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)

D15: 2nd Summer School materials and conclusions

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Start date of the project:
1.1.2005

Duration:
36 months

Organization name:
Faculty for Electrical Engineering, University of Ljubljana

Revision:
First Version

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

Dissemination level

PU	Public

Virtual Balkan Power Centre for
Renewable Energy Sources

Summer School 2006 Report

Fojnica, BiH

17th-22th July 2006

Introduction

The traditional Balkan Power Summer School (BPSS 2006) took place in Fojnica, BiH, between 17.-22.7.2006. This student's event was part of the 6.FP project "The Virtual Balkan Power Center for Advance of Renewable Energy Sources in Western Balkans (VBPC-RES Project, INCO-CT-2004-509205)", co-funded by European Commission. It was organized by the Faculty of Electrical Engineering, University of Tuzla and co-organized by the University of Ljubljana, Faculty of Electrical Engineering and INTRADE Energia d.o.o.. Eleven students from Slovenia, Croatia, Serbia, BiH and Macedonia who qualified at the Balkan Power Student Contest 2005 and 2006 were invited to participate in the BPSS 2006. They met in Fojnica to discuss Renewable Energy Sources, contemporary issues technologies and solutions. The lectures presented had the main goal of involving students in problems related to Renewable Energy Sources (RES) in the region of Western Balkan. The countries in the Western Balkan region have great, but insufficiently exploited RES potential. The efficient use of RES could significantly contribute to security and adequacy of supply within the region and in the wider neighbourhood. Special care should be devoted to innovative and viable solutions for electricity supply of underdeveloped areas and areas isolated due to war damage. Therefore this year's main topic of Summer School was the renewable energy sources in South – East Europe.

Academic program

A typical working day was divided into lectures in the morning followed by lunch and tecnical and social excursions. Six international lecturers prepared interesting lectures and exercises with focusing on RES technical and economic problems, solutions and policies. While the BPSS was devoted to policy and operational issues of RES as well as their potentials, expecially small hidro power plants, biomass and wind plants but also photovoltaics (PV) and other technologies received their fair share of attention. The SS students were accommodated in private appartments.

The academic programme was held by international lecturers, covering the following topics:

- Wind energy by Ms. Vesna Bukarica
- Small hydro power plants by Prof. Dr. Suad Halilćevič
- Geothermal energy by Dr. Kostas Karytsas
- Impact of RES on power system operation by Prof. Dr. Nikola Rajaković
- Economic aspects of RES Mr. Borut del Fabbro
- Electricity Market: a Case of Market Power in GENCO by Prof. Dr. Andrej Gubina

Technical tours

Besides the lectures also several technical tours were organized were students could see the practical application of theory about RES learned on lectures. Because Fojnica is situated in part of Bosnia with mountainous terrain with several streams and rivers there have been four small hydro power plants build so far all four by INTRADE Energija d.o.o. from Sarajevo. They have total installed capacity of approximately 7,5 MW and we have seen all four of them with. Besides seeing the installations we got also first-hand information about problems of building such objects like obtaining the permissions, dimensioning of the plants, building of the plants and financial details of such investment.

Cultural dimension and international bonding

Familiarizing the Balkan participants with elements of the BiH culture, history and tradition was also part of this year's Summer School. There were several activities like swimming in new Sarajevo baths at Iliđa, visiting culturally and historically most important parts of Sarajevo and visiting the pyramids in Visoko. Those pyramids are currently researched by archeologists from all over the world and are supposed to be 12.000 years old. All of the activities were well organized and coordinated. Also, the participants have started some nice friendships, exchanged contacts, and now they are keeping in touch. This event was the proof of the good collaboration that exists between the Faculty of electrical engineering, University of Tuzla, Faculty of Electrical Engineering, University of Ljubljana, and INTRADE Energija d.o.o., as well as between professors and students during the Summer School. Even from this point of view, the Summer School was a success.

