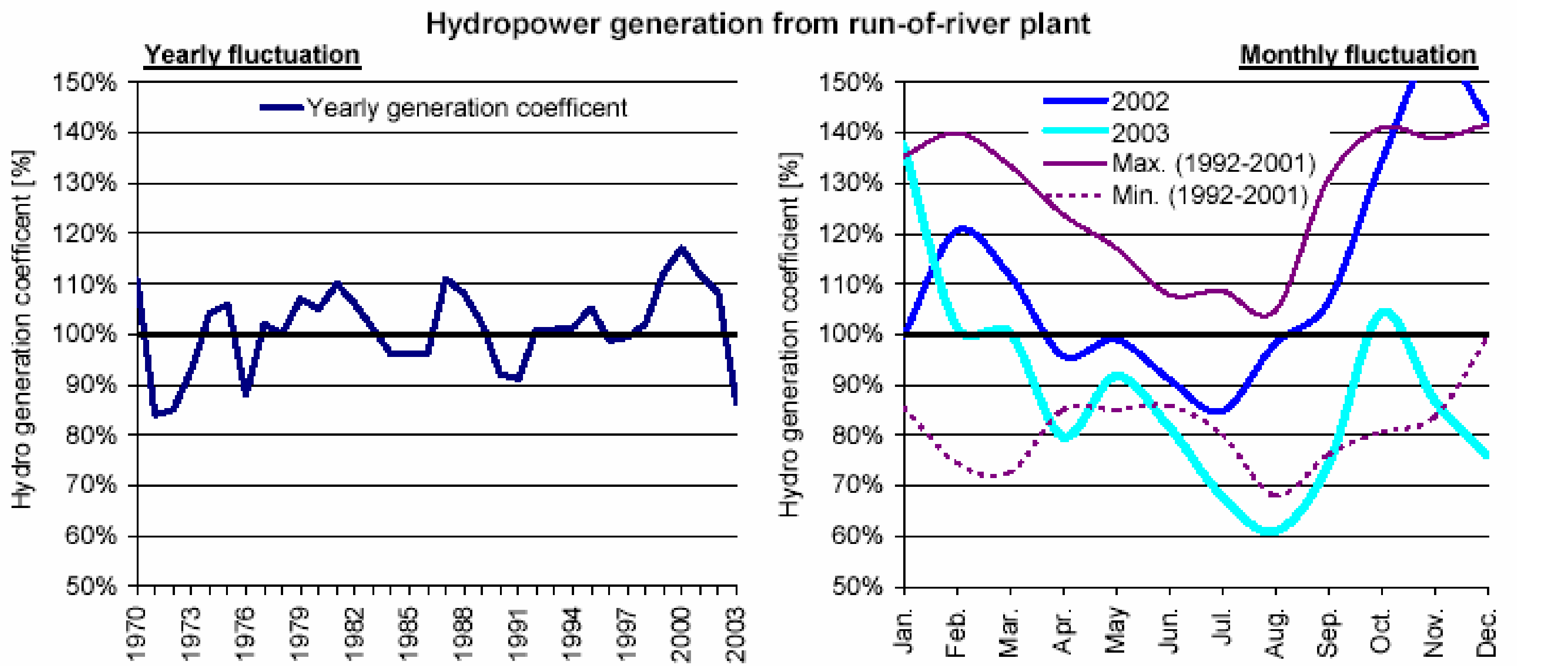
Hydropower

- mature technology: small-scale hydropower can expect further technical development
- requires detailed information on the local and geographical factors of runoff water: available head, flow volume per unit of time
- the most important impacts are the displacement of local communities, changes in fish amount and fish biodiversity, sedimentation, biodiversity perturbation, water quality standards, human health deterioration, and downstream impacts
- distinguish between the potential for new plant and the potential for upgrading or refurbishment of existing plant
- Large scale vs. small scale hydropower

The estimated hydropower potential and exploitation in EU

Countries	Economical Feasible Potential (GWh/a)	Production from Hydro Plants (GWh/a)	Exploitation Ratio (%)
Selected 15 EU Countries of which	390.000	320.000	82
Austria	50.000	38.000	76
France	72.000	70.000	97
Germany	25.000	25.000	100
Italy	55.000	52.000	95
Spain	40.000	35.000	88
Sweden	85.000	68.000	80
Selected non-EU countries of which	480.000	250.000	52
Romania	30.000	16.000	53
Switzerland	36.000	34.000	94
Turkey	120.000	40.000	33

Source: IEA, Eurostat, Hydropower & Dams and own interpolation/computations



Annual (left-hand side) and monthly (right-hand side) volatility of electricity generation from run-of-river hydropower plant in Austria generation from run-of-river hydropower plant in Austria

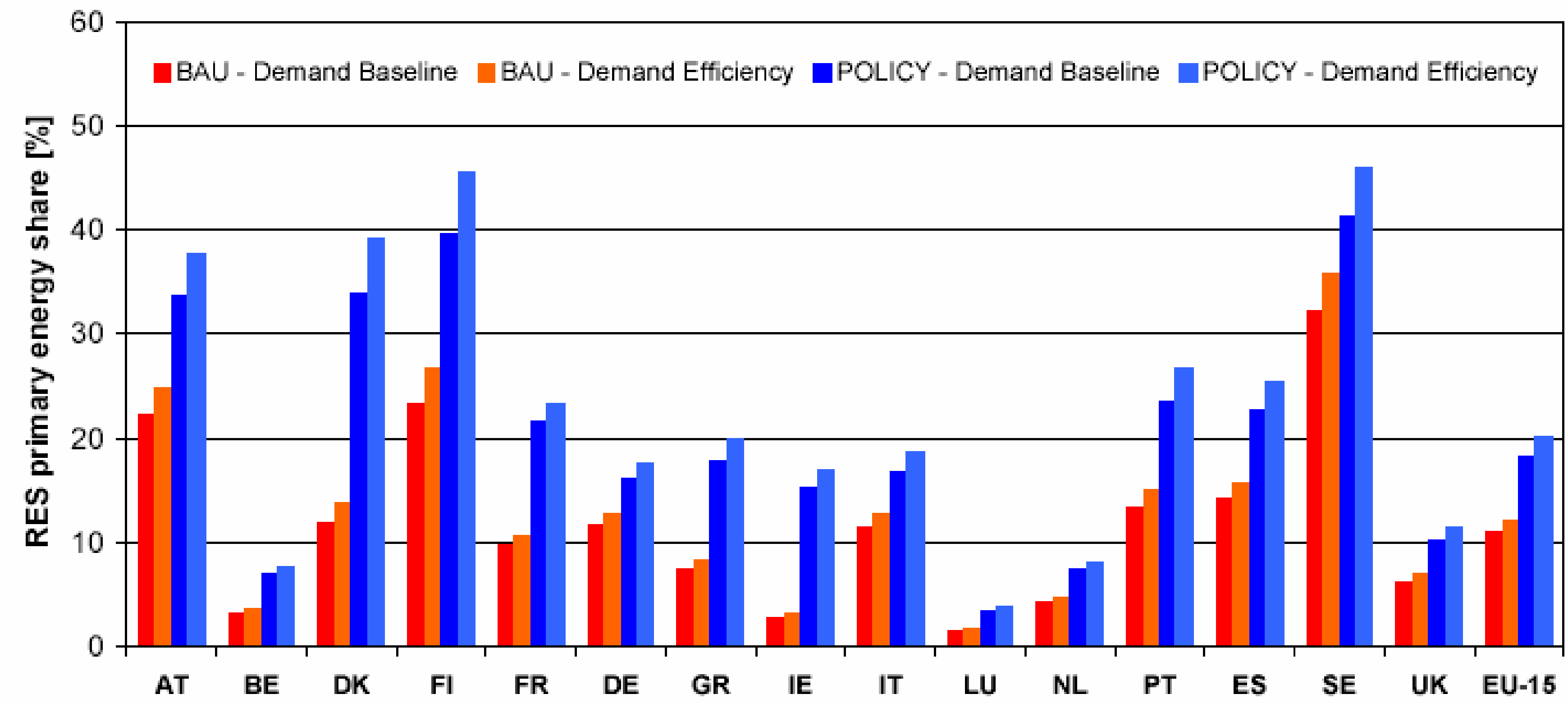
Energy: Total Primary Energy Supply

- **Total Primary Energy Supply (TPES) measures the amount of primary energy demanded in an economy**

- **Expansion of the European Union added nearly 203 Million tonnes of oil equivalent (Mtoe) of energy demand:**

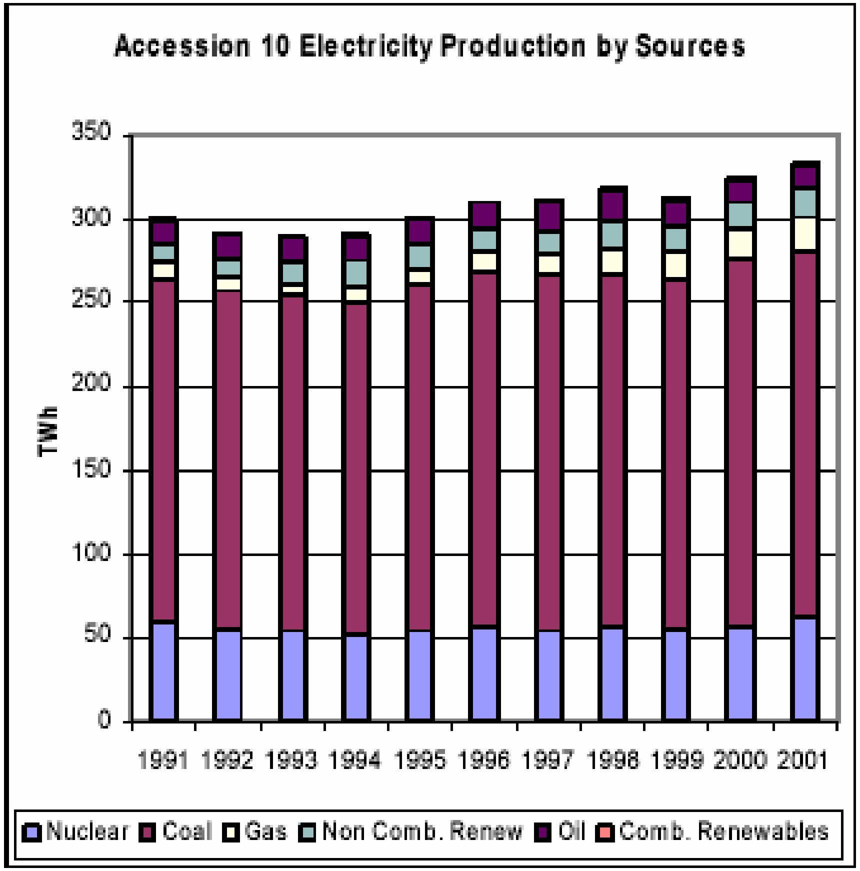
  Latvia, Lithuania and Estonia added over 17 Mtoe; Czech Republic, Hungary, Poland, Slovak Republic and Slovenia, added nearly 183 Mtoe; Cyprus and Malta added over 3 Mtoe.

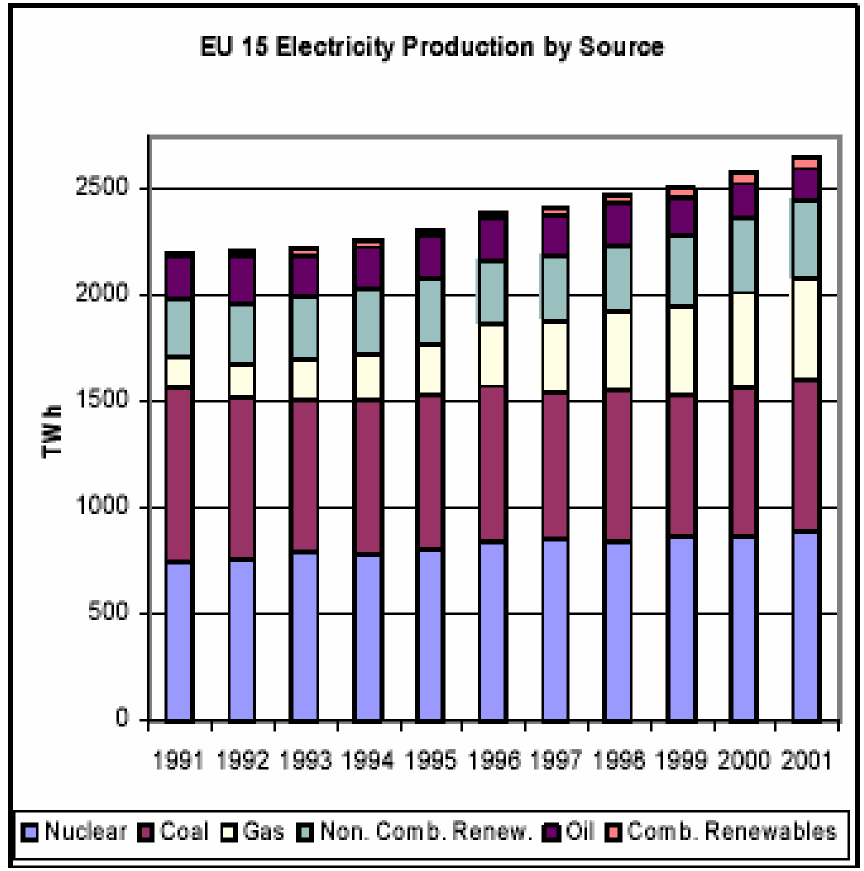
- **The expansion to the European Union “25” raises EU TPES by 13.6%, from 1,495 Mtoe to over 1,981 Mtoe.**

- 

Share of RES primary energy in EU-15 member states in 2020

Electricity Production by Source





Comparison of Electricity Generation with Renewables:

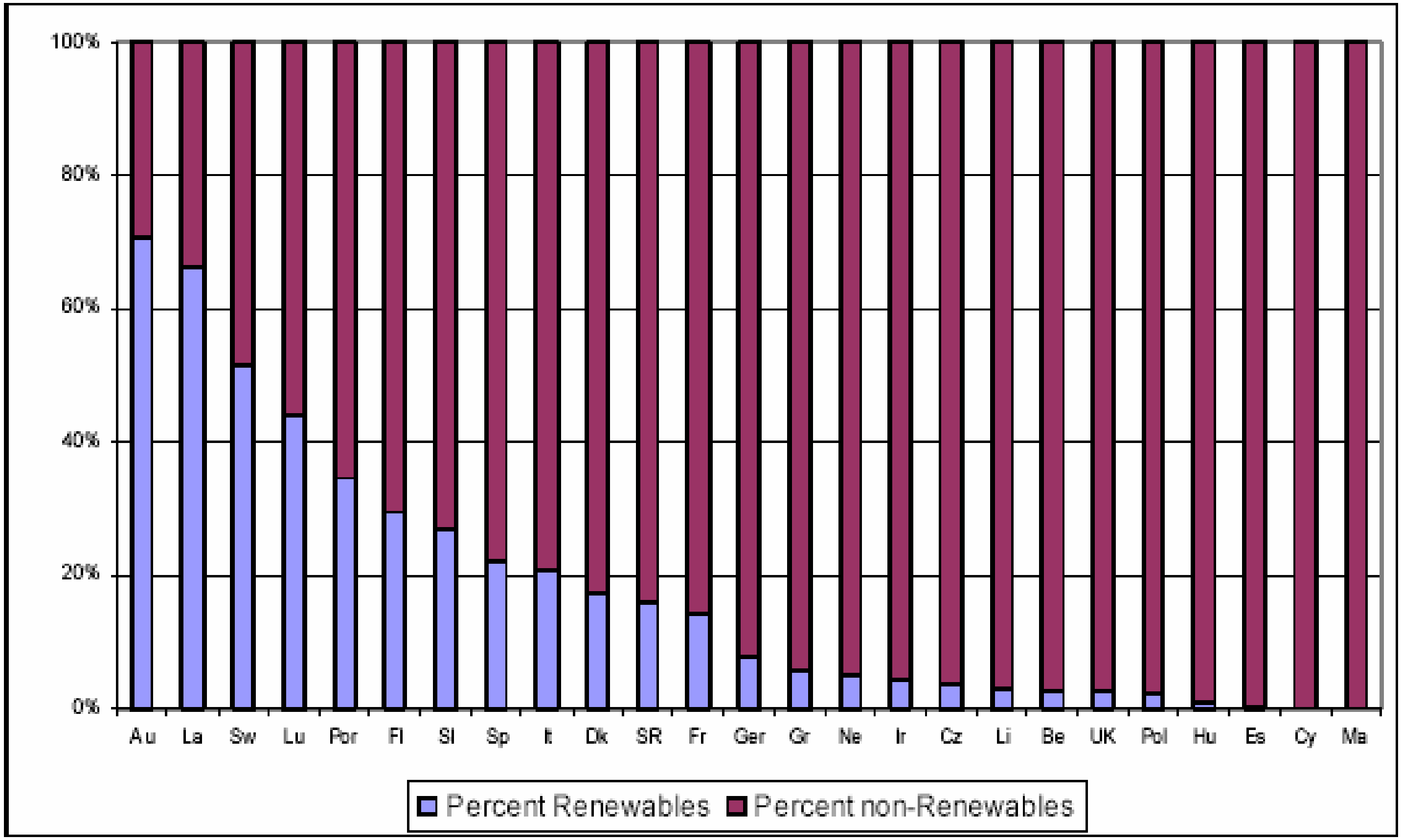
In 2001, Accession 10 electricity generation with renewables reached nearly 18.5 tWh

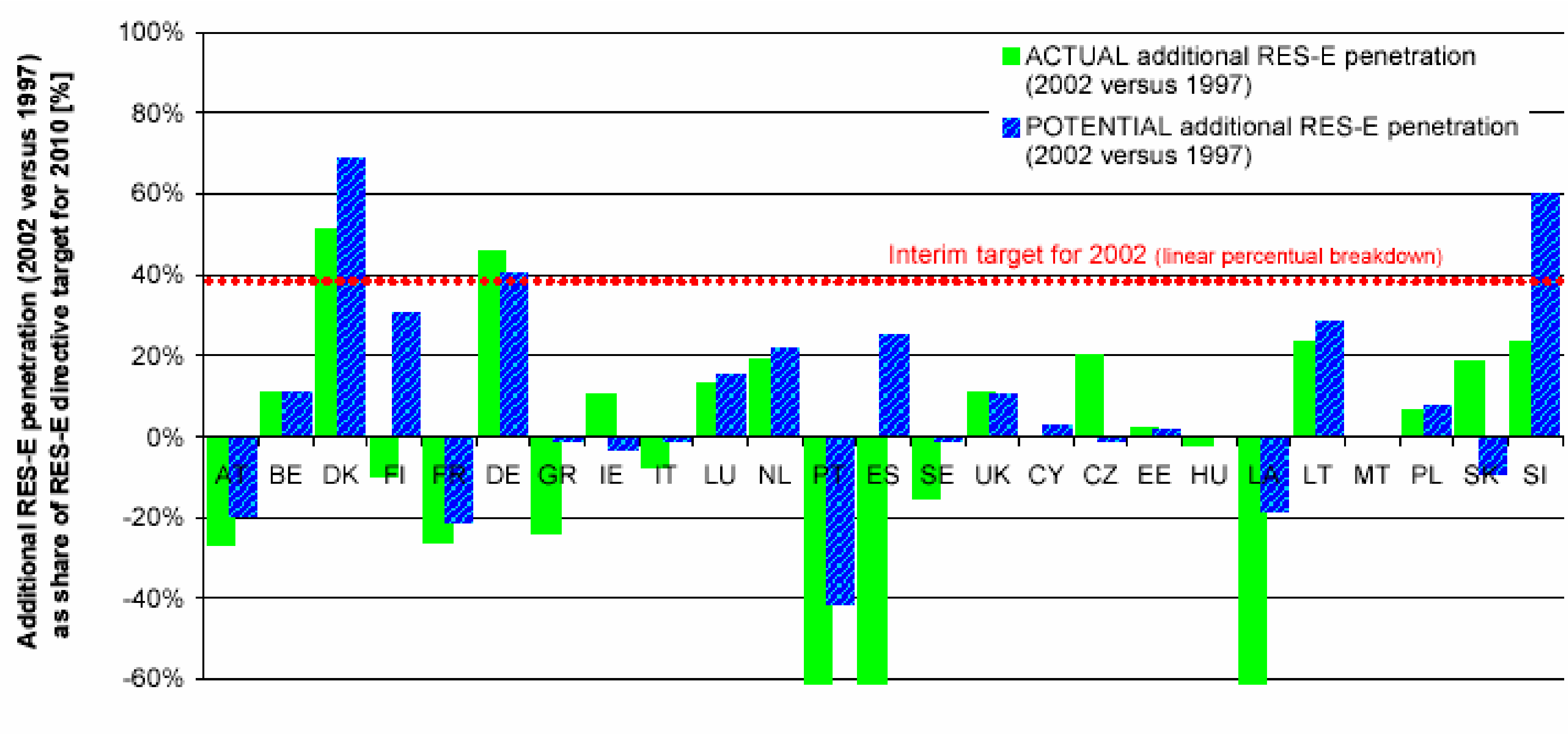
- Electricity generation with renewables was 5.5% of total generation
- Renewables electricity generation is increasing at 4.4% annually since 1991.
- Only Latvia and Slovenia are currently over the EU 2010 target of 20%

In 2001, EU 15 electricity generation with renewables was over 422.3 tWh

- Electricity generation with renewables was 15.9% of total generation
- Renewables electricity generation is increasing at 3.9% annually since 1991
- Austria, Sweden, Luxembourg, Portugal, Finland, Spain and Italy are currently over the EU target of 20%

Renewable Electricity Generation Targets





RES target achievement at country level: comparison of actual and potential additional RES-E penetration (2002 versus 1997)

Conclusions

- **Renewable energy sources have the potential to make a large contribution to the sustainable energy future of the European Union. In particular they can help to reach the environmental goals of the EU - with regard to the commitments under the Kyoto Protocol - , increase the security of supply by mitigating the dependence on imported fuels**
- **Increase social welfare by creating new employment opportunities. Finally the development of renewable energy sources contributes to the goal of the Lisbon process to reach sustainable economic growth and to improve the competitiveness of the European Union on a global scale by creating lead markets for innovative technologies.**
- **The challenge of increasing the share of renewables in each sector of the energy system has been recognized by the European Union and translated into a comprehensive regulatory framework.**
- **The existing EU legislation needs to be adopted into national legal and policy measures of member states following the two main objectives of:**
- **the removal of economic barriers to the development of renewable energy sources by introducing financial support mechanisms and promotion schemes,**
- **the mitigation of non-economic barriers such as administrative barriers, market imperfections, technical obstacles and grid restrictions.**

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General Module

IMPACT OF RES ON POWER SYSTEM OPERATION

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Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

Introduction

Distributed generation (DG):

- Optimal planning of locations and optimal sizing
- Optimal operation, control, and maintenance

Relevant technical issues:

- Quality of (electricity) supply
- Active control of distribution networks with DG
- Short circuit level limitation

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Operational topics in distribution networks with DGs

- Load flow and optimal load flow
- State estimation
- Network reconfiguration
- Network restoration
- Reactive power and voltage control
- Unit commitment
- Load profiles, load prediction
- Economical operation

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Load flow and optimal load flow applications in networks with DGs

- New and modified algorithms and methods for accurate and fast power flow and optimal power flow analyses are needed.
- The objective of OPF applications can be minimization of costs or maximization of profit.
- It is important to determine priority objectives, which should be achieved by adjusting of different power system control variables, while satisfying all physical and operating constraints.

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Overview of methods for load flow calculations in distribution networks

- Iterative method for power flow calculations in radial networks (backward and forward calculations)
- Compensation method for networks with small number of loops
- Modified Newton-Raphson method
- Fuzzy methods

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OPF problem formulation

- General form of an optimization problem is to minimize the objective function:
- $F(x)$
- subject to the equality constraints:
- $g_i(x) = 0 \quad i = 1,2,...,l$
- and subject to the inequality constraints:
- $h_j(x) \geq 0 \quad j = l+1,...,m$
- where $x = [y\ u]$ is a vector of system variables which consists of dependent variables (state variables) vector y and of independent variables (control variables) vector u.

Conventional nonlinear OPF methods

- Kuhn-Tucker's technique of optimization,
- Techniques of optimization with penalty functions,
- Gradient methods,
- Newton's type method,
- Lagrange multipliers methods, ...

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Possible objectives

- minimization of the active & reactive power losses,
- optimization of the voltage profiles,
- minimization of the generation fuel costs,
- minimization of the system energy costs,
- maximization of the profit,
- maximization of the system performance,
- optimization of the power exchange with other systems,
- maximization of the voltage & flow security indices,
- control generator's MW & MVAR settings within the specified limits,
- control voltage regulators (transformer tap positions) etc.

Lagrange multipliers method

- The idea is to expand the objective function with two additional terms:
-
- $L(z) = f(x) + \lambda_e^T g(x) + \lambda_n^T h(x)$ (5.1)
- where: $z = [\, x \;\; \lambda_e \;\; \lambda_n \,]$ – expanded vector of variables
- λ_e – Lagrange multipliers vector for the equality type constraints
- λ_n – Lagrange multipliers vector for the inequality type constraints

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System of nonlinear equations

$$\frac{\partial L(\mathbf{x},\lambda_e,\lambda_n)}{\partial \mathbf{x}} = \frac{\partial f(\mathbf{x})}{\partial \mathbf{x}} + \left[\frac{\partial g(\mathbf{x})}{\partial \mathbf{x}}\right]^T \lambda_e + \left[\frac{\partial h(\mathbf{x})}{\partial \mathbf{x}}\right]^T \lambda_n = w(\mathbf{x},\lambda_e,\lambda_n) = 0$$

$$\frac{\partial L(\mathbf{x},\lambda_e,\lambda_n)}{\partial \lambda_e} = g(\mathbf{x}) = 0$$

$$\frac{\partial L(\mathbf{x},\lambda_e,\lambda_n)}{\partial \lambda_n} = h(\mathbf{x}) = 0$$

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Matrix equation

$$\begin{bmatrix} \frac{\partial w(x^k,\lambda_e^k,\lambda_h^k)}{\partial x} & \frac{\partial w(x^k,\lambda_e^k,\lambda_h^k)}{\partial \lambda_e} & \frac{\partial w(x^k,\lambda_e^k,\lambda_h^k)}{\partial \lambda_h} \\ \frac{\partial g(x^k)}{\partial x} & 0 & 0 \\ \frac{\partial h(x^k)}{\partial x} & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta x^{k+1} \\ \Delta \lambda_e^{k+1} \\ \Delta \lambda_h^{k+1} \end{bmatrix} = \begin{bmatrix} w(x^k,\lambda_e^k,\lambda_h^k) \\ g(x^k) \\ h(x^k) \end{bmatrix}$$

Newton iterative procedure

$$x^{k+1} = x^{k} + \Delta x^{k+1}$$

$$\lambda_e^{k+1} = \lambda_e^{k} + \Delta \lambda_e^{k+1}$$

$$\lambda_n^{k+1} = \lambda_n^{k} + \Delta \lambda_n^{k+1}$$

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Newton type matrix equation

$$\begin{bmatrix} \frac{\partial^2 L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \mathbf{x}^2} & \frac{\partial^2 L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_e \partial \mathbf{x}} & \frac{\partial^2 L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_n \partial \mathbf{x}} \\ \frac{\partial^2 L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_e \partial \mathbf{x}} & 0 & 0 \\ \frac{\partial^2 L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_n \partial \mathbf{x}} & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta \mathbf{x}^{k+1} \\ \Delta \lambda_e^{k+1} \\ \Delta \lambda_n^{k+1} \end{bmatrix} = \begin{bmatrix} \frac{\partial L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \mathbf{x}} \\ \frac{\partial L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_e} \\ \frac{\partial L(\mathbf{x}^k,\lambda_e^k,\lambda_n^k)}{\partial \lambda_n} \end{bmatrix}$$

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Short version

$$H(z^k)\Delta z^{k+1} = \nabla L(z^k)$$

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Objective function

$$f(\mathbf{x}) = P_\gamma = \sum_{i=1}^{N} P_{Gi} - \sum_{i=1}^{N} P_{Pi} = \sum_{i=1}^{N} P_{Gi} - \sum_{i=1}^{N} P_{Pi}^{nom} \cdot \left(\frac{U_i}{U_i^{nom}} \right)^{K_{PUi}}$$

N is the number of nodes within the actual distribution network

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Equality constraints

$$P_k = U_k \sum_{m=1}^{N} U_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] - P_{Gk} + P_{Pk} = 0$$

$$Q_k = U_k \sum_{m=1}^{N} U_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] - Q_{Gk} + Q_{Pk} = 0$$

Nonequality constraints

$$U_i - U_{i\max} \leq 0$$

$$U_{i\min} - U_i \leq 0$$

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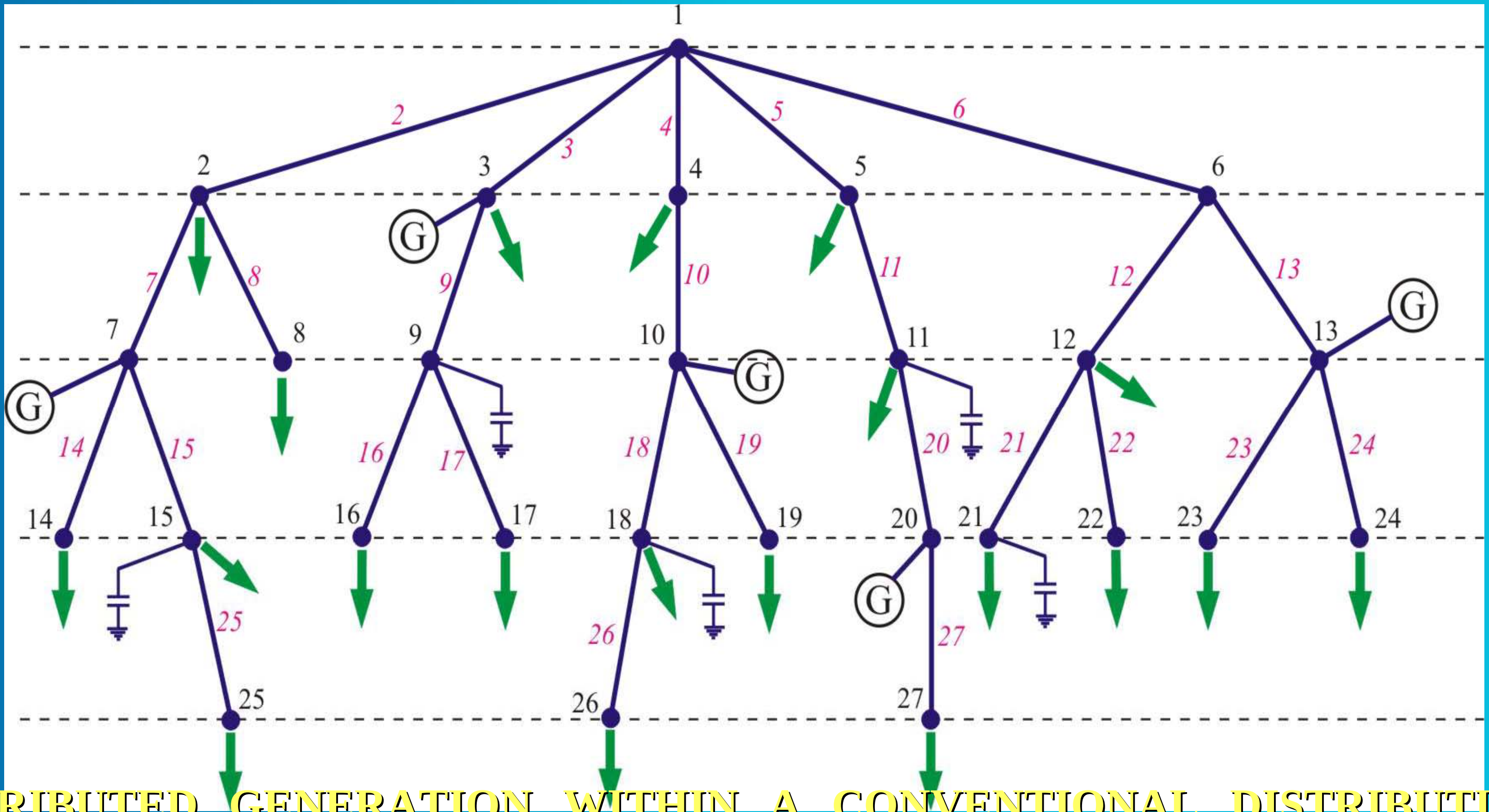
ILLUSTRATIVE EXAMPLE



DISTRIBUTED GENERATION WITHIN A CONVENTIONAL DISTRIBUTION NETWORK

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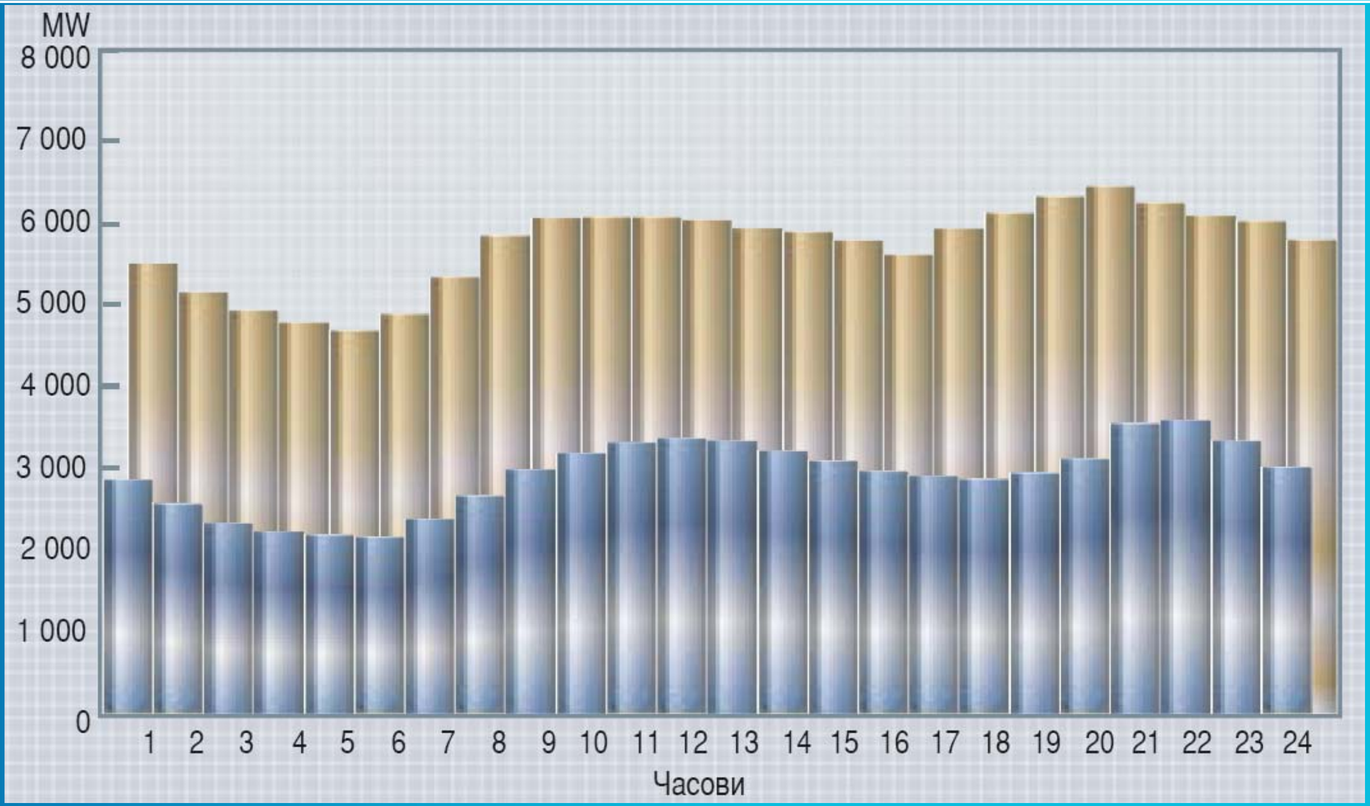
Dayly load profiles for the EPS system



Illustrative examples for 2004
Day with the peak load (13.2.)
And day with the minimal load (8.8.)

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Load (state) estimation problem in networks with DGs

- Load (state) estimation is improved in networks with DGs due to measured voltages in PV nodes
- The higher number of small generators the better opservability conditions
- Number of measurement (billing) points is increased

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Network reconfiguration in distribution networks with DGs

- With DGs basic reconfiguration objectives are changed
- Reformulation of losses minimization problem
- Fider load balancing should include unit commitment
- Optimization of voltage profiles with DGs is different

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Network restoration in distribution networks with DGs

- Network restorations procedures after emergencies (faults, loss of load,…)
- Alternative ways of voltage restoration are different then in passive networks

Reactive power and voltage control in networks with DGs

- Reactive flows are different in networks with DGs
- Voltage controlable bus in the point of DG connection
- Recalculation of reactive load profiles

Unit commitment in distribution networks with DGs

- Unit commitment should account for technical constraints of DGs
- Coordination with transmission system operation
- Short term load forecasting
- The objective is to minimize the total production costs over the operational planning period
- Constraints: availability of renewable primary energy, load demand requirements, technical limitations (minimum up and down times, ramp rates, transmission line capacity limits, spinning reserve limits,…)

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Load profiles and impact on operation of networks with DGs

- Monitoring of load profiles
- Objective of effective operation

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Economical operation in networks with DGs

- Optimal economic operation from the point of view of:
  - Owner of DGs
  - Owner of distribution network
  - Owner of the whole system
  - Combinations

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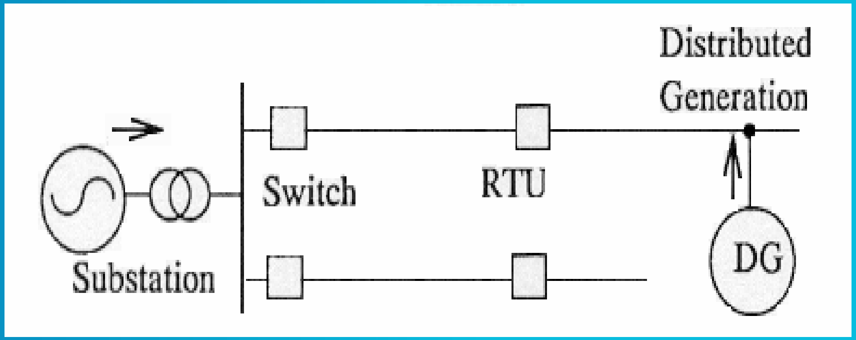
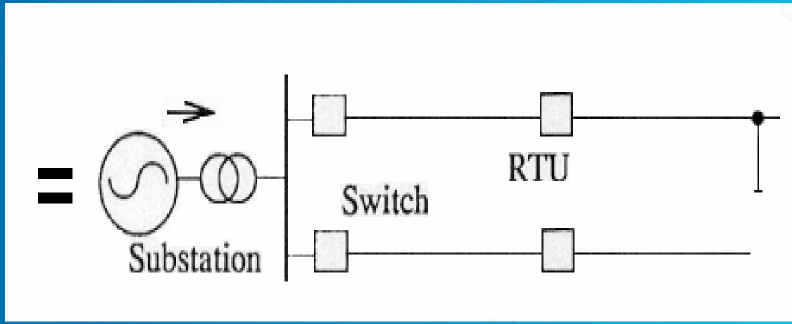
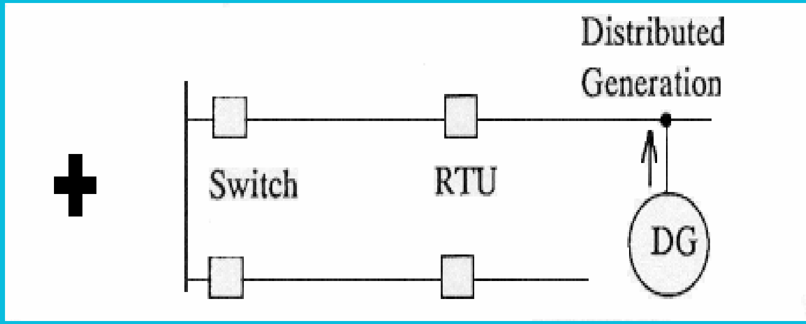
Superposition concept







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Reduction of loads

Reduction of node loads in accordance with the small generator power

Losses are neglected and loads are independent of voltage magnitudes

$$\underline{S}_{newi} = \frac{\underline{S}_i}{\sum_{i=1}^{N} S_i} S_{genj}$$

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System performance in networks with DGs

- Active power losses
- Reactive power losses
- Injected reactive power
- Critical voltage drop
- The squared sum of voltage deviations
- Critical feeder current reserve
- Critical current reserve of supply transformer

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System performance – active power losses

$$ILP^{h} = \mathrm{Re}\left\{\sum_{i=1}^{NF}\sum_{j=1}^{NFSi} \underline{Z}_{ij}\,\underline{I}_{ij}^{h\,2}\right\}$$

- Active power losses are the sum of losses in passive network and the losses in the network with single DG
- The lower values of the ILP index indicate better system performance
- *h* option for DG location
- *NF* Number of feeders in DN
- NFS_i number of sections for the feeder *i*
- $\underline{Z}_{ij}$ impedance of the section *j for the feeder i*
- $\underline{I}_{ij}^{h}$ current of section *j* for feeder *i* in configuration *h*

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System performance – reactive power losses

- Reactive power losses are the sum of losses in passive network and the losses in the network with single DG
- The lower values of the ILP index indicate better system performance

$$ILQ^h = \mathrm{Im}\left\{ \sum_{i=1}^{NF} \sum_{j=1}^{NFSi} \underline{Z}_{ij} \underline{I}_{ij}^{h^2} \right\}$$

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System performance – injected reactive power

- Relative value of the injected reactive power
- The higher values of the injected power indicate better system performance

$$IQ^h = \frac{\sum_{k=1}^{NG} Q^h_{genk}}{\sum_{k=1}^{NG} Q_{gen\max k}}$$

NG number of DGs (here NG=1)

$Q_{gen\ max\ k}$ max. Injected reactive power for gen. k

$Q^h_{gen\ k}$ actual injected reactive power for gen k

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System performance – critical voltage drop

- The lower values of the voltage drop indicate better system performance

$$IV^h = \max_{\substack{i=1,NF \\ k=NFTi}} \left(\frac{V_r^h - V_{ik}^h}{V_r^h} \right)$$

V_r^h bus voltages in both superposition cases, for the option h
V_{ik}^h the node k voltage for the feeder in the option h NFT the number of TS MV/LV which are supplied by the feeder i

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System performance – squared sum of voltage deviations

- The lower values of the squred sum indicate better system performance

$$IVD^{h} = \sum_{k=1}^{N} \left(V_{r}^{h} - V_{k}^{h} \right)^{2}$$

System performance – critical feeder current reserve

- The lower values of the IJ index indicate better system performance

$$IJ^{h} = \frac{1}{\min\limits_{\substack{i=1,NF \\ j=1,NFSi}} \left(\dfrac{I_{ij}^{r} - I_{ij}^{h}}{I_{ij}^{r}} \right)}$$

I_{ij}^{r} rated current of the section i for the feeder j

I_{ij}^{h} actual current of the section i for the feeder in the configuration h.