Participants:

Participant	**Country**
Gregor Taljan	Slovenia
Iztok Zlatar	Slovenia
Gregor Cimerman	Slovenia
Urban Taljan	Slovenia
Magdalena K'čeva	Macedonia
Elena Mančeva	Macedonia
Frosina Paunkovska	Macedonia
Velimir Lacković	Serbia
Luka Lugarić	Croatia
Jasmina Nalič	BiH
Marina Beneš	BiH

Lecturers

- UNI-LJ: Prof. Andrej Gubina
- UNTZ: Prof. Suad Halilčević
- ETF: Prof. Nikola Rajaković
- CRES: Dr. Costas Karytsas
- IBES: Mr. Borut del Fabbro
- UNIZG: Ms. Vesna Bukarica

Wind energy

Vesna Bukarica, M.Sc.E.E.

Faculty of Electrical Engineering and Computing,
University of Zagreb
Croatia

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

Aim of lectures

- 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

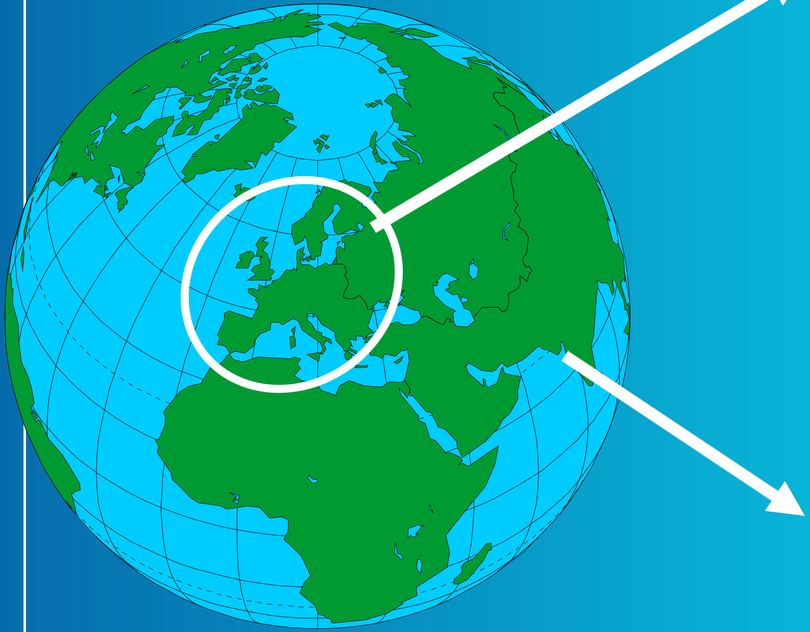
Content of lectures

- 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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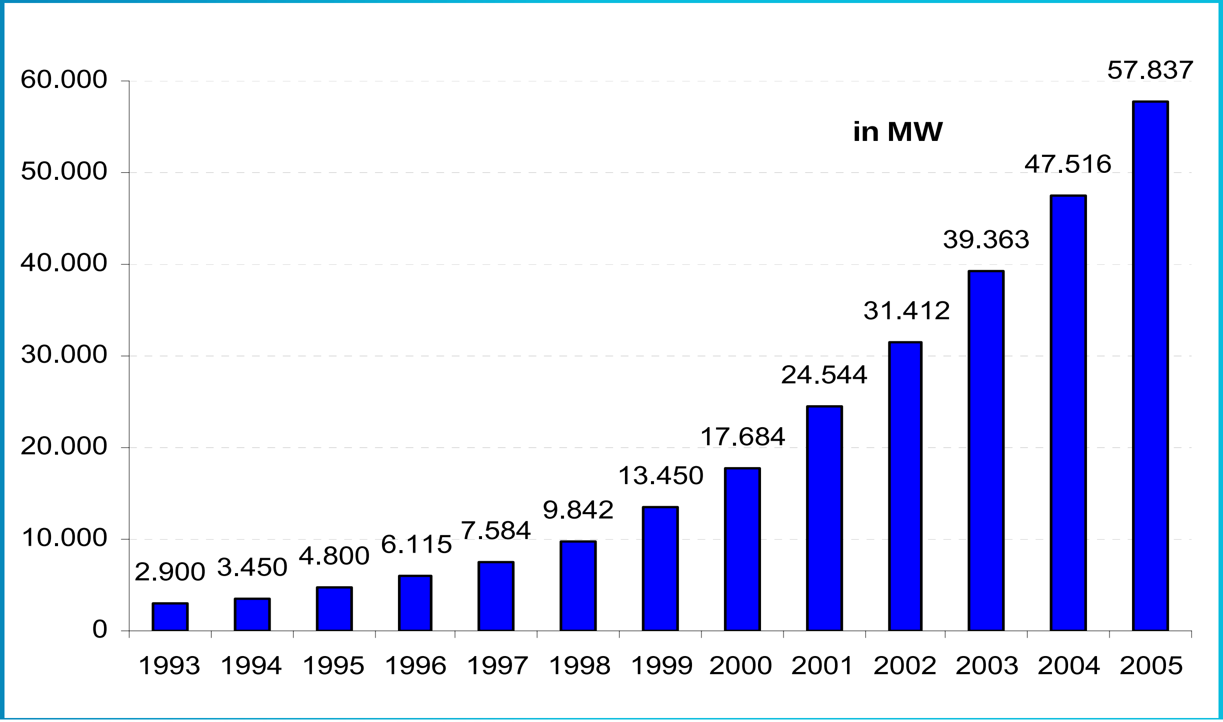
Status of wind energy use

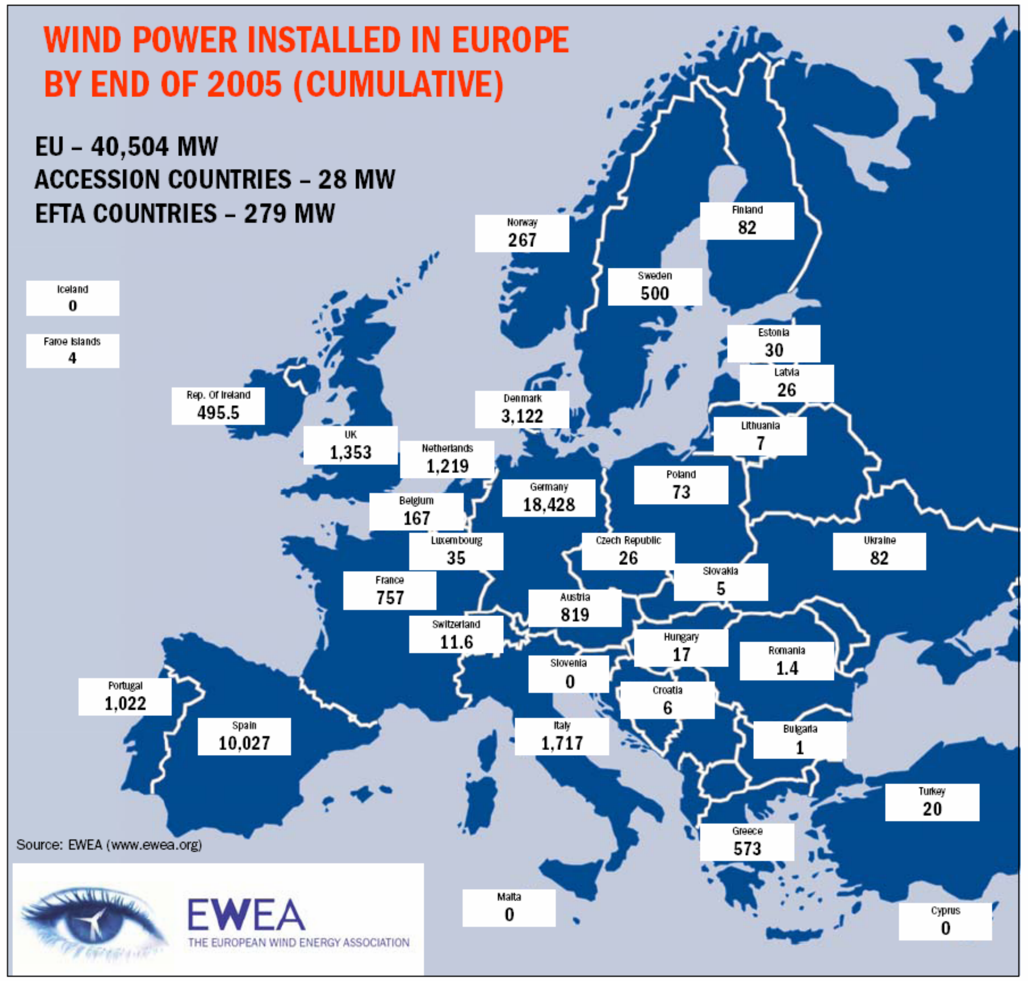
- Installed world capacities have grown in time period 1993-2005 from 2,900 MW to 57,837 MW (annual average growth rate of 28.4%)



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

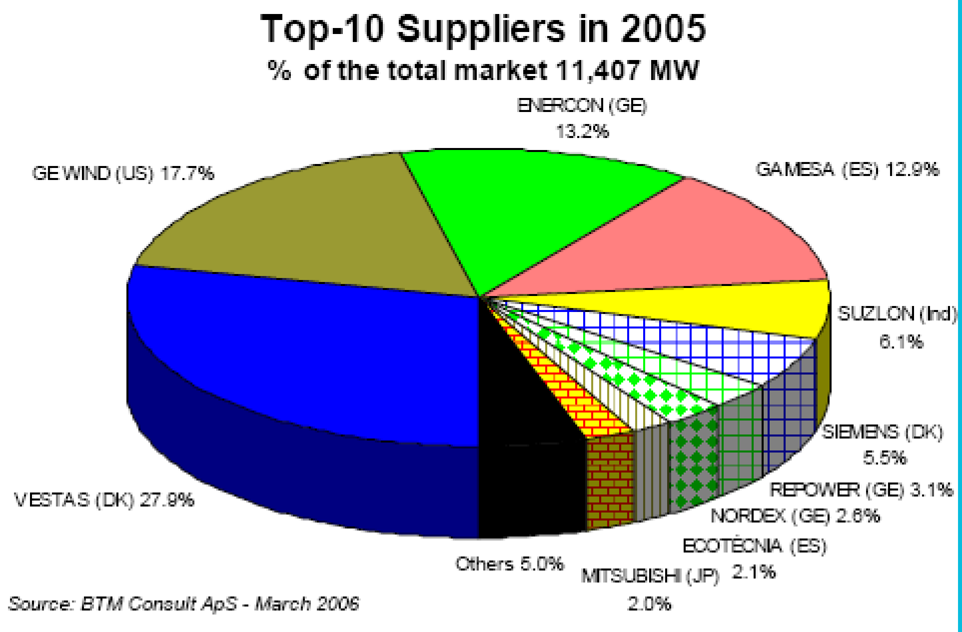
Status of wind energy use, III



Source: EWEA (www.ewea.org)