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System performance – critical current reserve of the supply transformer

- The lower values of the index IS indicate better system performance

$$IS^h = \frac{1}{\min\limits_{i=1,NTS}\left(\dfrac{I_{TSi}^r - I_{TSi}^h}{I_{TSi}^r}\right)}$$

I_{TSi}^r rated current of the transformer i
I_{TSi}^h actual current of the transformer i in the option h

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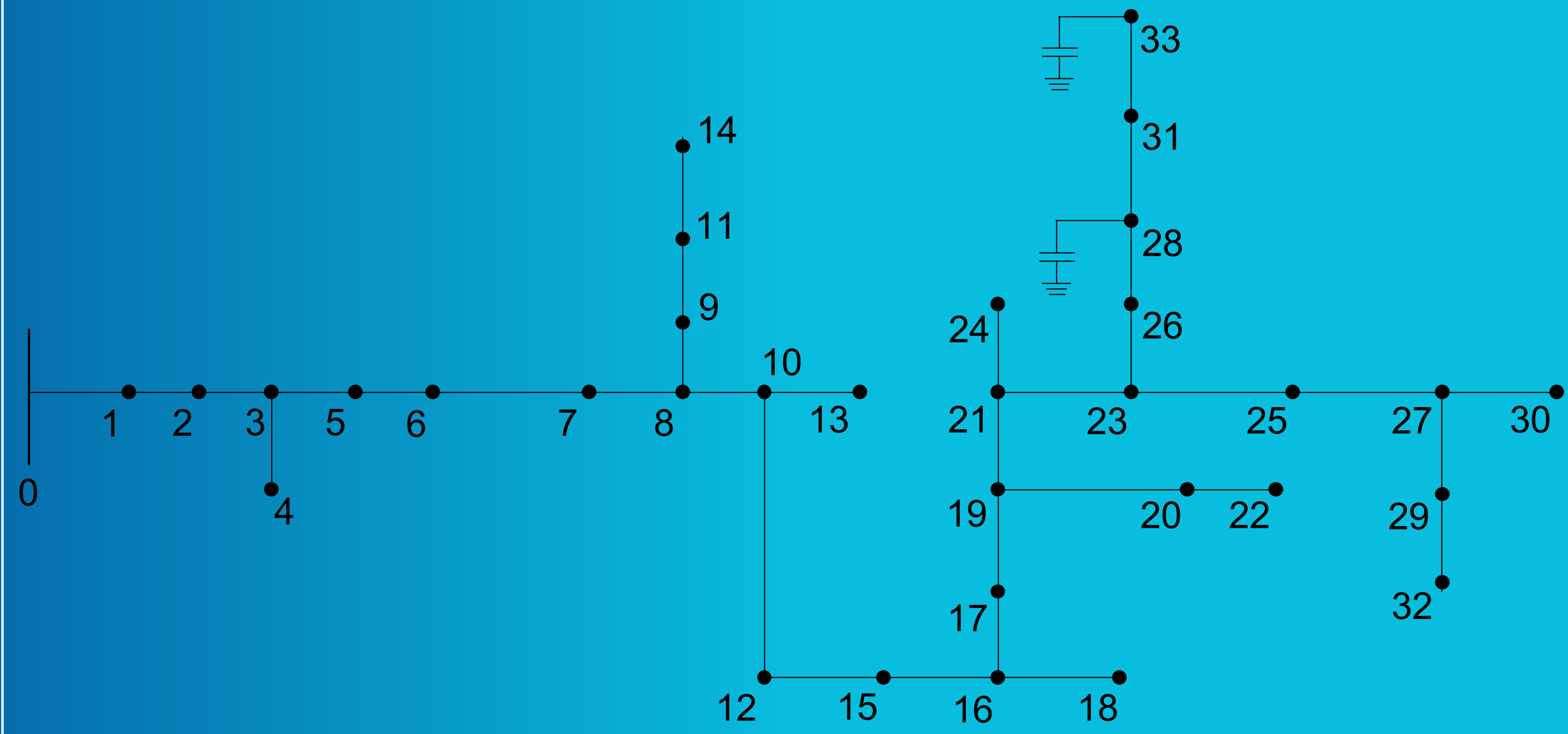
IEEE 34 distribution test network



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DG network connection - technical data about distribution network (DN)

MV and LV distribution networks with radial configuration are considered

- **grounding type at different voltage levels,**
- **maximal allowed three-phase short circuit currents (powers),**
- **standardized value of the single phase-to-earth fault current is 300 A (or 1000 A) …**

Technical data about DGs

- installed power between 25 kVA and 16000 kVA

- AC synchronous generators,
- AC asynchronous generators,
- DC generators with the static transforming devices (invertors DC/AC 50 Hz),
- asynchronous generators with the frequency transforming devices (invertors AC/AC 50 Hz)

- maximum allowed voltage deviation at the connection point to the distribution network

Technical requirements for the connection of the DGs to the DN

- equipment for parallel operation with the distribution network
- equipment for combined operation, parallel or isolated type of operation

- The small power station should satisfy four primary criteria:
    1. upper limit of the installed power,
    2. limits in regards to flickers,
    3. limits to levels of higher current harmonics,
    4. limits to short circuit powers

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Technical requirements for the connection of the DGs

Each connection of the DGs consists of:

- connection line
- switching, measurement, protection and other devices at the point of the connection of the small power station
- switching, measurement, protection and other devices at the point of the connection to the distribution network
- equipment and devices for the measurement point

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Technical requirements for the measurement location

- Location of the measurement equipment

Each measurement point should be equipped with the following devices:

- digital active electric energy meter
- digital reactive electric energy meter
- control device of the measurement group

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Protection requirements

Two types of protection should be taken into consideration:

- system protection
- protection of the connection line

- Voltage protections (U> and U<)
- Frequency protections (f> and f<)
- Over-current protections (I>> and I>)

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Reactive energy control in the small power station

$\cos\varphi \geq 0{,}95$

- individual, group or central reactive energy compensation installations
- automatic control of the power factor is needed when the small power station has very variable power output (wind generators,...)

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Operation

The first and the most important owner's obligation is to maintain the secure and reliable operation of the network (minimize the propagation of disturbances from the small power station to the network)

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Connection schemes of the DGs to the DN

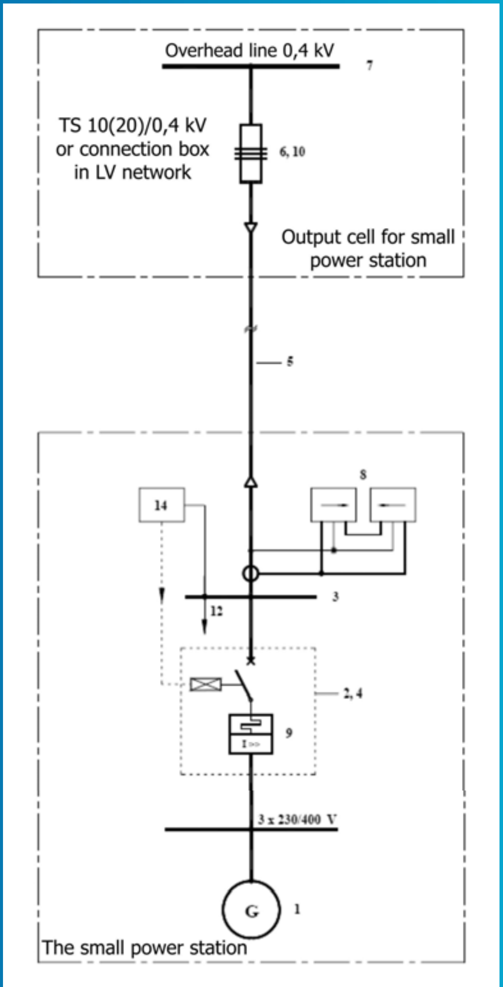

Fig. 1

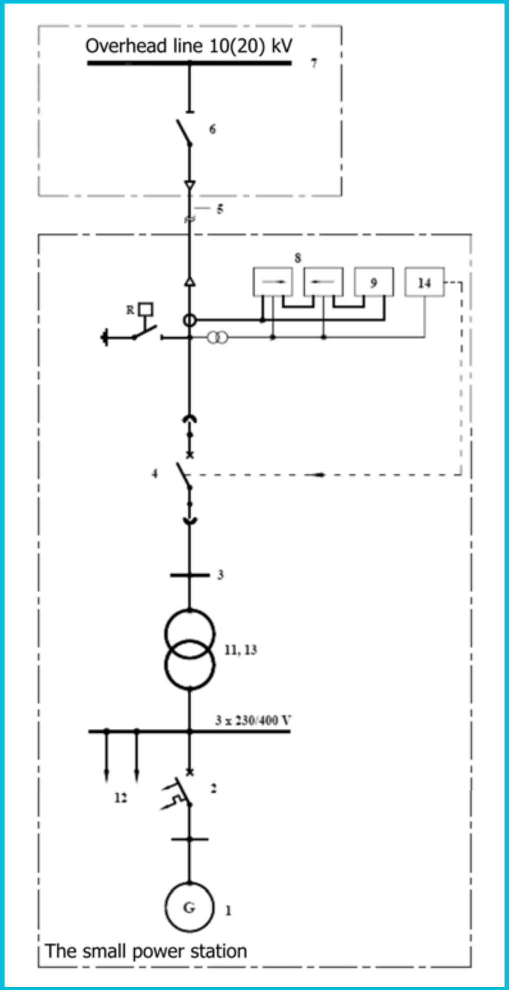

Fig. 2

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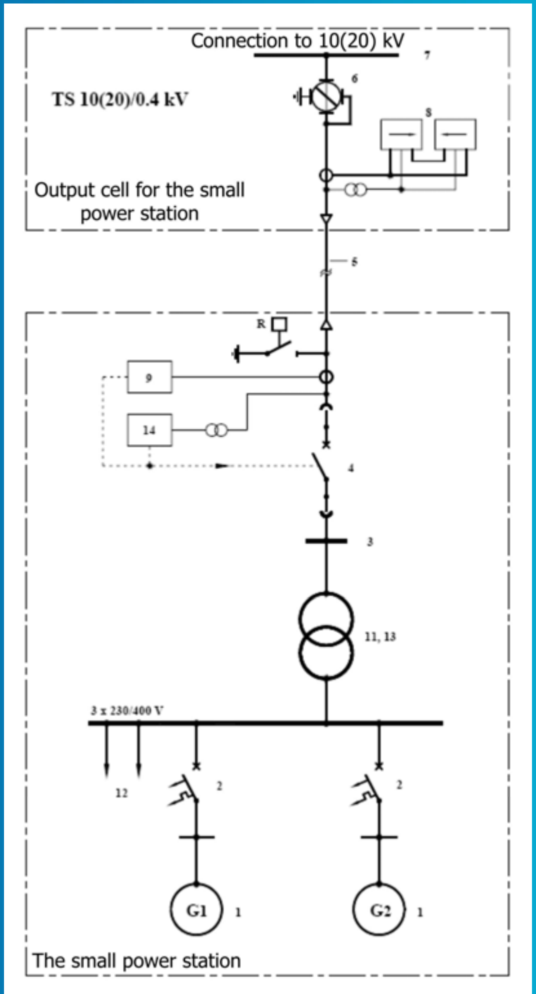
Connection to 10(20) kV
TS 10(20)/0.4 kV
Output cell for the small power station
3 x 230/400 V
The small power station

Fig. 3

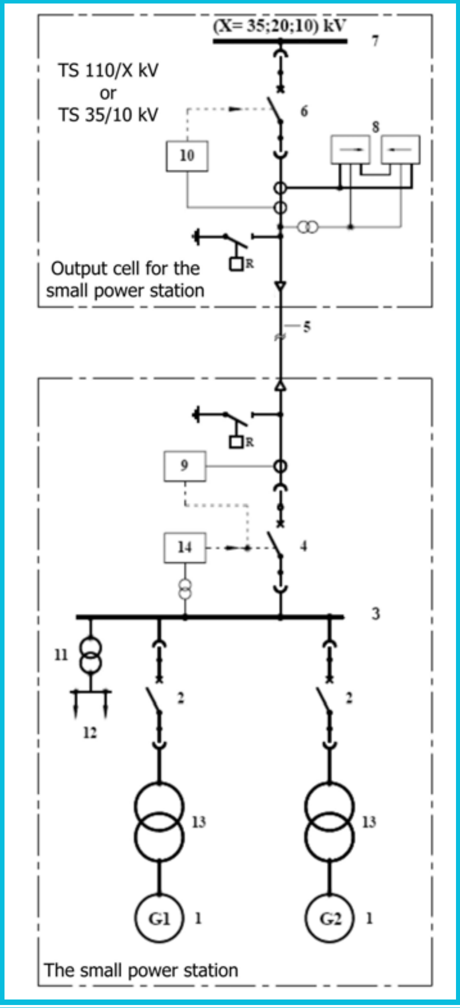
(X= 35;20;10) kV
TS 110/X kV or TS 35/10 kV
Output cell for the small power station
The small power station

Fig. 4

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Renewable Energy Sources Technology, Economics and Policy Curriculum

Economic aspects of RES

General module

Author: Borut Del Fabbro

ISTRABENC **Energetski sistemi**

Competitiveness of RES

- **RES are usually not competitive with fossil fuels**
- **The price of fossil fuels does not include the costs of externalities:**
  - **CO_2 emissions cause global warming**
  - **Other pollution (SO_2, smoke, ashes)**
- **In order for RES to be competitive usually subsidies or other incentives are needed**

Characteristics of Renewables

- High Up-Front costs (investment)
- Low cost O&M
- Stability of Output:
  - Small HPP, Wind, Photovoltaics – possible high variations between years
  - Geothermal – extremely constant

Production costs

production costs per kWh =

(fixed costs + variable costs) / production

fixed costs = cost of capital (=interest + principal) + insurance + other f.c.

variable costs =

fuel costs + maintenance costs + other v.c.

Fixed costs

fixed costs = cost of capital (=interest + principal) + insurance + other f.c.

Variable costs

variable costs =

fuel costs + maintenance costs + other v.c.

Overview of RES from an economic aspect

- **Active solar**
  - **energy efficiency dubious**
  - **exclusively dependent on subsidies**
- **Passive solar**
  - **in warm and sunny places usually feasible also without subsidies**
- **Wind**
  - **exclusively / mostly dependent on subsidies**

Overview of RES from an economic aspect (2)

- Small HPP
  - mostly dependent on subsidies
- Solid Biomass
  - normal combustion/fireing
  - gasification
  - steam turbine
  - generation of electricity exclusively dependent on subsidies
  - generation of heat independent of subsidies – feasible also under purely market conditions
- Biogas
  - exclusively dependent on subsidies

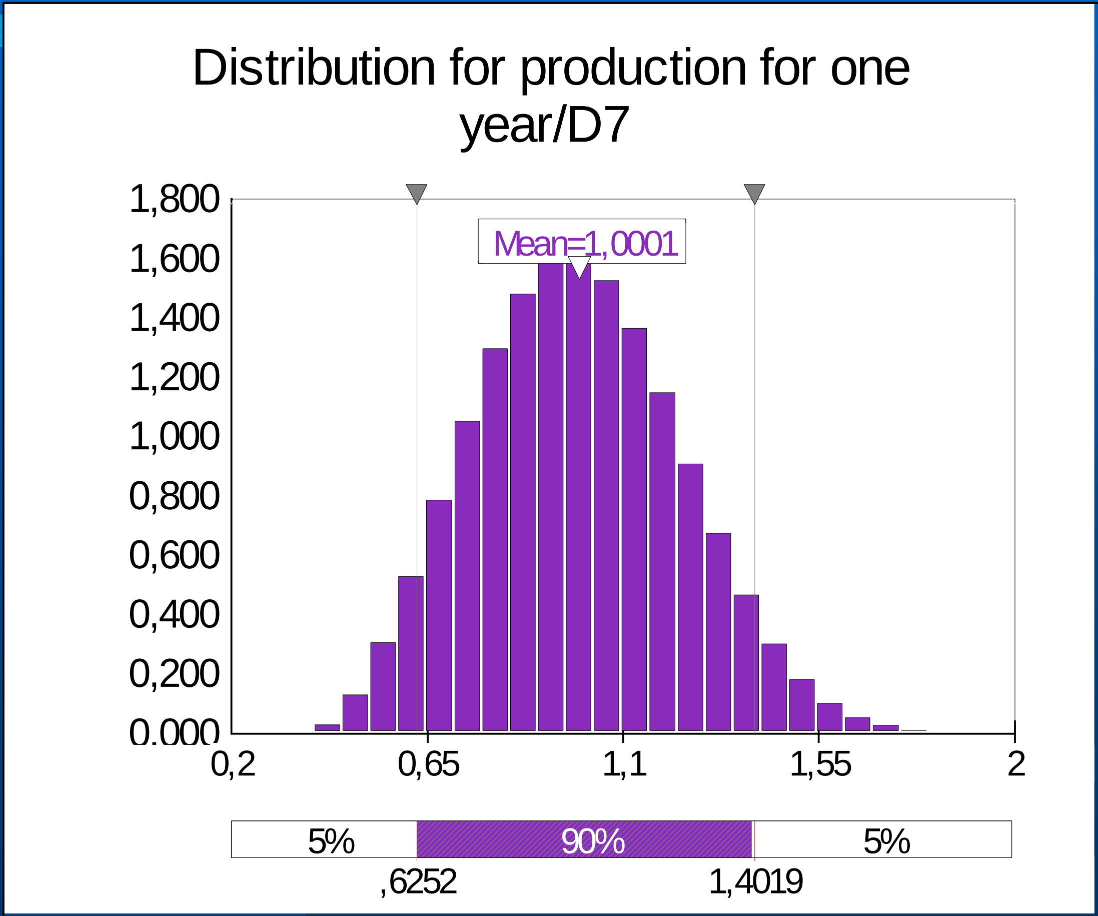
Breakeven prices for RES

	Approximate breakeven prices per MWh
solar	500 - 550 €
biogas	140 - 170 €
solid biomass	90 - 110 €
wind	60 - 70 €
small HPP	45 - 70 €
market price - base - 1 year ago	
	42 €
market price - base - 3 months ago	
	78 €
market price - base - today	
	53 €

Overview of RES from an economic aspect - summary

- Electricity production from RES is largely dependent on subsidies and other financial incentives
- Heat production from RES (biomass, solar) is competitive also under market conditions

Production uncertainty



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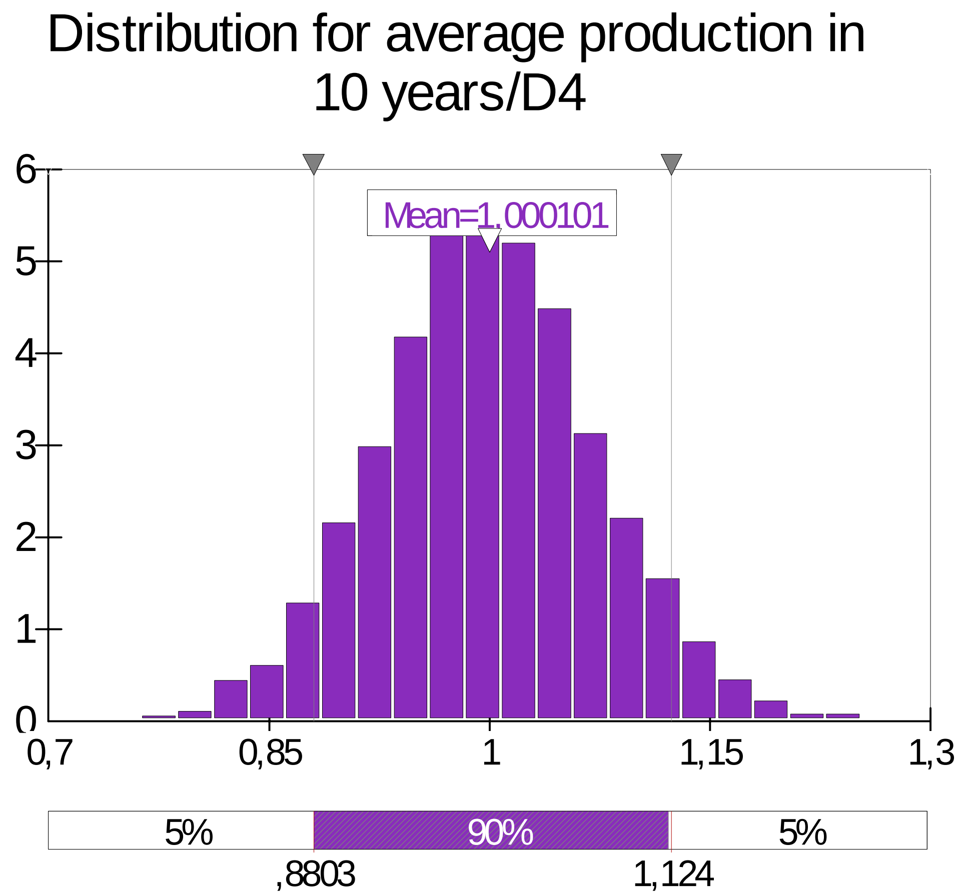
5%	63%
10%	70%
15%	75%
20%	79%
25%	83%
30%	87%
35%	90%
40%	93%
45%	96%
50%	99%
55%	102%
60%	106%
65%	109%
70%	112%
75%	116%
80%	120%
85%	125%
90%	131%
95%	140%

Production uncertainty – effect of “bad luck”



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40%	98%
45%	99%
50%	100%
55%	101%
60%	102%
65%	103%
70%	104%
75%	105%
80%	106%
85%	108%
90%	110%
95%	112%

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Renewable Energy Sources Technology, Economics and Policy Curriculum

General module

Overview of Renewable Energy Sources Policy and Supporting Mechanisms in Europe

Author:

As.Prof. Andrej Gubina, Ph.D.

Laboratory of Energy Policy

University of Ljubljana, Faculty of Electrical Engineering

Overview

- Introduction
- Policy Instruments for the Promotion of RES
  - Main Instruments in the Sectors
    - Electricity, Heat and Transport
  - Combining Several Support Schemes
  - Success Stories and Key Barriers
- Recent Policy Developments

What is Energy Policy?

- A plan of action for tackling issues related to
  - energy supply,
  - demand,
  - development of energy related industry and trade and
  - consequences of energy activities.

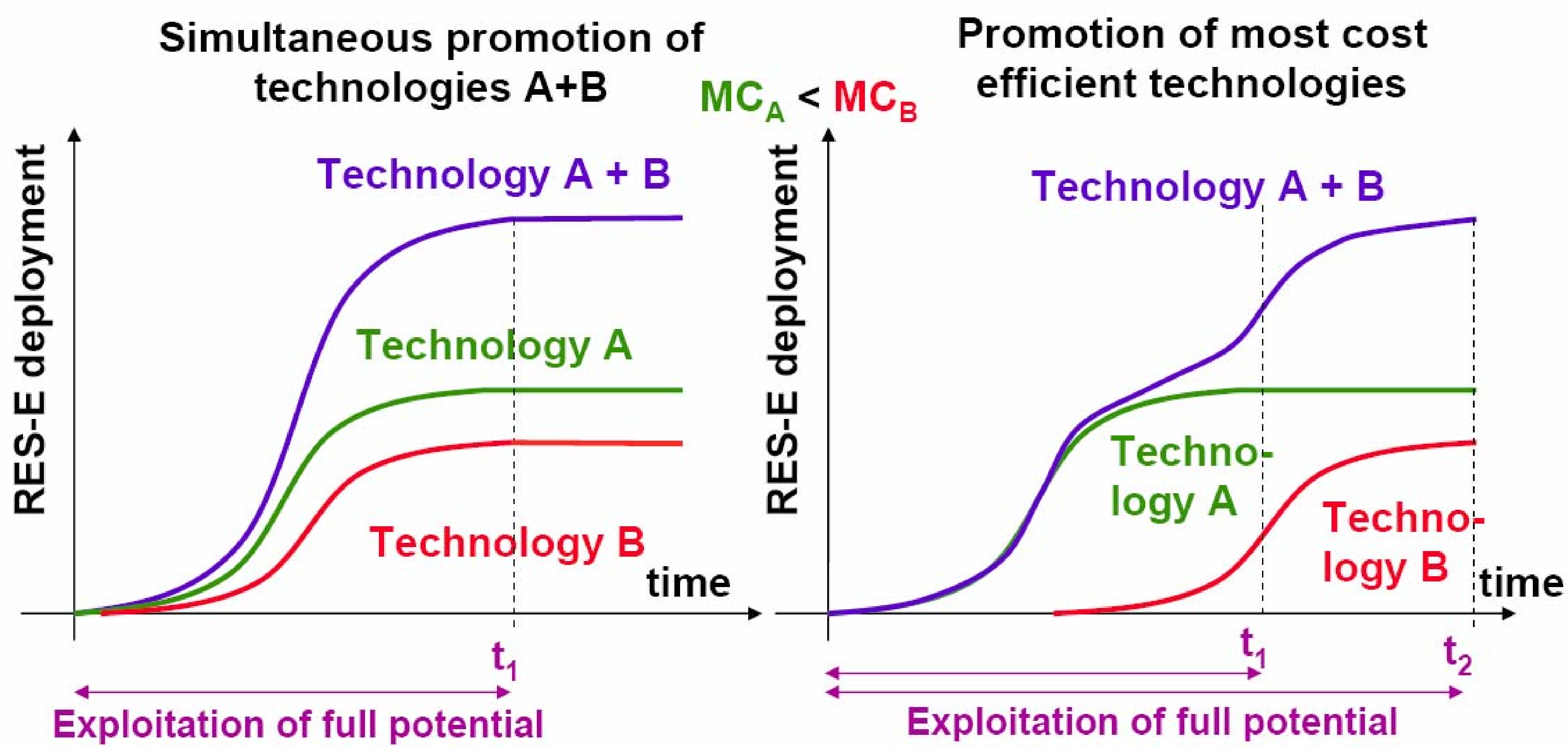
The elements of a Policy

- Statement of purpose
- Clear and measurable goals:
  - E.g. % improvement, time schedule
- Tools, methods and activities planned
- Responsibilities
- Progress towards targets:
  - Process for monitoring and evaluation
- Policy review/improvement process.

How to Set Up a Policy?

- Define the subject of the policy,
- Review state of the art,
- Define goals and specific targets to pursue,
- Select instruments, methods and activities,
- Delegate responsibilities,
- Set up clear guidelines based on experience,
- Define supporting bylaws to be adopted later,
- Set up process for periodic amendment and improvement of policy,
- Test it on small scale first, prepare rollout plan,
- Set deadlines for implementation.

Support of RES Technology: Policy Choice



EU Policy Goals in RES

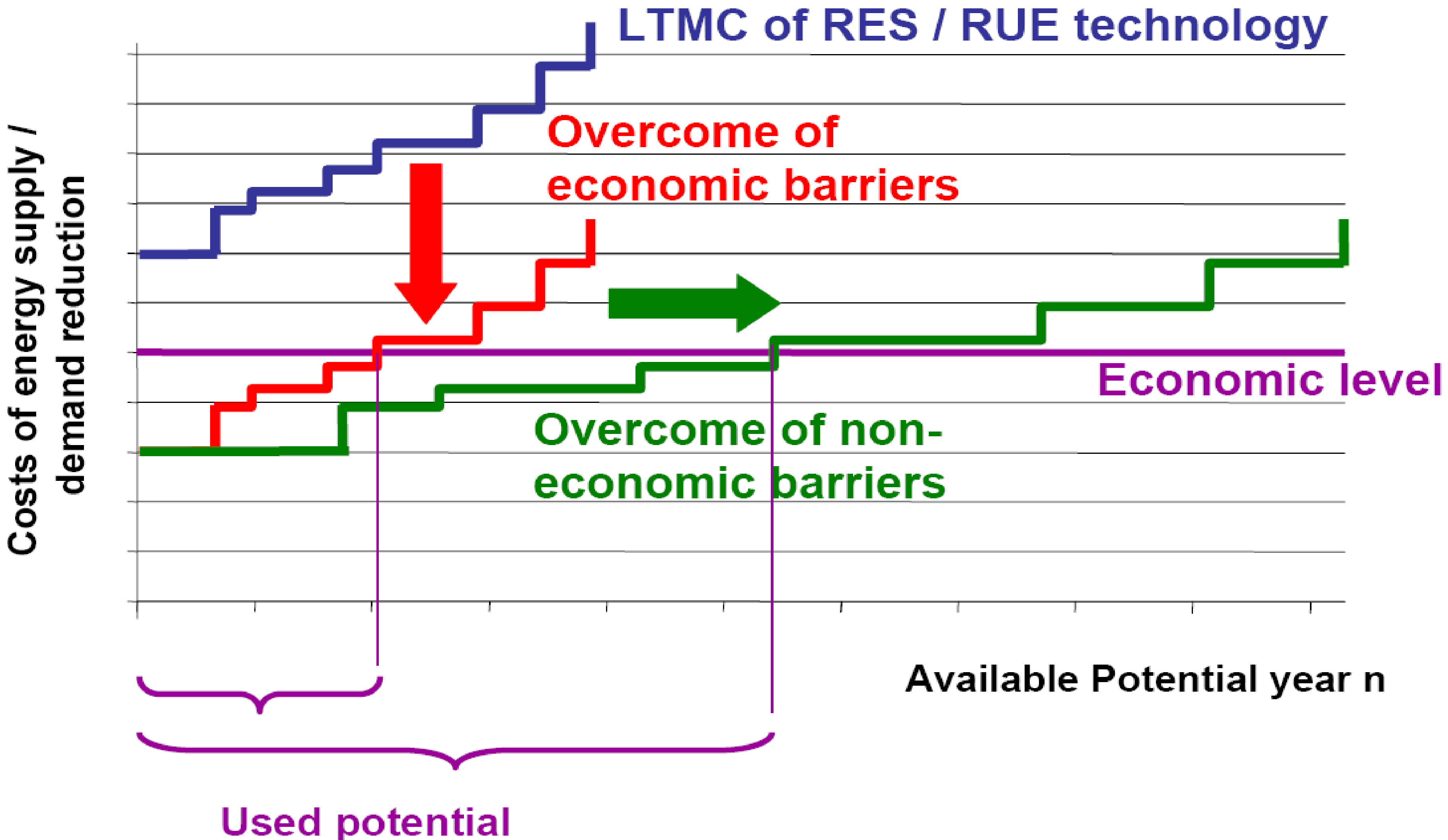
- Reach Environmental goals of EU – Kyoto Protocol
- Increase of security of supply
  - Decreasing the dependence on imported fuels and
  - Diversification of electricity generation sources
- Increase of social welfare
  - Creating new employment opportunities
  - Supporting social cohesion
- Contribution to the goal of the Lisbon process:
  - Sustainable economic growth
  - Improvement of the global competitiveness of the EU

Policy: Barriers to RES Growth

- Removal of economic barriers: introducing
  - Financial support mechanisms and
  - Promotion schemes,
- Mitigation of non-economic barriers:
  - Administrative barriers,
  - Market imperfections,
  - Technical obstacles and
  - Grid restrictions.

- How to achieve Security of (energy) supply?
  - Supply is secure if all the **demand is supplied** at all times, and **adequate reserve** is provided for emergency situations.
  - It is achieved through **diversification of electricity production sources** and through **decrease of dependence** on imported fuel sources.

Policy: Barriers to RES Growth, 2



Policy Papers for RES Deployment

- 1997: White Paper “Energy for the future”
  - Target of share of RE in primary energy consumption: 6% in 1997 to 12% in 2010.
- 2001/77/EC: RES-E Directive
  - EU-25 target of 21% share of RES-E in demand by 2010
  - Indicative targets for all 25 member states.
- 2001: Directive on the energy performance of buildings
  - Renewable heating applications support
- 2003/30/EC: Directive on the promotion of biofuels
  - Share of biofuels in total transport: 0,6% (2003) → 2% (2005), 5.75% (2010)
- 2003/96/EC: Energy taxation Directive
  - Several mid-term indicative targets and other requirements.
- 2006: Green paper on security of energy supply in Europe

Indicative Targets for RES-E Consumption for EU-25 in 2010

EU-15	Target (%)	EU-10	Target (%)
Austria	78.1	Cyprus	6
Belgium	6.0	Czech Republic	8
Denmark	29.0	Estonia	5.1
Finland	31.5	Hungary	3.6
France	21.0	Latvia	49.3
Germany	12.5	Lithuania	7
Greece	20.1	Malta	5
Ireland	13.2	Poland	7.5
Italy	25.0	Slovak Republic	31
Luxembourg	5.7	Slovenia	33.6
Netherlands	9.0		
Portugal	39.0	**Total EU-15**	22
Spain	29.4	**Total EU-10**	11
Sweden	60.0	**Total EU-25**	21
United Kingdom	10.0		

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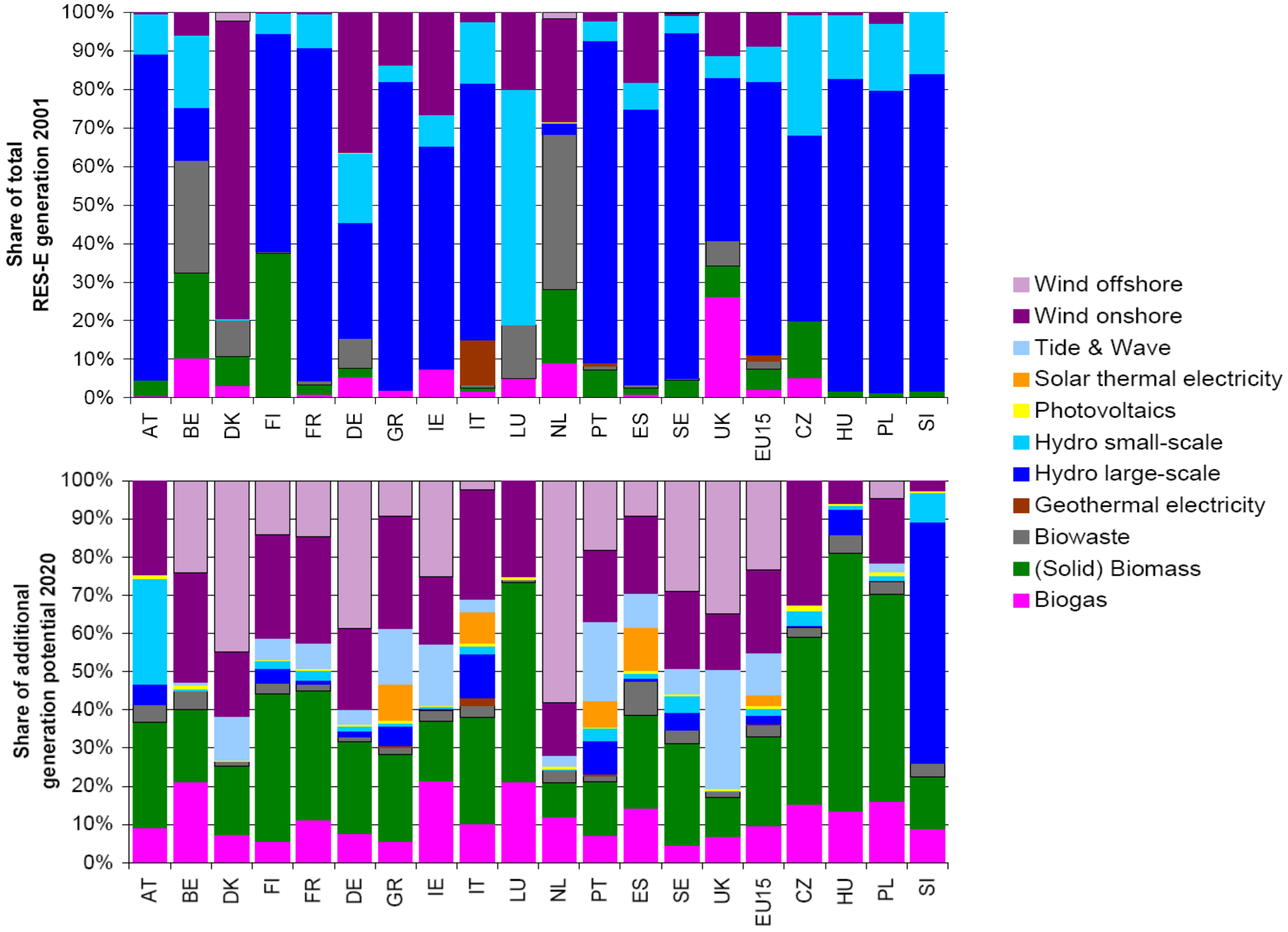
Monitoring of RES Policy Measures

- What is the progress towards targets?
- Monitoring needs to focus on:
  - Is everybody on the same page?
    - Adoption of EU legislation into national legislation
    - Translation into national action plans and policy instruments
  - How do we measure performance?
    - Provision of framework to analyse the impacts of national policies
  - How successful are you?
    - Measurement of progress of the EU-25 states to the targeted deployment of RE.
- How do you know your policy is working and that you chose the right instruments?
  - You **achieve the goals** that you have set at the beginning.
  - They must be measurable and realistic.

RES-E: Achieved and additional Potential, 2001



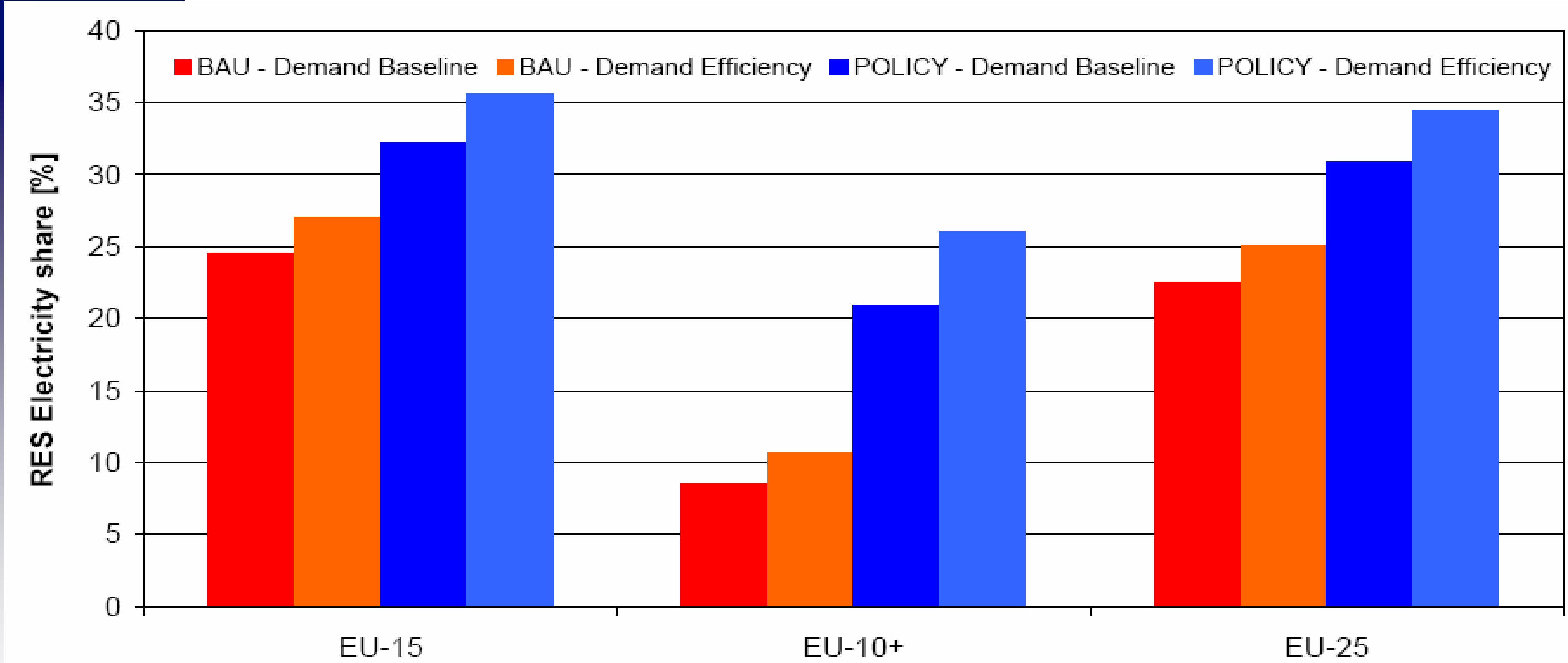
Interaction of Policies

- Policies must adapt to the changing market environment.
- Issues to impact "Holy Three Directives" (White Paper, RES-E Directive and Directive on Biofuels) :
  - EU Enlargement: new RES exploitation prospects (e.g bioenergy).
  - Interaction with other policies, e.g. environmental policies,
  - Completion of internal EU energy market,
    - Free consumer choice $\rightarrow$ enhanced competition
    - Possibility to distinguish green products from conventional power.
    - Enhanced by required disclosure of fuel mix and environmental impact
  - Interaction with the Common Agricultural Policy (CAP reform)
    - The CAP is a highly important element of a consistent RES strategy.
  - The establishment of a carbon market – GHG emissions trading,
  - Affects the economic valuation of investment opportunities.

Monitoring of the policies

- Monitoring of the implementation on national level
- Detailed analysis of existing national
  - RES objectives and Policies
  - Promotion schemes + Barriers
- Result: proposal for a 15 year strategy (2020)
- Scenarios for future evolution:
  - Business-as-usual (BAU): Present policies and barriers
  - Policy scenario (PS): Best practice national policies are selected
  - Both assume the technology learning effect and economies of scale
- Methods for forecasting of RES penetration
  - Model-based: explicit modeling of relationships
  - Econometric analyses: correlations on historical data
    - Best practice policy implementation and corresponding RES penetration

Share of RES-E production in 2020



Overview

- Introduction
- Policy Instruments for the Promotion of RES
  - Main Instruments in the Sectors
    - Electricity, Heat and Transport
  - Success Stories and Key Barriers
- Recent Policy Developments

Main Instruments in the Sectors

- The three main energy consumption areas that EU has designed policy support for:
  - Electricity, Heat and Transport.
- The main RES policies and measures in Europe are focusing on RES-E.
  - Choice of instruments has not been prescribed or harmonized in Europe
  - Each country adopted own unique set of promotion instruments.
- National RES goals:
  - Environment,
  - Security of supply,
  - Employment support for national (emerging) renewable industries.

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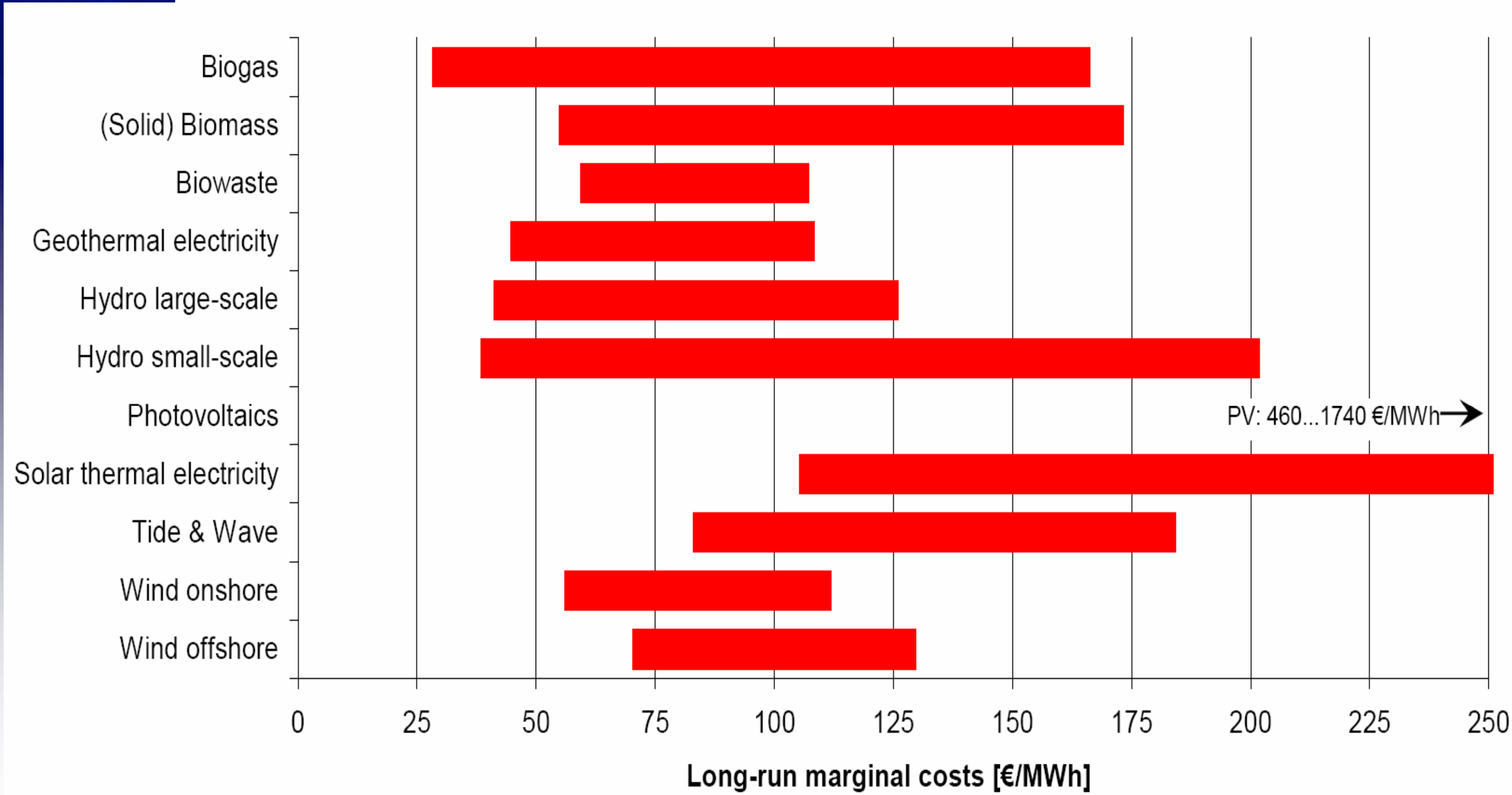
RES-E: Supporting Instruments

- Main instruments to support generation of RES-Electricity are:
  - Fixed feed-in tariffs,
  - Quota obligations,
  - Green certificate system,
  - Fiscal incentives,
  - Tender scheme.

Evaluation Criteria of Policy Instruments

- How do you know which instrument is the right one?
  - Effectiveness: quantitative goals, capacity or production
  - Market efficiency: price competition, min. of costs
  - Certainty for RES-E industry: system stable in the short/long term?
  - Cost effectiveness: costs per kWh of RES-E
  - Stakeholder support for the system
  - Equity: long-term sustainability of the system
    - fair distribution of costs and benefits of RES-E implementation over various stakeholders.

Long-term marginal gen. costs (2002) of RES-E technologies



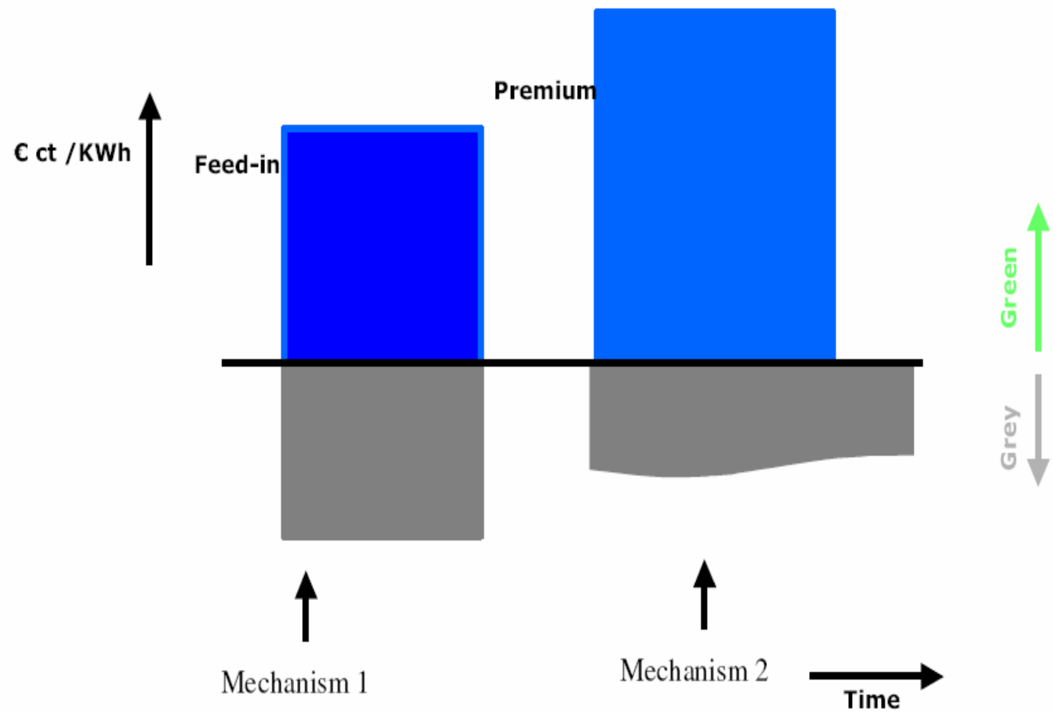
RES-E: Fixed feed-in tariff (FIT)

- Qualified Producer (QP) status is awarded to producers if they:
  - Use RES to generate electricity
  - Use CHP system with a above-average efficiency
- Distributor has to buy electricity from QP

- What is the Feed-in Tariff?
  - Feed-in Tariff (FIT) is an **instrument** for RES support.
  - It allows the **qualified producers** to receive a fixed price for all their produced energy, OR sell energy on the market independently, receive market price and a fixed premium.