Status of wind energy use, IV

- ➢Market share (manufacturers) → trend is concentration



Top-10 Suppliers in 2005

% of the total market 11,407 MW

Source: BTM Consult ApS - March 2006

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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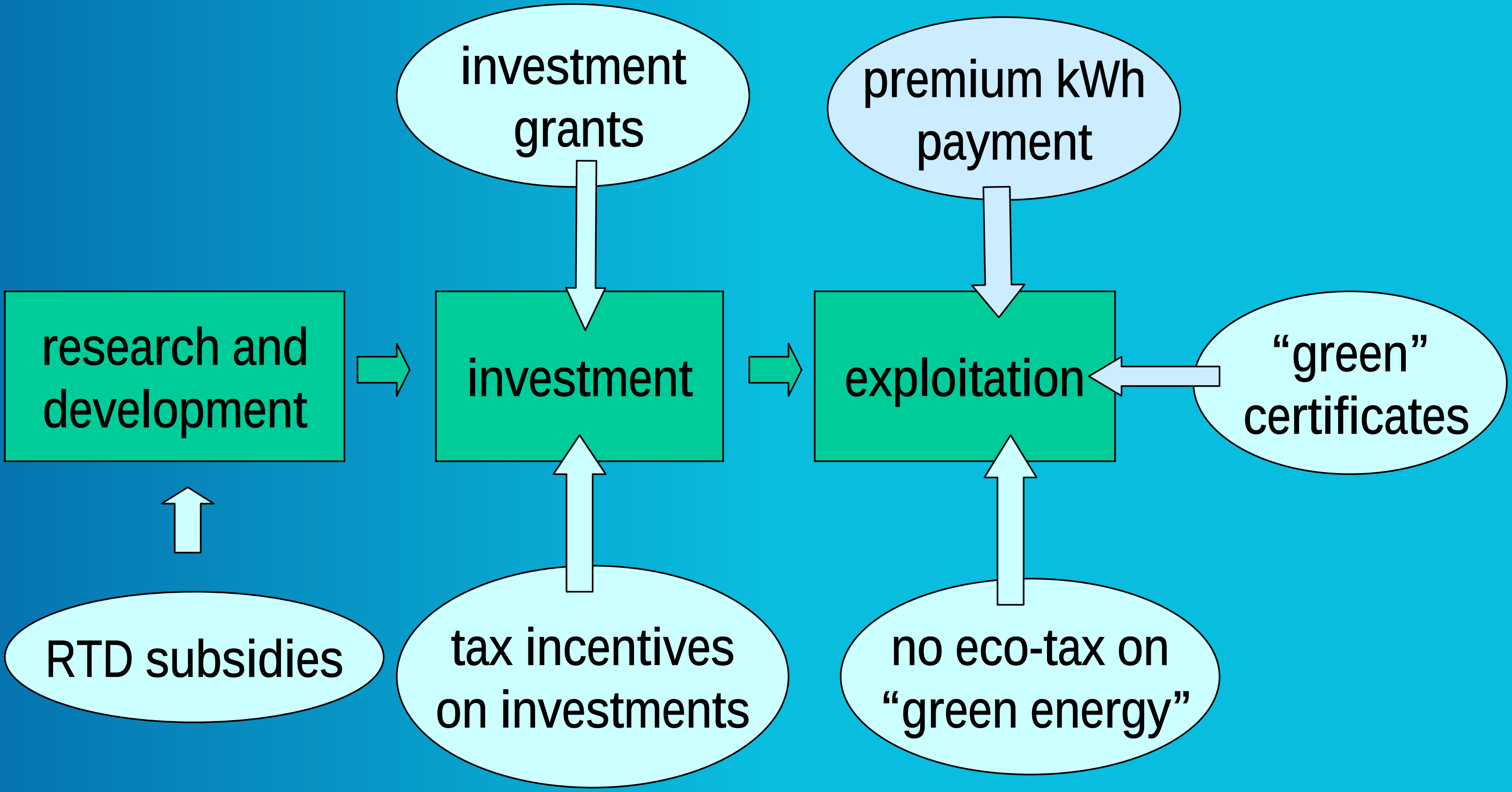
Wind energy status in Croatia, III

- 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

Regulatory framework



Source: ALTENER

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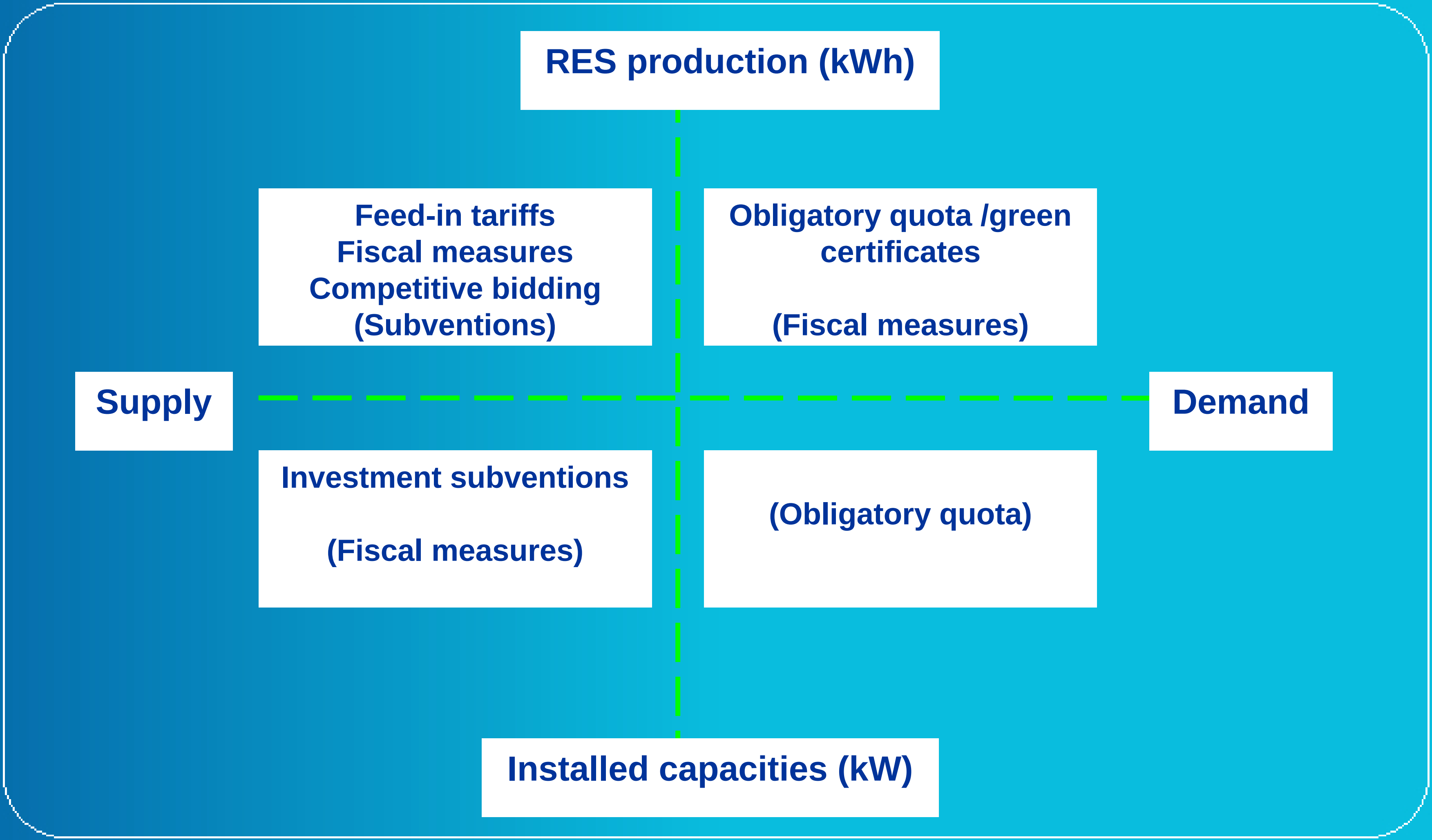
Regulatory framework, II



RES production (kWh)

Feed-in tariffs
Fiscal measures
Competitive bidding
(Subventions)

Obligatory quota /green certificates

(Fiscal measures)

Supply

Demand

Investment subventions

(Fiscal measures)

(Obligatory quota)

Installed capacities (kW)