RES-E: Fixed feed-in tariff (FIT)

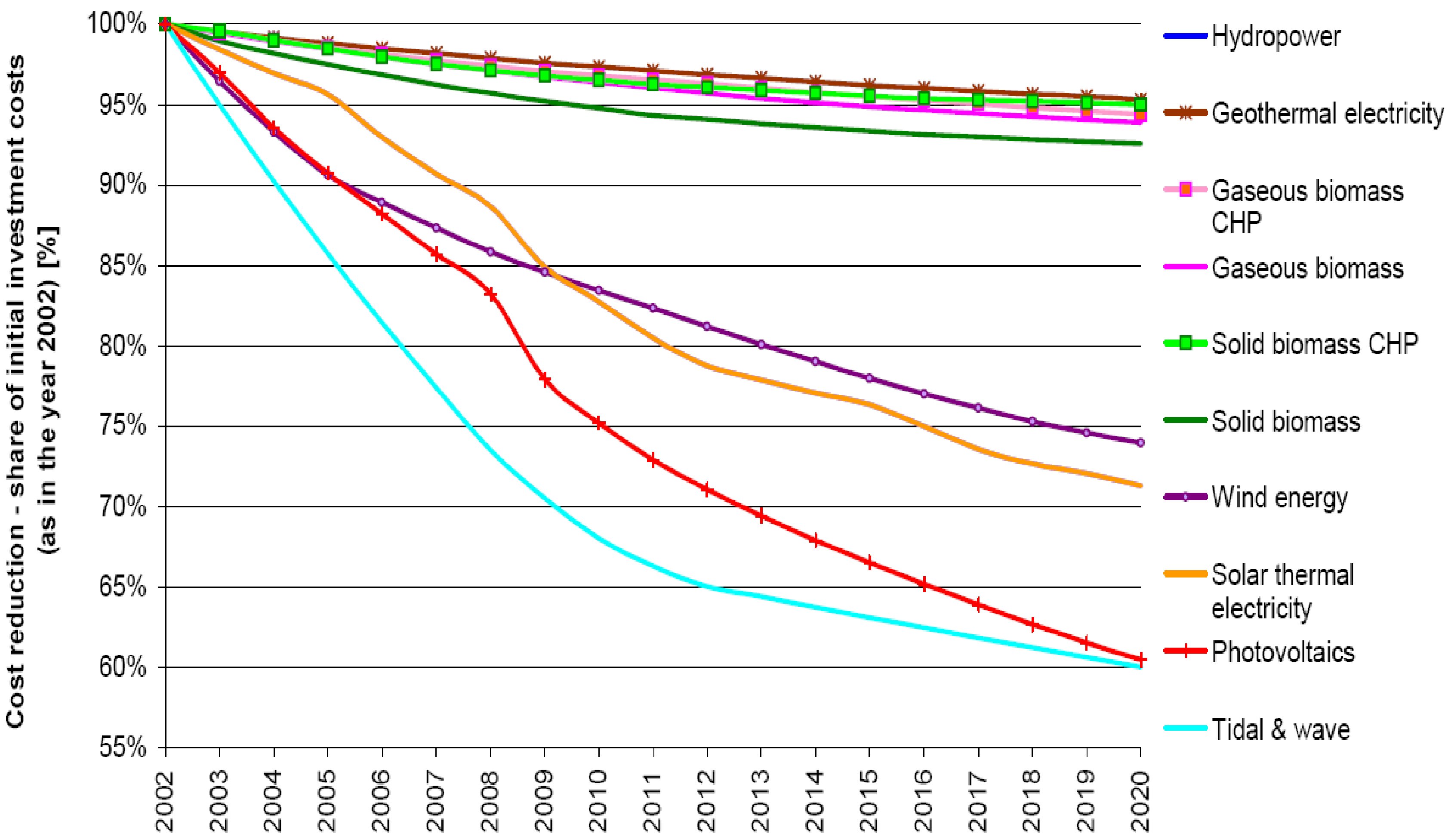
- Qualified Producer has two options to sell electricity:
  - To distributor at the fixed regulated tariff (% of average electricity tariff). Option know as *feed-in tariff*;
  - Free market sale: independently sell electricity on the market at market price + receive fixed premium from distributor.
- Every year, QP can choose the best option for him.



RES-E: Fixed feed-in tariff (FIT)

- Main instrument for RES-E generation support in EU-25.
- Advantages:
  - Investors get longer-term certainty about receiving support,
    - Much lower investment risks of future return on investments
    - Significantly lower capital costs for RES investments
  - Lower costs for society.
    - Stepped tariffs reduce producer surplus (by limiting windfall profits)
    - A tariff can be reduced over time in line with technology learning.
  - Can be designed to promote a broad portfolio of RES technologies.
    - Early market diffusion of less mature technologies,
    - Higher dynamic efficiency (lower costs for society in the long term).
- Disadvantages:
  - FIT do not stimulate sufficient competition among RES generators
    - Does not bring down the costs of RES technology investments.
    - Generation costs for individual installations might be higher.
  - Relies on more government involvement than quota system.

Development of Investment Costs (BAU scenario)

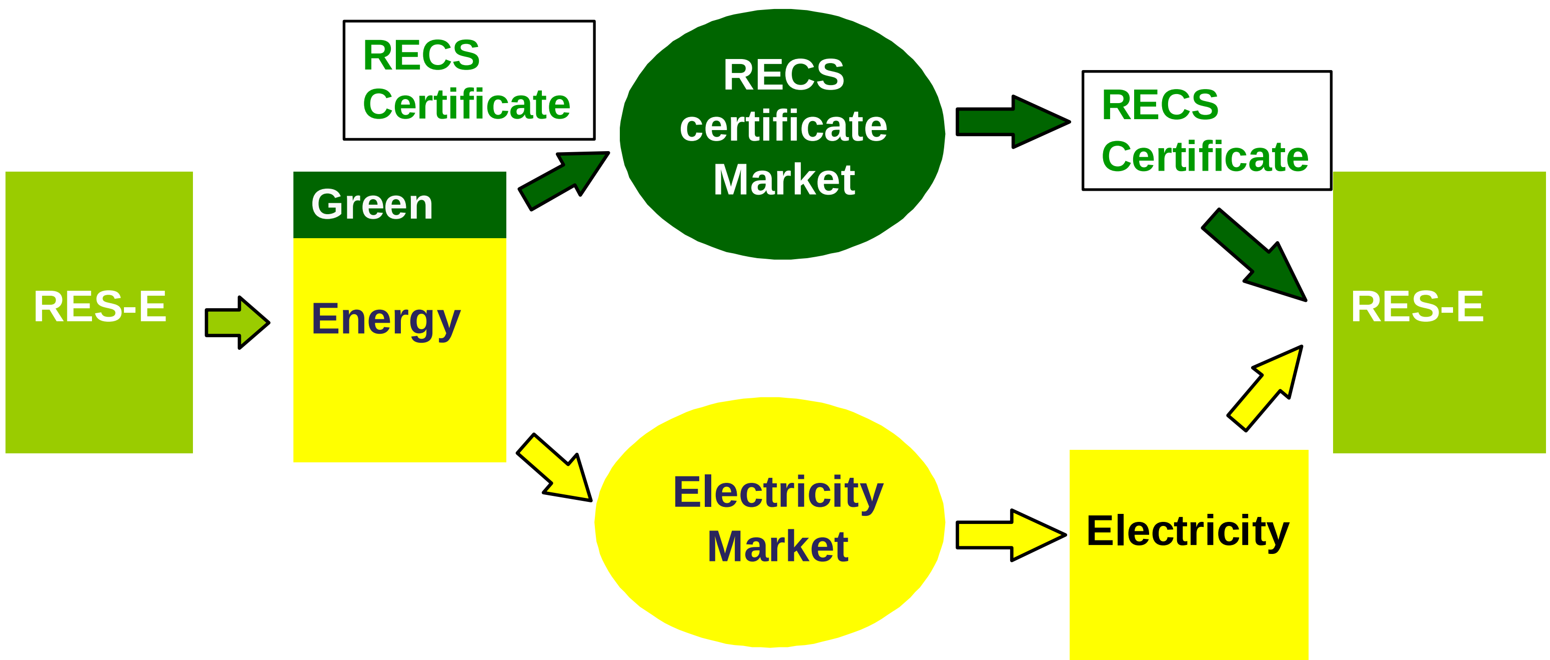


Renewable Quota Obligations (RQO)

- RQO are relatively new, used in 5 of 25 EU states (BE, IT, SE, UK, PL).
- Impose minimum shares of renewables on
  - Consumers, Suppliers or Producers.
- The system is often combined with green certificate systems.
- Advantages:
  - Relies more on market forces and competitive policies than FIT
  - Provides a strong incentive for short-term technology cost reductions.
- Disadvantages:
  - Initial stage of development,
  - Complexity of the system,
  - Risk of supporting only lower-cost technologies.
  - Only works well when designed carefully.
- Basic concepts of RQO and FIT are gradually converging.

RES-E: Tradable Green Certificates (TGC)

- Known as Tradable Renewable Certificates (TREC)
- Market-based instrument for transfer of production attributes or environmental quality of RES-E separately from electricity.
  - For each 1 MW of electricity 1 TGC is issued.
  - Buyer assures that RES-E is produced somewhere in Europe.



Tradable Green Certificates (TGC), 2

- What are Tradable Green Certificates?
  - Tradable Green Certificates are an instrument for RES support.
  - They can be used to
    - transfer, trade and consume
    - the environmental benefit of electricity from RES
    - independently from electricity.
- Several national and international systems exist
- Main ones are
  - RECS certificates: www.recs.org
  - Guarantees of Origin (GoO): based on RES directive (2001/77/EC)

Tradable Green Certificates (TGC), 3

- Several national and international systems exist, main ones are
  - RECS certificates: www.recs.org
  - Guarantees of Origin (GoO): based on RES directive (2001/77/EC)
- Advantages:
  - Completely market based
  - Internationally supervised, standardized, universal
  - Can distinguish among supported technologies: the buyers decide!
  - Can be a foundation for green retail products
- Disadvantages:
  - Double counting can be an issue
  - Voluntary market alone is not sufficient to sustain trading.
  - Obligatory market is coupled with Quota obligations and works well.
- Certificate systems are becoming increasingly popular, linked to different support schemes:
  - UK, IT, SE (considering: CZ, PL): to Quota obligation
  - NL: to FIT / Tax exemption
  - BE: to FIT / Quota

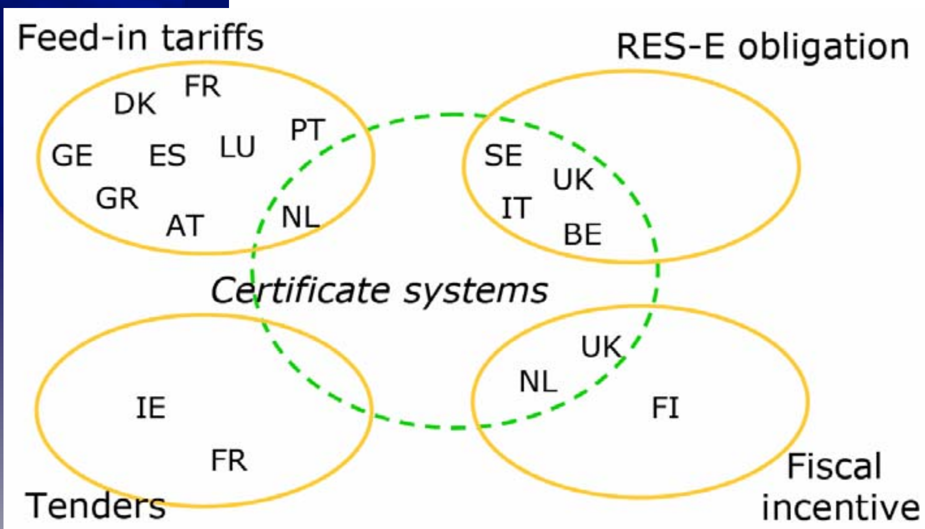
RES-E: Tax / Fiscal incentives

- Indirect financial support through taxes.
- Fiscal incentives are
  - Producer: tax exemption of CO2
  - User: reduced energy taxes.
- Advantages:
  - Convey direct message to final energy consumers about the added value of RES-E.
- Disadvantages:
  - No longer-term certainty about investments → increased investment risks.

RES-E: Tender scheme

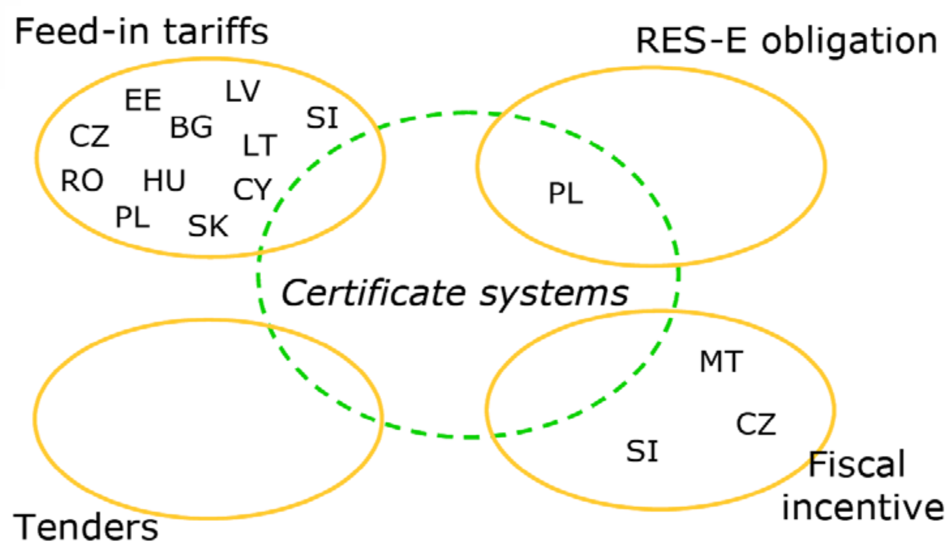
- Gov't issues a tender for licenses for building RES-E generation.
- Tender scheme has been used in the UK and is still used in Ireland and France.
- Advantages:
  - Draws attention towards RES-E investment opportunities
  - Incorporates competitive element.
- Disadvantages:
  - Overall number of implemented projects very low,
  - Much lower penetration of renewables than anticipated.

RES-E: Overview of Renewable Electricity Support Systems



- EU-15

- EU-10

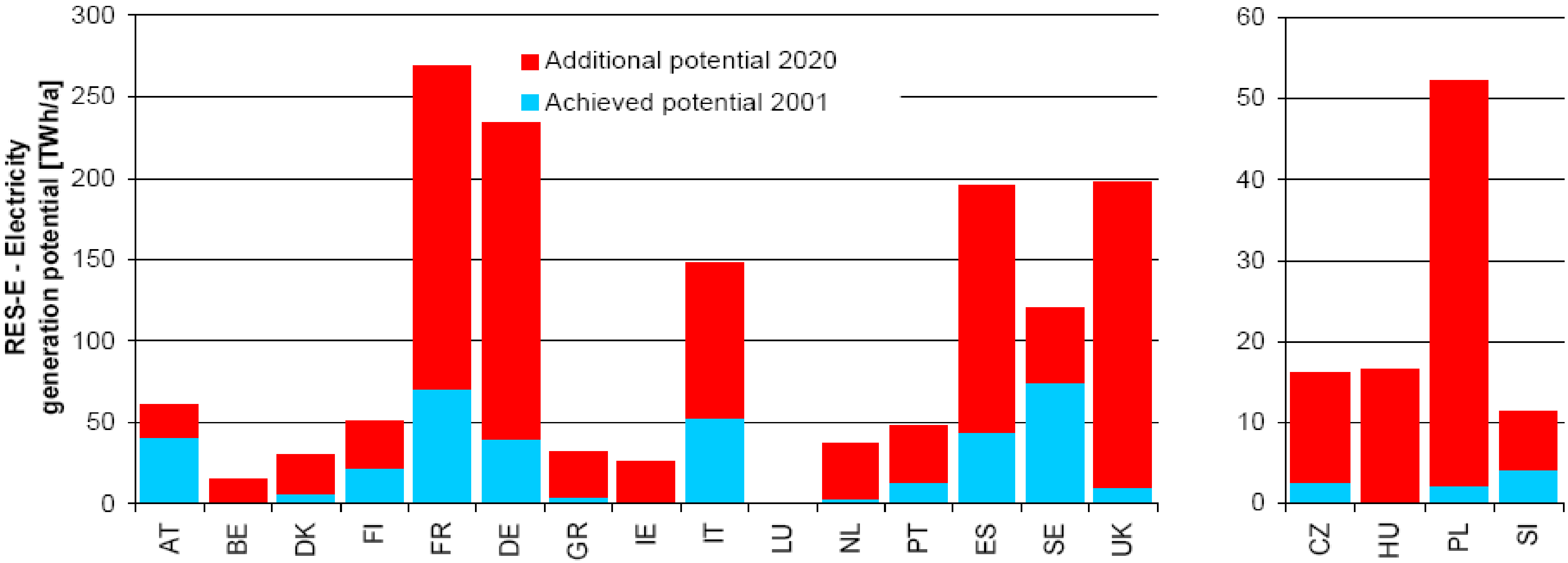


Status of the RES-E market

- RES-E continued to increase in recent years.
  - Most countries are still behind targets.
- Wind: high growth rates are to continue offshore.
- Biomass: starts growing, but slowly in most countries.
  - Large unexploited potentials in new member states
- PV: growing, constant high rates
  - DE: new FIT → accelerated growth!
- Active solar thermal el.: to grow by 15-20% annually
- Wave, Tidal: Significant growth in the medium term
- Geothermal: small growth.
- Hydro: small growth.
  - Large hydro: Most environmentally sustainable potential exploited (Some remaining potential for refurbishments.)

RES-E: 2001 vs. Potential in 2020

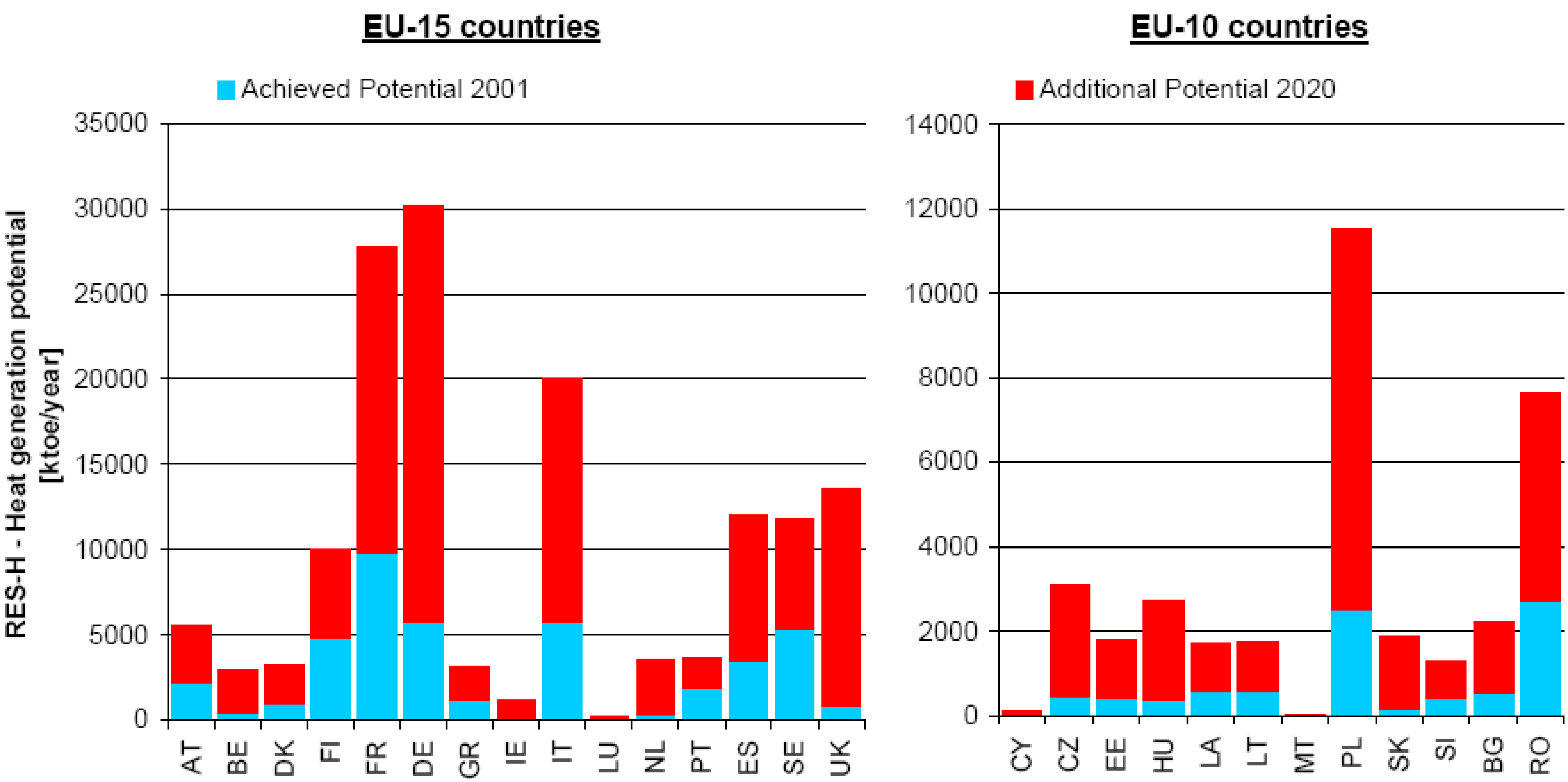
- Where can the RES-E generation potential evolve?