Regulatory framework, III

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

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

Physical principles of wind energy use

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Content of lectures

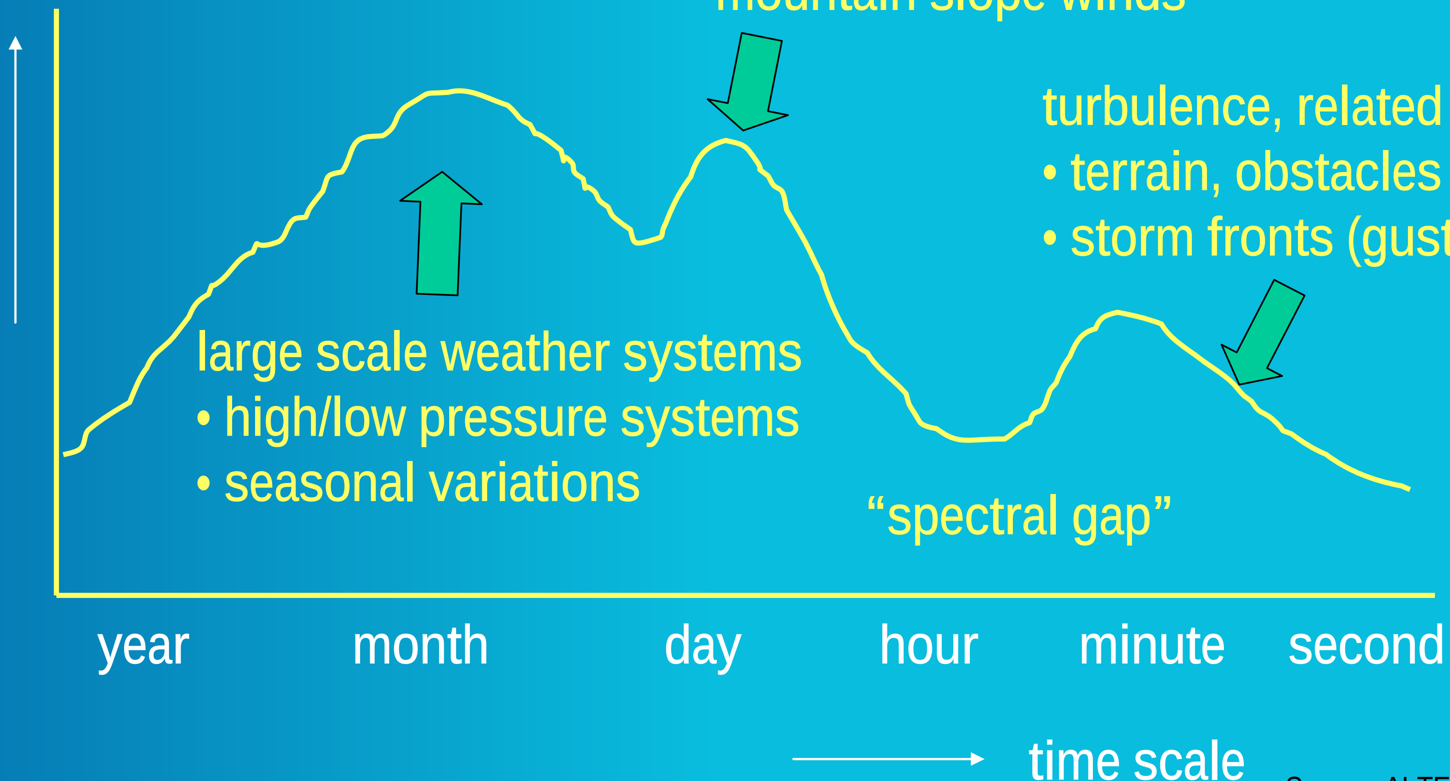
- Wind characteristics
  - Time and space variability
- Wind statistics
  - Measure – correlate – predict
  - Wind atlas
- Wind energy production
  - Use of wind statistics
  - Power curve
  - Energy production
- Further reading

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)