Instruments to Support RES Heat (RES-H)

- Europe: very few policy incentives for RES-H
- Mainly concentrated on local support policies.
  - Local objectives: industrial support or employment opportunities
  - Mainly solar thermal panels and small scale biomass heating
  - DK: obligation scheme to support solar heating in large buildings
- First EU-wide policy:
  - Directive on the energy perf. of buildings (EPBD), 2002.
  - Promoting selected RES-H technologies
- Efforts still required to build European RES-H market
- Promotion of qualified, skilled manufacturers,
  - Financial support mechanisms to close the price gap to natural gas,
  - Increasing awareness of users and knowledge of installers.

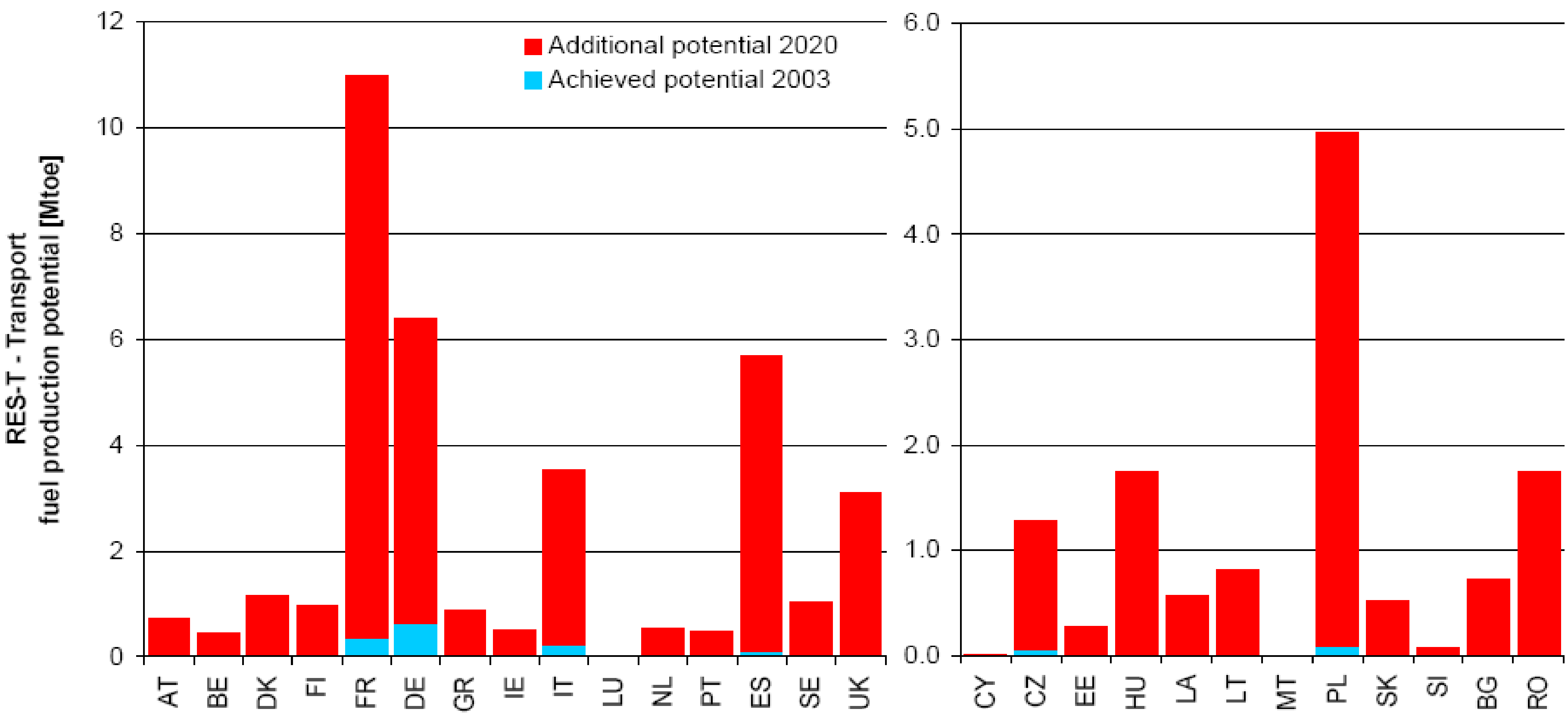
Heat: 2001 vs. Potential in 2020



Instruments to Support Biofuels for Transport (RES-T)

- Biofuel: early development stage on European market
- Directive on the promotion of biofuels (2001)
  - Share of biofuels in total transport:
    - 0,6% (2003) → 2% (2005), 5.75% (2010)
  - No common approach to promotion policies.
- EC: full tax exemptions for biofuels
  - biodiesel, bioethanol
  - More competitive with conventional transport fuels.
  - Impressive growth: DE, FR, ES, IT
- Most countries still have no indicative national targets
  - Instruments: compensation schemes and tax exemptions
  - Tax exemptions for biofuels effective for market position.
    - AT, CZ, DE, FR, IT, PL, ES, FI, SE
- Major biofuel production: in DE, FR, IT, PL, CZ.

Biofuel: 2003 vs. Potential in 2020



Combining Support Schemes

- Measures need to be combined to be effective.
  - RES-E Directive - clear goal to combine measures.
  - Specific support instruments (FIT, Quotas etc.)
  - Capital subsidies, long-term policy and target setting
- Integrated policies:
  - Combine Rational use of energy (RUE) with RES supply.
  - Directive on the Energy Performance of Buildings
- RUE is combined with
  - decentralised energy production, preferably from RES

Overview

- Introduction
- Policy Instruments for the Promotion of RES
  - Main Instruments in the Sectors
    - Electricity, Heat and Transport
  - Success Stories and Key Barriers
- Recent Policy Developments

LABORATORY FOR ENERGY POLICY

Success stories and key barriers

- Specific instrument design or implementation
  - Not instrument type
- Alleviation of market barriers:
  - Political uncertainty:
    - Uncertain or unclear long-term institutional setting
  - Complex administrative systems
  - Grid connection rules and planning issues
  - Transparency of grid connection costs
  - Tender schemes:
    - stop-start nature;
    - uncertainty of winning a bid
- Social acceptance:
  - biomass, large-scale wind.

Success factors

- DE: Combination of FIT + investment support
- UK: redistribution of ROQ buyout revenues,
- BE: high penalties for non-performance
- AT: mandatory disclosure of fuel mix
- Key factor:
  - clear and long-term institutional setting → good investor security.

Barriers

- Complex administrative systems: BE
  - Long lead times for actual project realisations
  - Higher investment uncertainty.
- Regional grid weaknesses : PT, ES, IT, IE.
  - Much RES-E planned and ready for construction,
  - Implementation delayed, expected grid connection problems.
- Political uncertainty: DK, AT, NL, FI, IT, SE
- Markets with high FIT (NL, PT) or strong investment climate (IE) but without long-term certainty →
  - Investors were reluctant
  - Higher equity/debt ratios or higher interest rates,
  - Lower RES penetration than expected from the level of financial support.

Overview

- Introduction
- Policy Instruments for the Promotion of RES
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Recent policy developments, RES-E

- Most significant changes, 2002 – 2004
  - AT, FR, NL, SI: new feed-in systems.
  - SE: introduced a renewables obligation for end users, linked to a TGC system.
  - IE: large tender rounds for wind energy issued.
  - ES: very attractive feed-in tariffs for solar thermal electricity generation introduced.
  - DK: changed most of its formerly successful schemes.

Recent policy developments

- RES targets
  - RES-E: EU RES-E Directive: leading policy document for national target setting
    - October 2005, a Report on policies and measures
  - RES-H: Few national selective targets
  - RES-T: No clear national targets
- National policies are constantly evaluated, fine-tuned, and new sets of instruments arise.

LABORATORY FOR ENERGY POLICY

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Renewable Energy Sources Technology, Economics and Policy Curriculum

General module

Overview of Renewable Energy Sources Policy and Supporting Mechanisms in Europe

Part – 2

Authors:

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ISTRABENZ ENERGETSKI SISTEMI

TRADING GREEN ENERGY

renewable support schemes

Bucharest, October 2005

Outline

- Why RES?
- RES on market
- Certificate systems
- Feed-in tariffs
- Practical examples: Austria and Slovenia
- Harmonization of rules in EU
- Future perspectives
- Conclusions





Advantages of RES_E

- The EU set down indicative targets for the production of electricity from renewable energy sources for all Member States, assuming the following advantages
  - environmental protection,
  - sustainable development,
  - increase in local employment,
  - positive impact on social cohesion,
  - contribution to security of supply and
  - meeting the Kyoto targets more quickly.

Market for Electricity from RES: RES-E

Supply of RES-E:

- 3 time/space separate levels
  - Physical flow of electrical energy
  - Financial contract on electricity supply
  - Financial contract on selling characteristics of energy

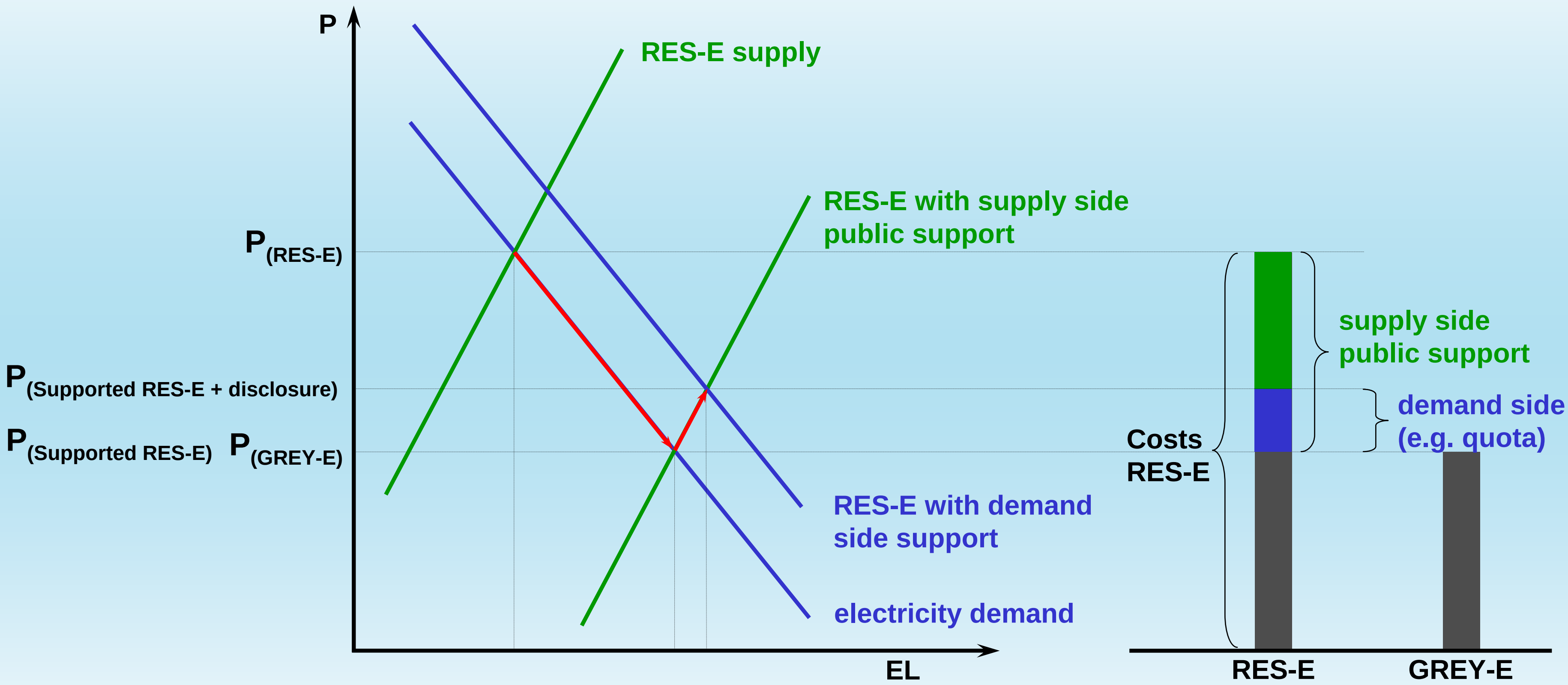
Green certificates

- Instrument for transfer of the information on production attributes of RES-E.
- Project RECS - First international initiative for certificates

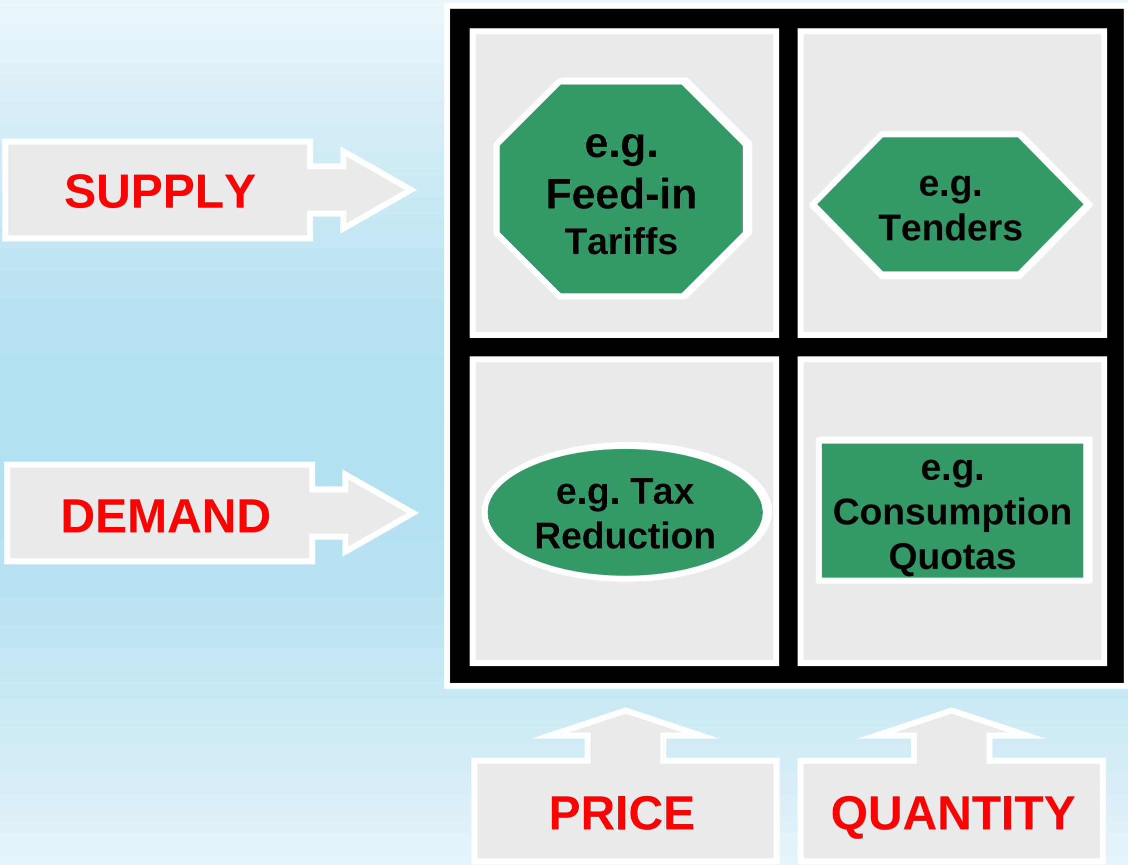
Guarantees of Origin (GoO):

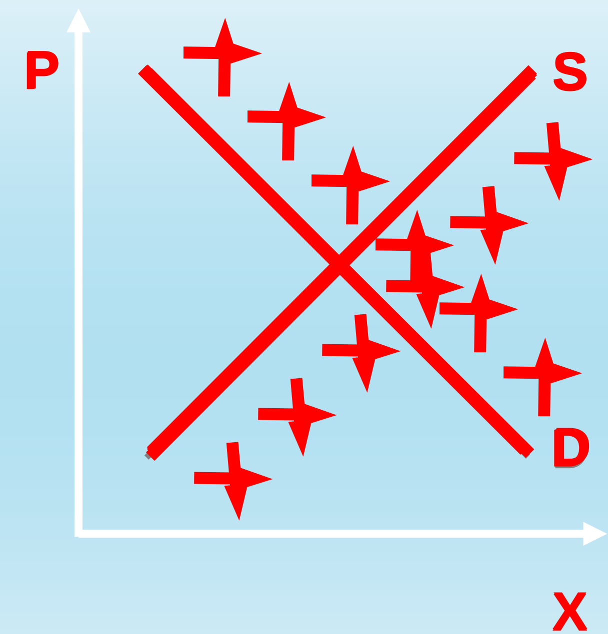
- Dir. 2001/77/EC, Art. 5: GoO for each MWh RES-E
- Slovenia: several bylaws in preparation.
  - Trading with GoO separated from trading with electricity.

WHy RES-E market needs to be supported?



RES-E Support Systems





The two major support systems

- Certificate system makes national and international trading possible, supports renewable energy production at the best and most productive sites

For mature markets

- Feed in tariffs, if fixed for a minimum period of at least the first 10-15 years of operation period, give interested investors a high economic security.

For emerging markets

RECS System

RECS International

- Largest international association of energy companies
- Promotes international trading with green certificates
- AIB (Association of Issuing Bodies) development and activity of RECS system:

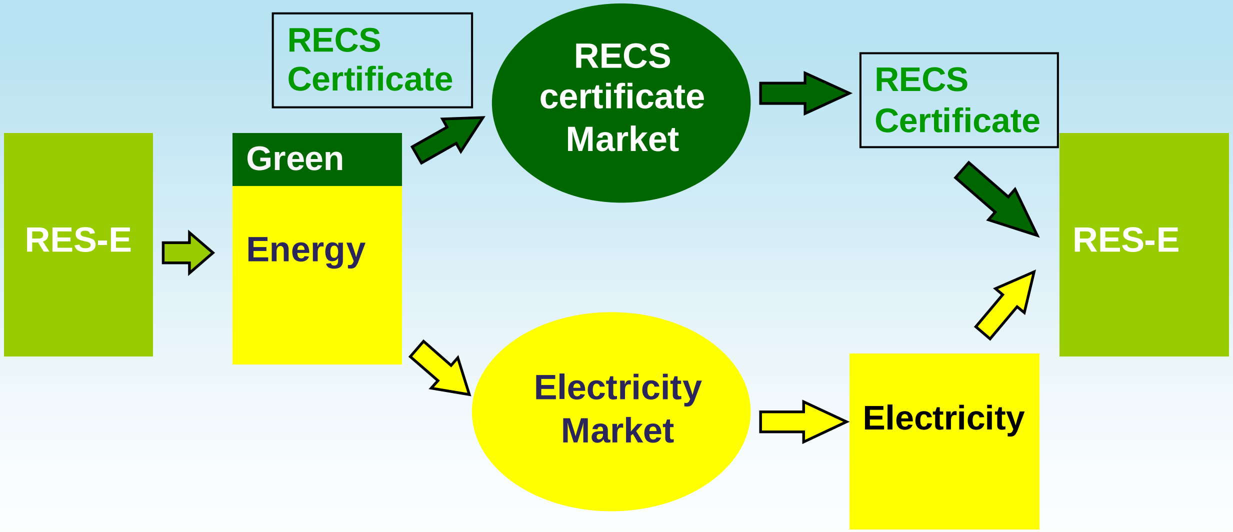
Slovenia: RECS is successful

- Issuing Body in Slovenia: AGEN-RS.
- Auditing Body: TÜV Sava Bayern, Germany
- National and international sales of certificates

Green Certificates trade

"Wholesale market" for RES-E

- Buyer assures production of RES-E in Europe.
- Trading with Certificates and energy is independent
  - Energy: traded for the future
  - Certificates: issued for the energy produced in the past
- Green certificate
  - Internationally supervised origin of RES-E
  - No double-selling of the same RES-E.

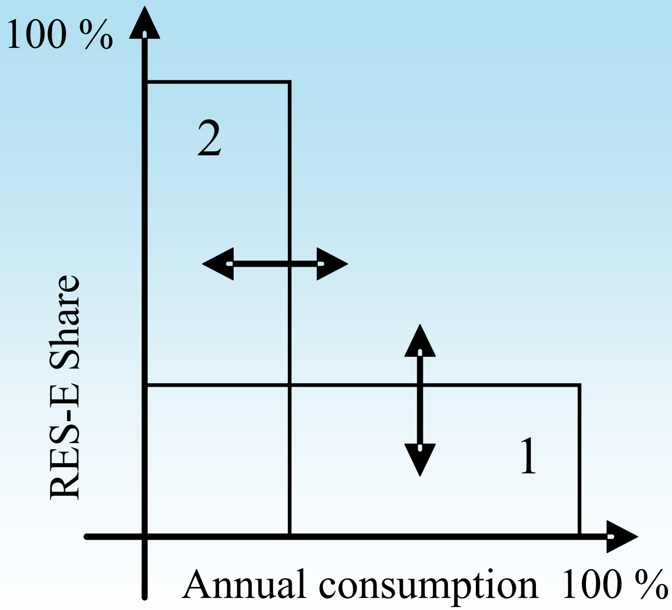


Retail Market for RES-E

RES-E end-products

- Green Certificates used for quality assurance
- Sales procedures differ in companies/countries
- Suppliers can influence demand considerably
    - Structuring and marketing of RES-E end-products.
- Energy labels used in RES-E products:
    - not harmonized nor comparable.
- A comprehensive marketing communication with buyers is necessary.

Two methods of RES-E products formation

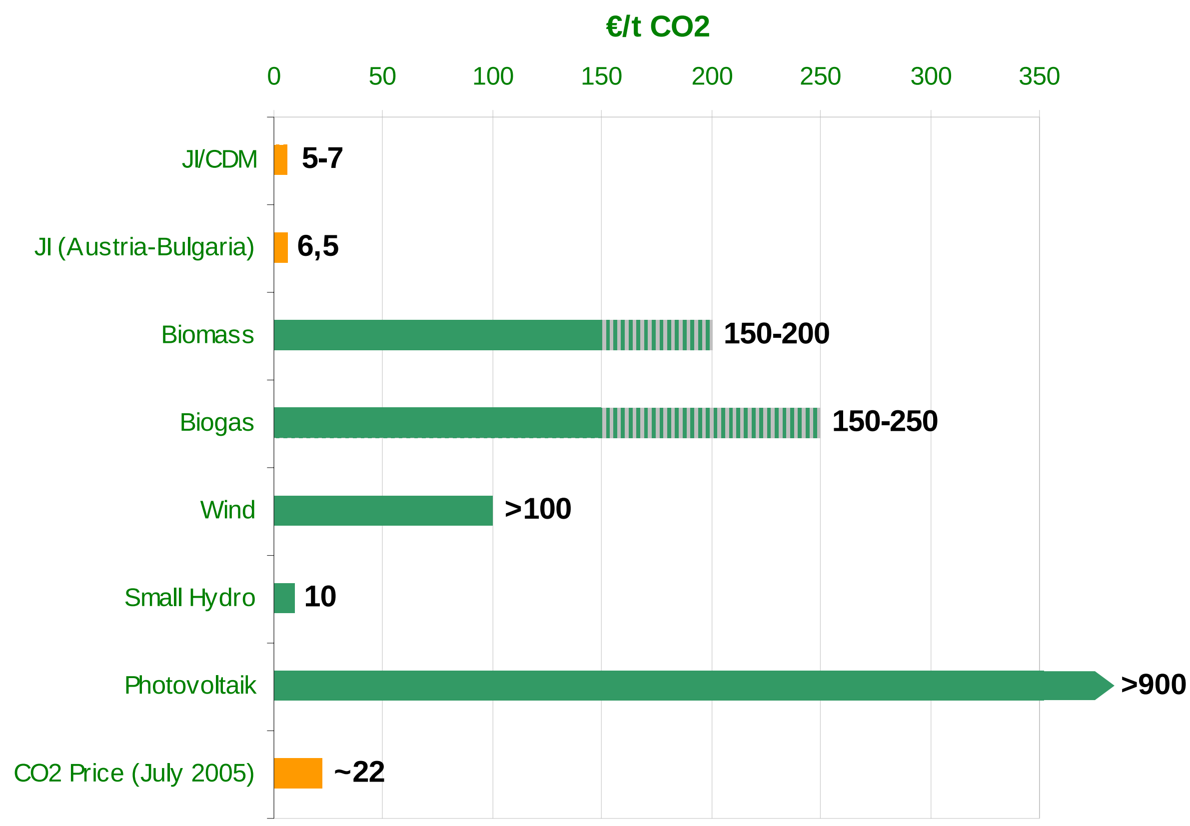


Subsidies create potential market distortions

- Economic theory states that subsidies in general have the potential to distort the market.

1. Additional costs are allocated differently to end consumers from one country to the other.
2. Different support levels create undue competitive advantages for some market participants.
3. Guaranteed support levels often lead to artificially high production costs, because power equipment producers align their prices to the support level.

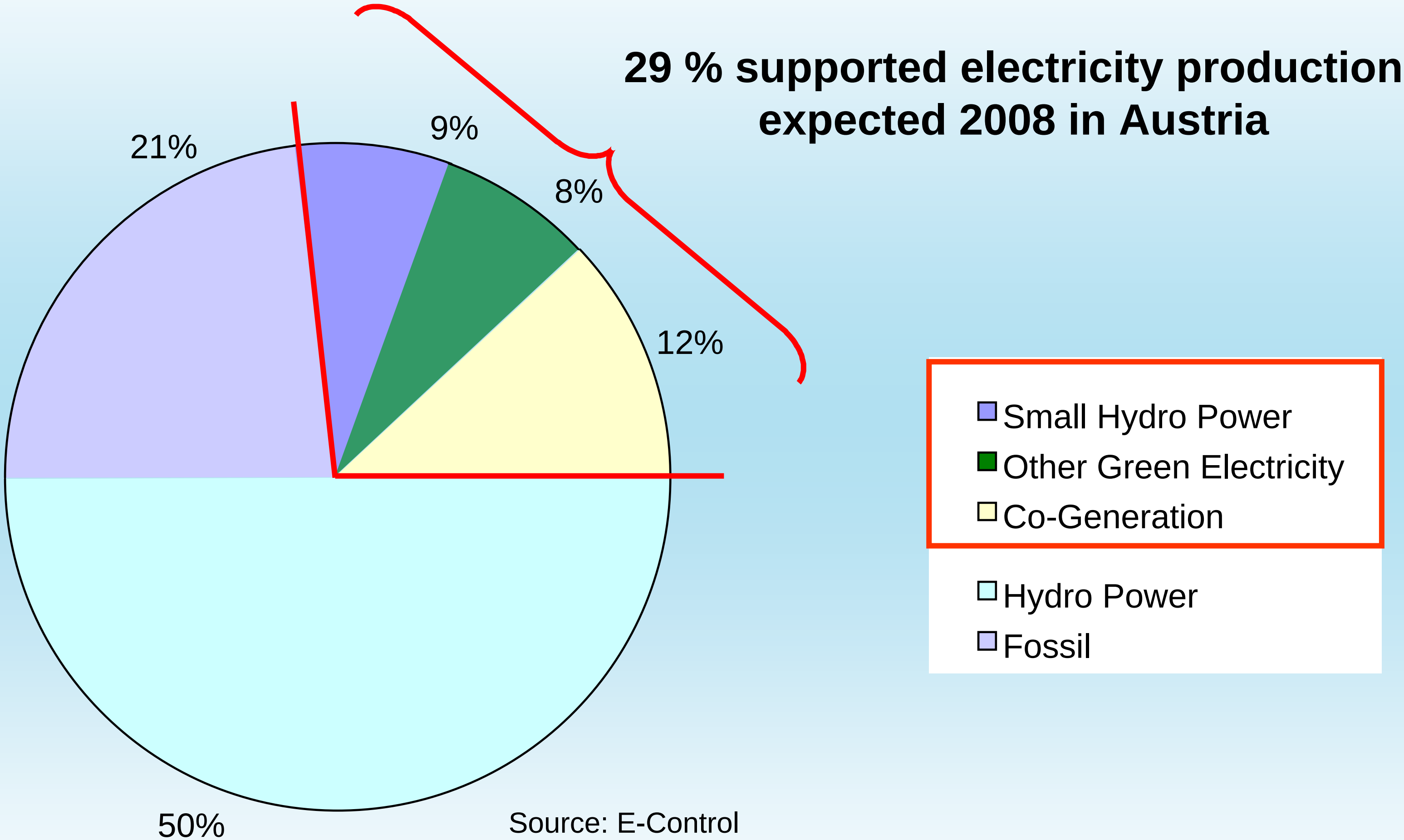
CO_2 Reduction Costs – Flexible Mechanisms vs. RES_E in Austria



Source: E-Control

Supported Electricity in Austria

29 % supported electricity production expected 2008 in Austria



Source: E-Control

RES electricity generation in Slovenia

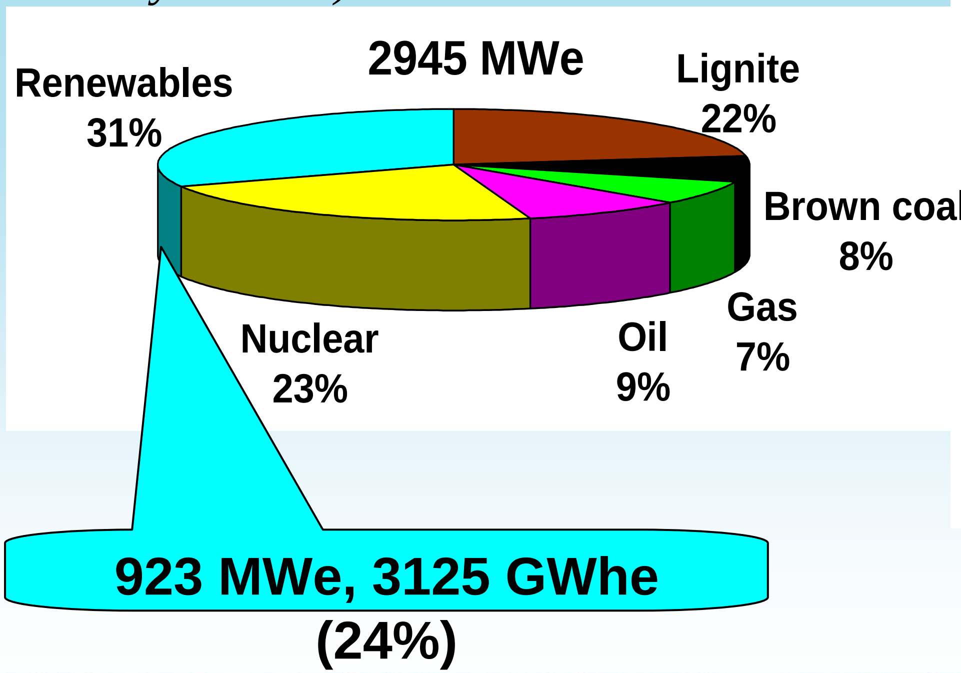
<u>TOTAL Installed el. gener. capacity:</u> ~ 3000 MW_e

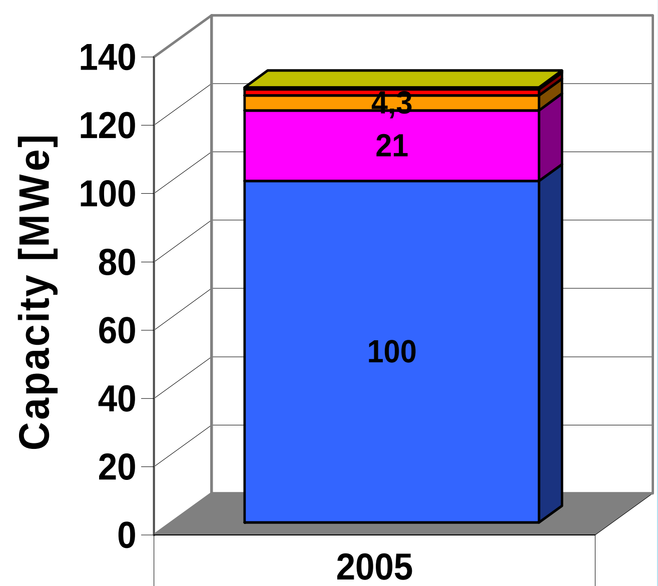
(50% of NPP owned by Croatia)

Installed capacity (<10 MW):

<u>~ 127 MW_e</u>

470 GWh (4%)





	2005
Wind	0,01
PV	0,1
Bio gas	0,5
Sevage gas	1,8
Landfill gas	4,3
Biomass	21
Small Hydros	100

SLOVENIA
Legal Framework for RES installations

Energy Act (1999, 2004)
Status of "Qualified electricity producers" (QP):

- with above-average efficiency CHP (Yearly efficiency $\geq$ 78%)
- **use of renewable energy sources (RES)**
- **in a manner consistent with the protection of the environment**

Network system operators:

- responsible for the purchase of all electricity offered by QP at the price determined by the Government
- obliged to conclude **long-term (10 years) feed-in contracts**.
- payment of a premium for the independent el. sales of QP
- all costs covered by the price for the use of networks.

Ministry for the Economy - responsible for QP policy:

- requirements for QP, setting and updating of feed in tariffs

Feed-in Tariffs (FIT) for QP

Uniform price or **binom tariff** (day/night, seasons)

Premium – varied by technology and primary source:

- **100%** for independent electricity sell
- **30%** for own electricity use (without use of public network)

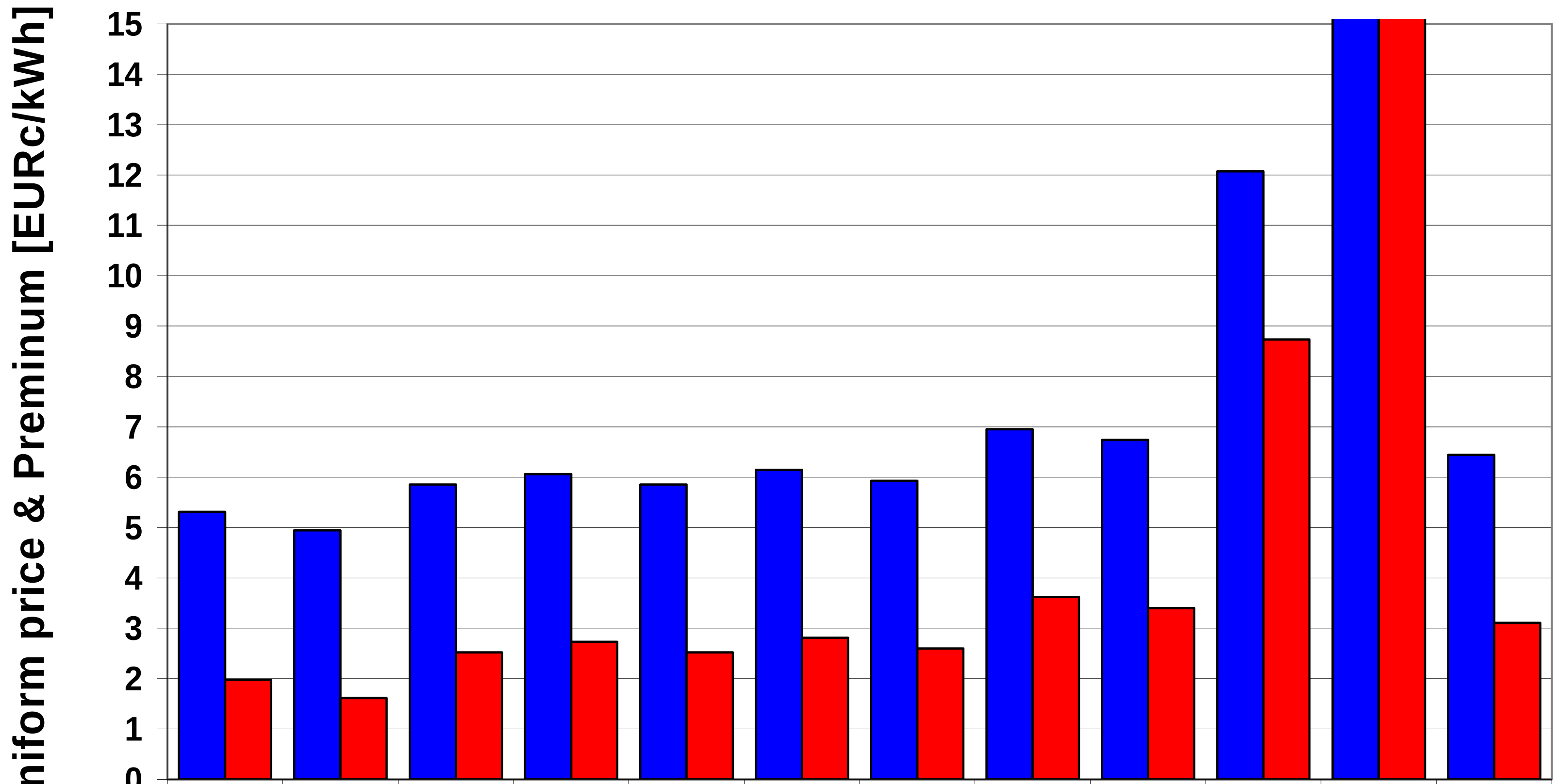
Reduction of FIT:

- **-5%** on transmission net., after 5 years, for each 10% invest. subsidy
- **-10%** after 10 years of operation

Micro QP (<36kW) – household tariff (two way counters)

FIT renewed once per year (inflation)

Feed-in Tariffs for QP (2)



	Land fill < 1MWe	Land fill < 10 MWe	Geotherm.	Wind < 1 MWe	Wind > 1 MWe	Small hydro < 1 MWe	Small hydro < 10 MWe	Biomass < 1 MWe	Biomass > 1 MWe	Bio gas	PV < 36 kWe	PV > 36 kWe
Uniform price	5,3	4,9	5,9	6,1	5,9	6,1	5,9	7,0	6,7	12,1	37,4	6,4
Premium	2,0	1,6	2,5	2,7	2,5	2,8	2,6	3,6	3,4	8,7	34,0	3,1

Subsidies and network costs

Subsidies and financing:

- **restricted investment subsidies:**
  - biomass, biogas, heat pumps and remote PV installations (yearly tenders).
- **financing (up to 50%) feasibility studies and project documentation**
- **Soft loans** (Environmental found of the RS)

Minimum costs of network prices for use of electricity from QP up to 1 MWe:

- **Consumers (even households eligible customers before 1.7.2007) pay the price for use of network reduced by:**
  - the network charge for the use of transmission network
  - supplement for preferential dispatch *(QP + Dom. coal protection)*

Certification

RECS certification system:

- Agency of energy (regulator) – designated certifier
- **Holding Slovenske elektrarne – main trader**

Guarantees of origin (2003/54/EC)

- Decree drafted
- Agency of energy (regulator) – issuing body

Green electricity market

EKOWATT

Private supply company created by owners of small hydro PP

- Small commercial customers and HH
- **Huge problems with energy balancing !**

Modra energija
Obnovljivi viri sedanjosti in prihodnosti

Holding Slovenske elektrarne

- ***Large hydro PP production***
- All eligible customers (industry, services)
- *Price supplement:* ***4 EUR/MWh***
- ***2005: ~ 600 contracts, 25 GWh***

ZELENA ENERGIJA

Distribution company Ljubljana

- **Own small hydro PP production**
- Households
- Very limited response (50 contracts)
- Recent decrease of price (*price supplement:* ***4 EUR/MWh)***

Modra energija
Obnovljivi viri sedanjosti in prihodnosti

Modra energija

2005: RES-E Market in Slovenia starts

- Stimulation of RES-E development
- Formation of the RES-E market
- Sales of RES-E in Slovenia.

Product : Modra Energija (Blue/Wise energy)

- Registered Brand
- Based on RECS certificates
- HPPs involved – Renewable Energy Declaration.

The price of ME: 1 SIT/kWh

- Fixed surcharge to end-consumer electricity price

Individual buyer can purchase

- between 10 and 100 % share of ME

Modra energija

Modri sklad (*Blue Fund*)

- Collects 60 % of the ME income
  - Financing of the projects that stimulate RES-E production
  - Development and reconstruction of RES-E production units
  - Research of RES.

Consumers of ME – benefits

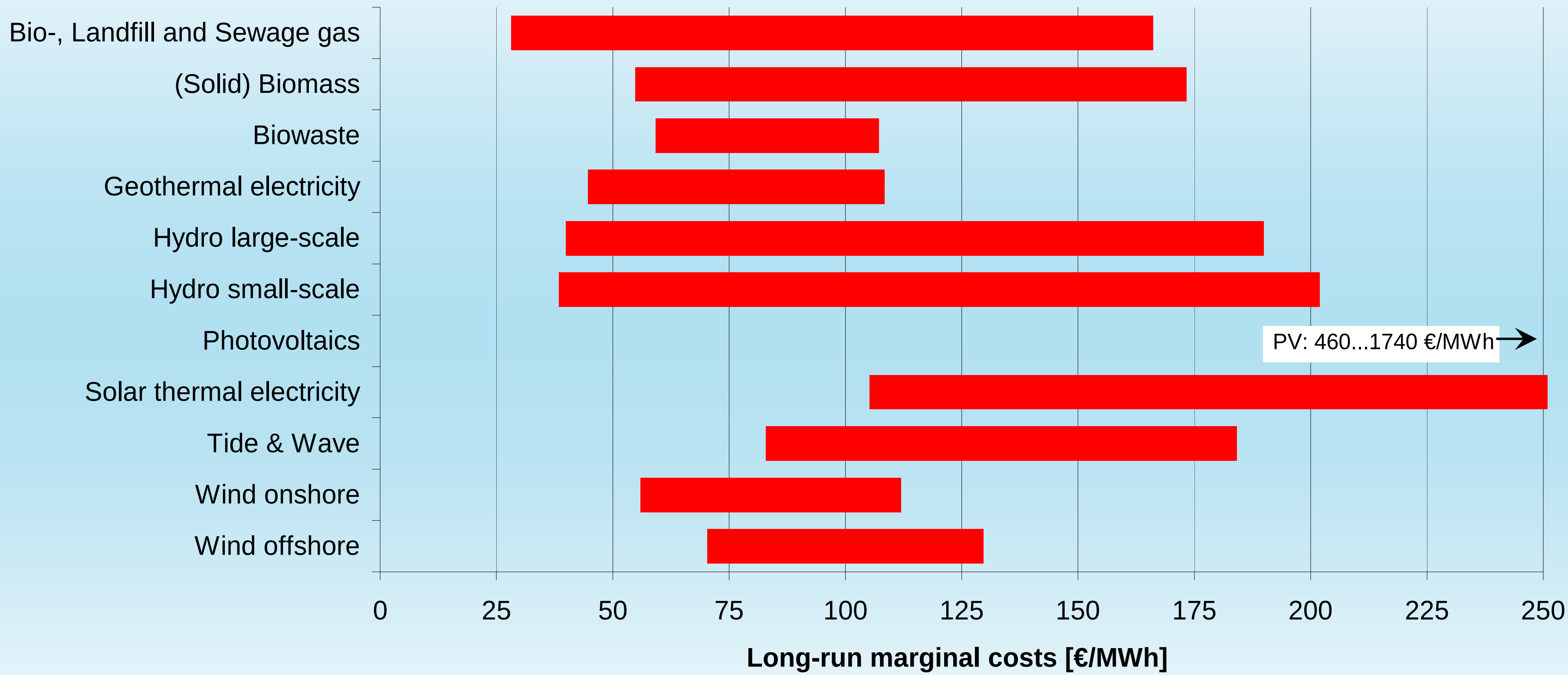
- Listed on a dedicated web site of Modra energija
- Improved visibility - high environmental awareness
- Official certificate/diploma:
  - Lists the purchased quantity of RES-E in the calendar year.
- Use of a special label in marketing of products and services.

Sales of Modra energija

- January 2005: sales begin
- July 2005 : more than 720 companies, individuals on board

RES-E Market in Slovenia: expected to grow

Different Costs of RES-E in EU-15 (2003)



Source: CEER – Current Experience with Renewable Energy Support Schemes in Europe

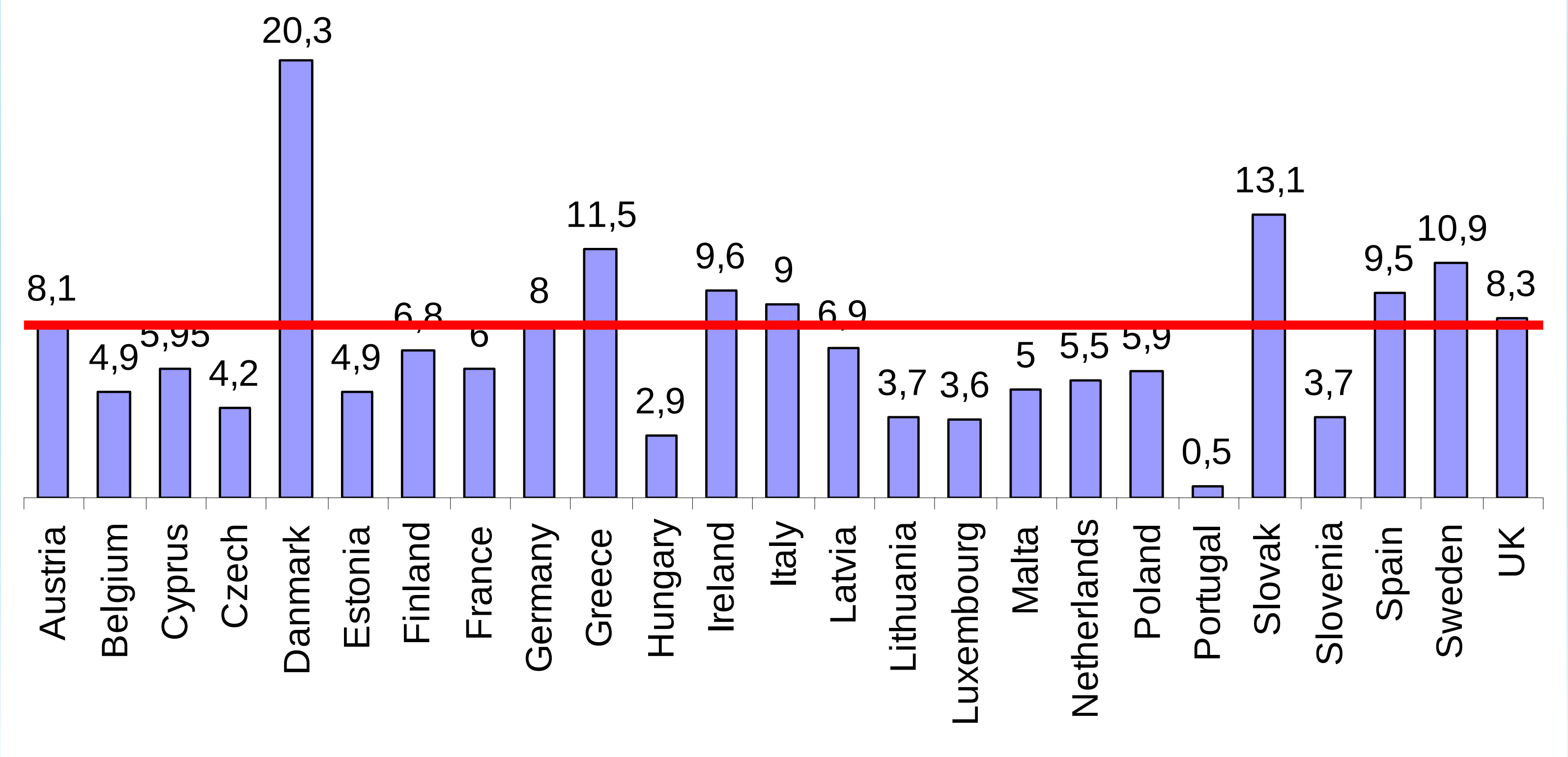
Support systems need to be harmonized!!!

- Green electricity support in Europe effects market distortions and cost-ineffectiveness
- Main problem: **no harmonised support system**
- A harmonised support system should fulfil the following standards:
  - reflecting the existing potentials of different energy sources within Europe,
  - enhancing competition between generators,
  - encouraging renewable electricity suppliers to improve operation performance and technological efficiency,
  - offering objective information to end consumers,
  - including additional costs and making them transparent and
  - introducing market based mechanisms.

ISTRABENZ ENERGETSKI SISTEMI

Indicative targets of the RES_E Directive

Different indicative targets lead to an unbalanced burden sharing within the different Member States and the targets are designed as a production target but meant as a consumption target = **distortion + confusion**.



+8% until 2010 = EU wide target

Increase of RES-E production from 1997 to 2010 in %

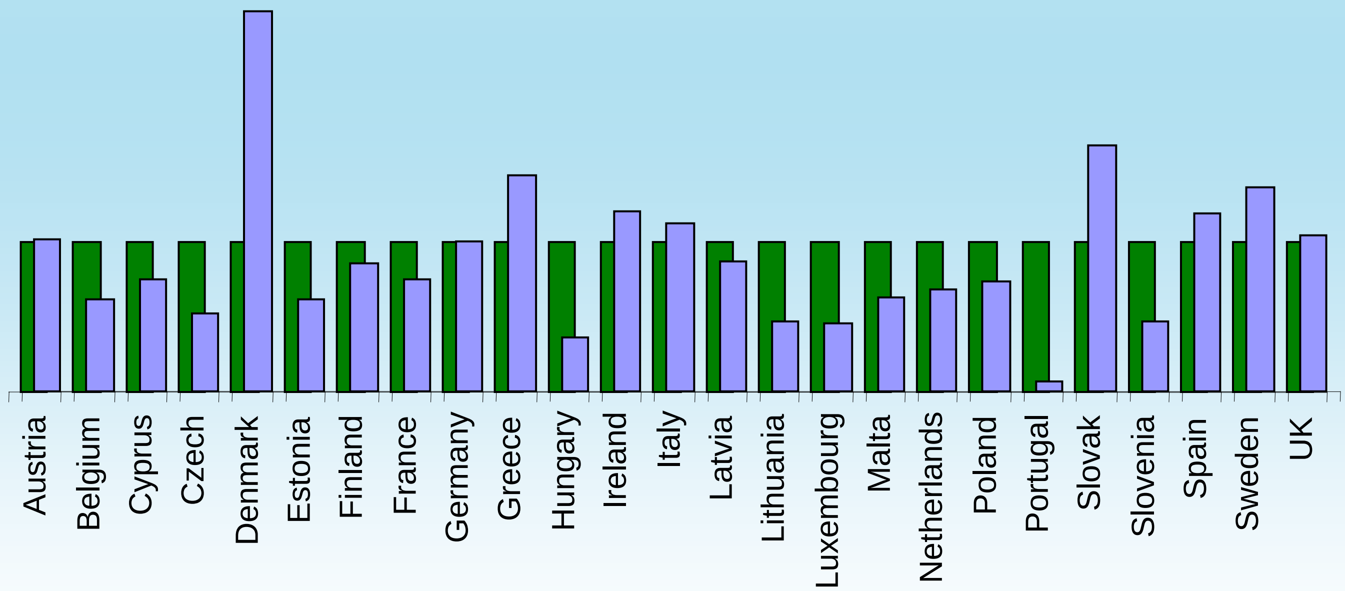
Possible solution: Pan-European certificate system

Change from different national to an overall target

Every end consumer within the geographical scope of the Internal Electricity Market has the same additional obligatory target

Penalties need to be equal

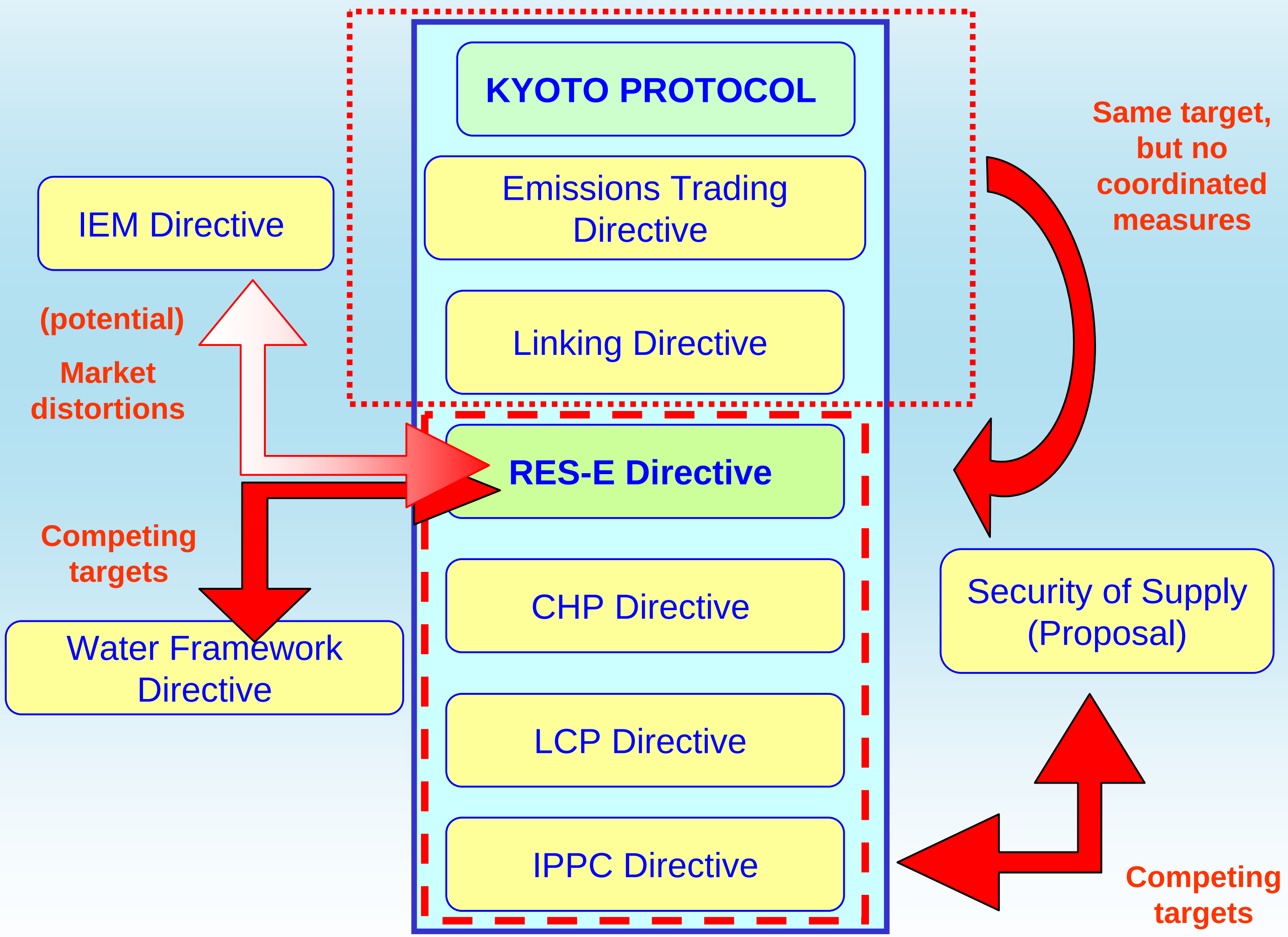
Penalties have to be paid into one single fund



Main barriers to the development of RES

- **Active or only declarative support** (whole energy sector)?
  - Acceptance of distributed generation?
- **Insufficient FIT for some technologies** (biomass, PV, micro units, etc)
  - expensive imported technologies – wider benefits to the economy?
- **Consistent and transparent spatial planning**
  - clear definition of potential investment area (exclusion of national parks, intact areas) to avoid conflicts of interests and speed up procedures.
- **Low electricity prices** (households, market uncertainty)
- **Bad project preparation:**
  - big environmental effects and low whole economy effects of RES projects
  - bad public communication – strong opposition (NGO, etc.)

Conflicts between targets of different EU Directives



CONCLUSIONS

- RES-E Market in Europe is quickly developing
- RES-E without incentives is not competitive on market
- 2 major support schemes
- Harmonization of EU RES market

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General module:

A theoretical framework for comparison of supporting mechanisms for renewable generation

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Contents

- Renewable energy in the international energy context
- Supporting mechanisms for renewable electricity generation
- Theoretical framework for comparison of supporting mechanisms

International energy context

- Sustainability
  - Climate change (CO_2, Kyoto protocol, AP6)
  - Other pollutants (SO_x, NO_x)
  - Availability for future generations
- Security of supply
  - External dependency on energy imports
    - Low political stability in exporting countries
  - Future scarcity
- Competitiveness
  - Energy has a direct and important impact on the economy
  - Availability of energy at reasonable prices is crucial
  - Higher and more volatile energy prices

Renewable Energy Sources (RES)

- Sustainable
  - Major player in CO_2 reductions
  - Environmentally friendly
  - Renewed for future generations by definition
- Secure supply
  - Usually local resource
  - Only guaranteed future energy source
- Competitive
  - Non-volatile prices
  - Not yet competitive with fossil energy sources?

Local context

- Large number of different supporting mechanisms
  - Very different levels of RES penetration
- Very different local context
  - Environmental commitment
    - Level of local support (public in general, government, institutions)
  - External dependency
    - Countries with highest penetration of renewable sources are highly dependent on energy imports
  - Regulatory framework and tradition
    - Market oriented or regulation oriented
    - Recent history and regulatory processes
  - Local resources
    - Fossil fuels and renewable energy sources

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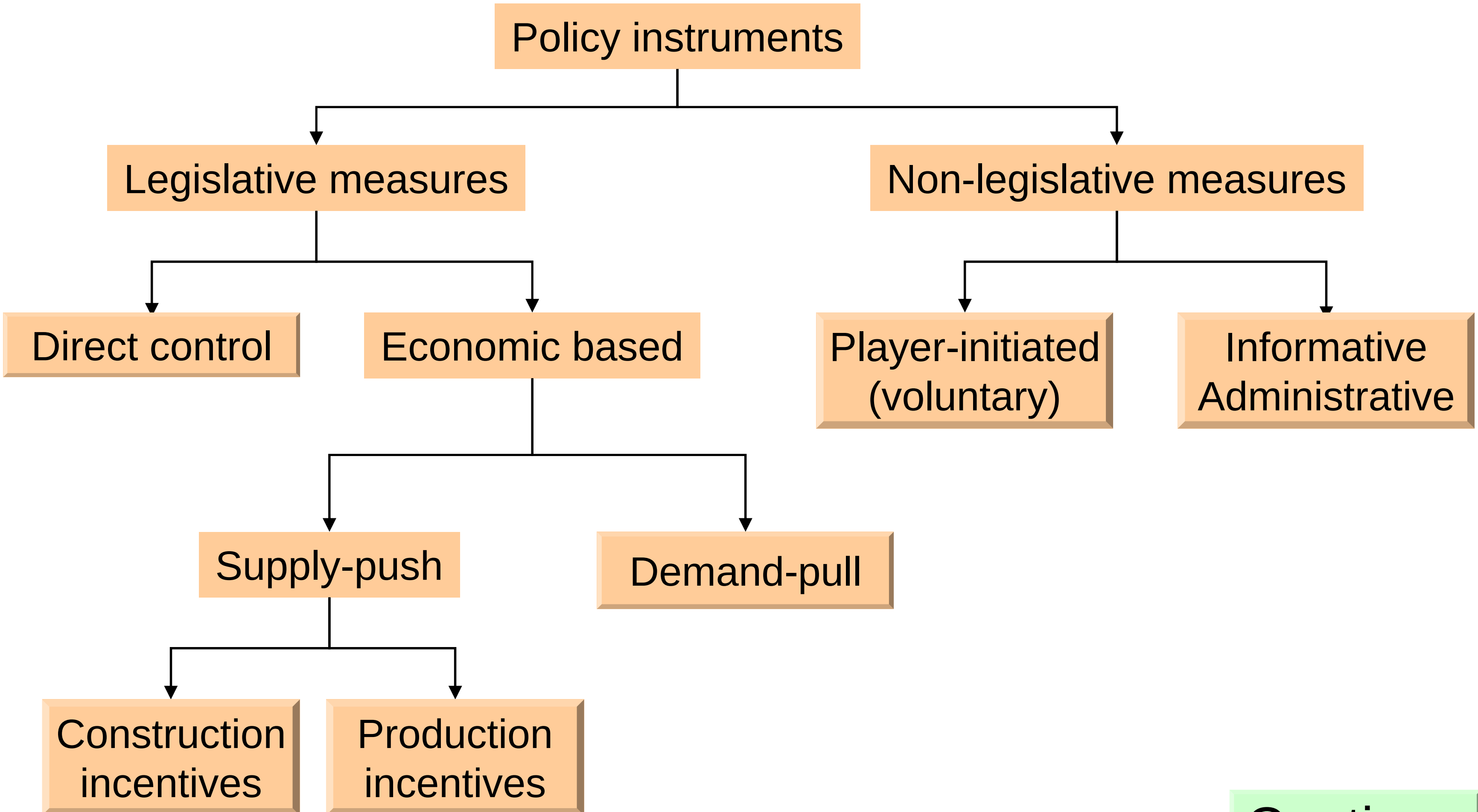
RES supporting mechanisms classification

From Enzesberger et al, 2002



Continue

Informative & administrative

- Policy instruments
  - Non-legislative measures
    - Informative & administrative

      Resource mapping

      Investor advising

      Publicity / campaigns

      Improved administrative procedures

These are necessary but not sufficient measures for RES uptake

Player-initiated (voluntary)

- Policy instruments
  - Non-legislative measures
    - Player-initiated (voluntary)

      Green pricing

      Certification

      Self-obligation

Marginal push for renewables

Direct control

- Policy instruments
  - Legislative measures
    - Direct control

      Forced investment

      Forced shut-downs

      Standards (safety, reliability)

Design to act where economic instruments cannot reach or are too risky (nuclear, safety issues)

Demand-pull

- Policy instruments
  - Legislative measures
    - Economic based
      - Demand-pull

        Tradable Green Certificates (Quota systems)

        Tax deductions for green power purchasers

One main type of RES supporting mechanism

Construction incentives

- Policy instruments
  - Legislative measures
    - Economic based
      - Supply-push
        - Construction incentives

          Direct subsidies

          Accelerated depreciation

          Tax deduction

          Below-market-rate loans

Usually in addition to some other mechanism

Production incentives

- Policy instruments
  - Legislative measures
    - Economic based
      - Supply-push
        - Production incentives

          Feed-in Tariffs (fixed tariff, market + premium)

          Tax exemption

          Competitive tenders for long-term power sales contracts

Second main type of RES supporting mechanism

Main supporting mechanisms

- Feed-in Tariffs (FiT)
  - Expanding throughout Europe
  - In a number of USA states
- Tradable Green Certificates (TGC)
  - Growing steadily, still a lot of questions about performance

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Setting the objectives of the policy

- Environmental objectives
  - CO_2, SO_x, NO_x emissions reduction
  - Sustainability
- Political objectives
  - Price volatility reduction
  - Low energy prices (long term)
  - Increasing security of supply
- Economic development vs. import costs
  - Local employment
  - Industry development
  - Local economic development

Policy evaluation (i)

- Effectiveness in terms of RES deployment
  - What is the target and has it been fulfilled
- Efficiency in terms of cost
  - Least cost solution
    - Least cost technology & better locations (high resources)
    - Cost impact in the existing system
  - Long-term cost reduction
    - Dynamic efficiency
      - Manufacturing, construction, know-how
  - Minimising cost transfer to final customers
  - Transaction costs

Policy evaluation (ii)

- System conformity
  - Integration in the system and regulatory framework
    - Network development
    - System operation
    - System security
    - Compatibility with other mechanisms (GHG emission reduction)
- Flexibility
  - Capacity to adapt to new and evolving data
- Local economic development induced

Factors affecting the results (i)

- Design
  - For each mechanism, there are several possible design choices that can affect performance
  - In addition, a combination or accumulation of different mechanisms may be used
- Settings
  - Time horizon, target in TGC, price in FiT, etc.
- Structure
  - Size of the market, number of potential participants
- Context
  - Physical, social and regulatory context

Factors affecting the results (ii)

- Context
  - Physical
    - Network & system capacity
    - Resource availability
      - RES and conventional
    - Local R&D and manufacturing facilities
  - Social
    - Agents (promoters, DSO, TSO, SO, regulator), society and administration attitude towards RES
  - Regulatory
    - Previous regulation (tradition)
    - Adaptation of TSO, DSO, SO regulation to RES penetration
    - Standards

TGC (Quota system)

- Preferred option of 'market mechanism promoters'
  - High competition between generators for least cost options
    - Both technologies and sites
  - Marginal cost of RES should be determined by the market
  - TGC allow burden to be shared between all consumers
  - Better market integration than FiT (see later)
- Disadvantages
  - Market will pick a winner
    - No support for a broad range of technologies
  - Pressure for best spots may concentrate RES deployment
    - NIMBY effect
    - Integration problems may arise
  - High risk for the investment (volume, price and regulatory)
    - Price may not be as competitive as expected

TGC: results

- Effectiveness
  - Until now, no record of meeting the intended target
    - Complex design prone to flaws and stakeholder pressure
    - Inherent high risk for promoters
    - Impact of a derivative market on risk mitigation?
- Efficiency
  - Practical experience
    - European (UK, Italy) experience show higher prices with TGC than with FiT
    - USA experience show need of additional support for RES deployment to happen
    - Australia has had low prices (ignoring the cost of supporting hydro and solar water heating), but this might be related to high resources and small target
  - Lack of dynamic efficiency for non-mature technologies

TGC: results

- System conformity
  - Does allow a certain level of integration into the market
    - Still the TGC premium distorts the wholesale market economic signal
  - Does not interfere with network integration
  - Concentration of RES deployment may stress
    - Network
    - System operation (high correlation of outputs)
- Flexibility
  - Changes in the target may jeopardise the stability of the market created, increasing the risk
- Local economic development
  - Does not seem to lead to local industry development, although it might be related to the small amount of RES being driven

TGC: assessment

- Design
  - Complex
  - Some improvements may be difficult to tune up
    - Support to specific technologies through technology quotas may lead to small markets and lose least-cost advantage
- Settings
  - RES target can radically change the characteristics of the supporting mechanism
    - As a marginal market, it is highly dependent on the marginal technology and spot price
      - Flat marginal cost curve is most suitable
      - Ambitious target may lead to high marginal costs

TGC: assessment

- Structure
  - Need a large market to avoid market power
  - Does not allow small- and medium-sized participants
- Context
  - Concentration of deployment in a few spots may lead to DSO, TSO and local community opposition
  - Availability of resources
    - Flat marginal cost curve is most suitable

FiT or market + premium

- Treats RES as a regulated activity
  - Installed capacity driven by the price
  - Low risk for the promoter
    - Allows deployment of a large spectrum of technologies at different stages of maturity
    - Allows small- and medium-sized facilities (increases social acceptance and widens installed capacity potential)
  - Allows deployment in non-optimal resource locations (reduces NIMBY effect)
  - High competition at the manufacturing and construction stages
- Disadvantages
  - Regulation picks winners
  - FiT may act as a barrier for a correct integration into the system
  - High short-term cost (high cost technology, sub-optimal spots)

FiT: results

- Effectiveness
  - Hard to meet the intended target exactly, but may be exceeded or fall short
  - Has driven most of today's RES facilities
- Efficiency
  - High cost in the short term
    - Although lower than TGC for the same technology and resource level (low associated risk)
  - High cost reduction induced in several technologies (dynamic efficiency)
    - Hard to transfer cost savings to customers
      - A predetermined decreasing path of tariff may help solve this problem
  - Strong competition at the manufacturing and building stages
    - Similar results to a RPI-X regulation

FiT: results

- System conformity
  - FiT is a barrier to system integration
    - Market + premium helps, but still has the same problems as TGC and also has other associated risks
  - Does not allow network integration without modification
  - Spread out RES deployment may help to avoid stress of
    - Network
    - System operation (non-correlation of outputs)
- Flexibility
  - Although in theory easily adapted, changes have been difficult because of strong lobbying activity
- Local economic development
  - Early adopters have seen large industrial development
  - Strong impact on the local economy due to high deployment

FiT: assessment

- Design
  - Simple (difficult to get it wrong)
- Settings
  - Price has dramatic effects on installed capacity
    - Target exceeded or shortfall
    - Seems not too difficult to set a price that drives deployment without exceeding target too much
    - Market + premium option is hard to tune correctly in the long term due to market volatility
- Structure
  - No major problem with the size of the market
  - Allows small- and medium-sized participants
  - Easy of entry

Combination of mechanisms

- (Midttun and Gautesen) suggest that these mechanisms are complementary and should be implemented at the same time
  - FiT for emerging technologies
  - TGC for mature technologies

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Thank you for your attention

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