Variability of wind in time



contribution to wind speed variability

daily patterns (often thermal driven):
- sea breeze
- mountain slope winds

turbulence, related to
- terrain, obstacles
- storm fronts (gusts)

large scale weather systems
- high/low pressure systems
- seasonal variations

Source: ALTENER

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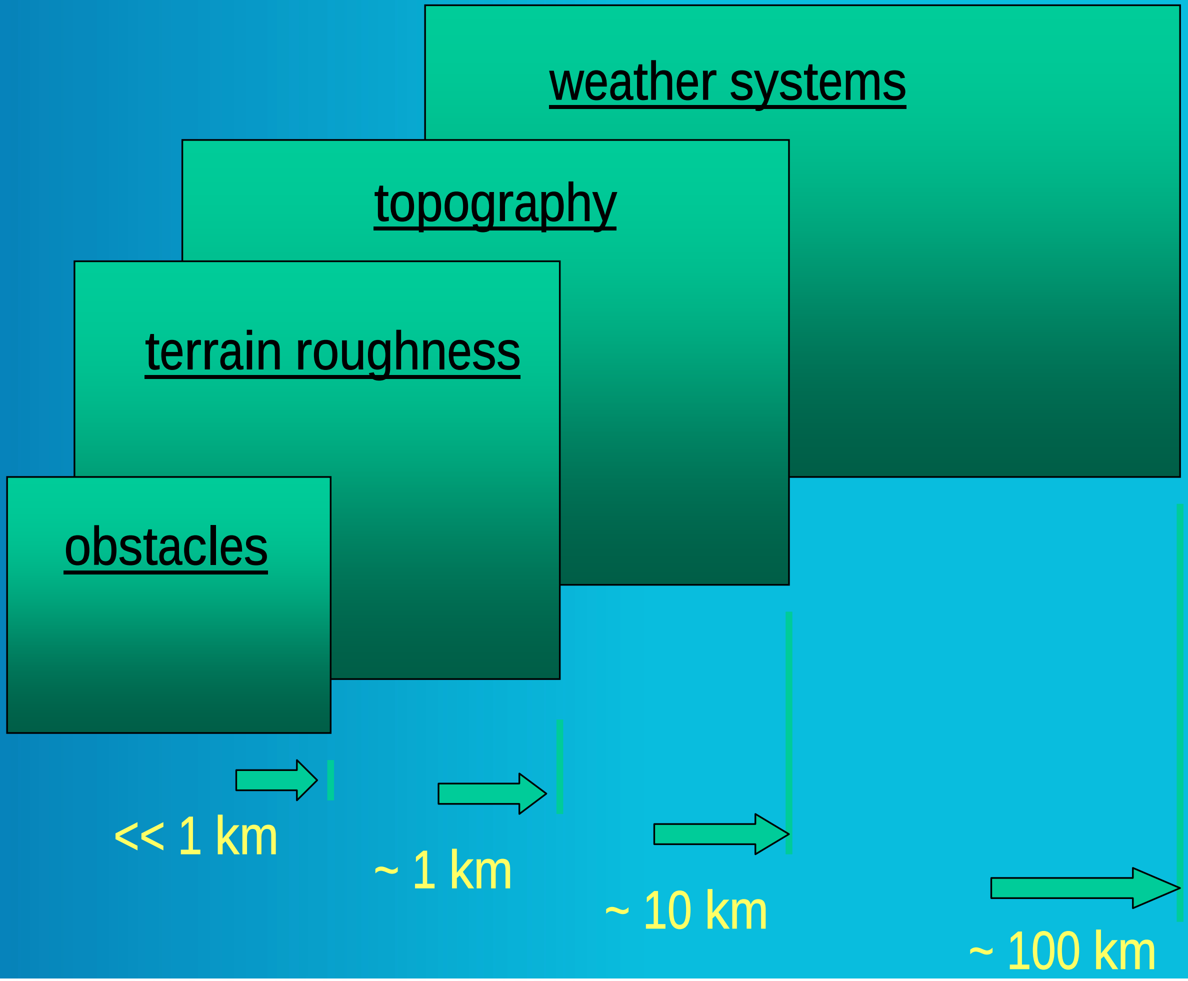
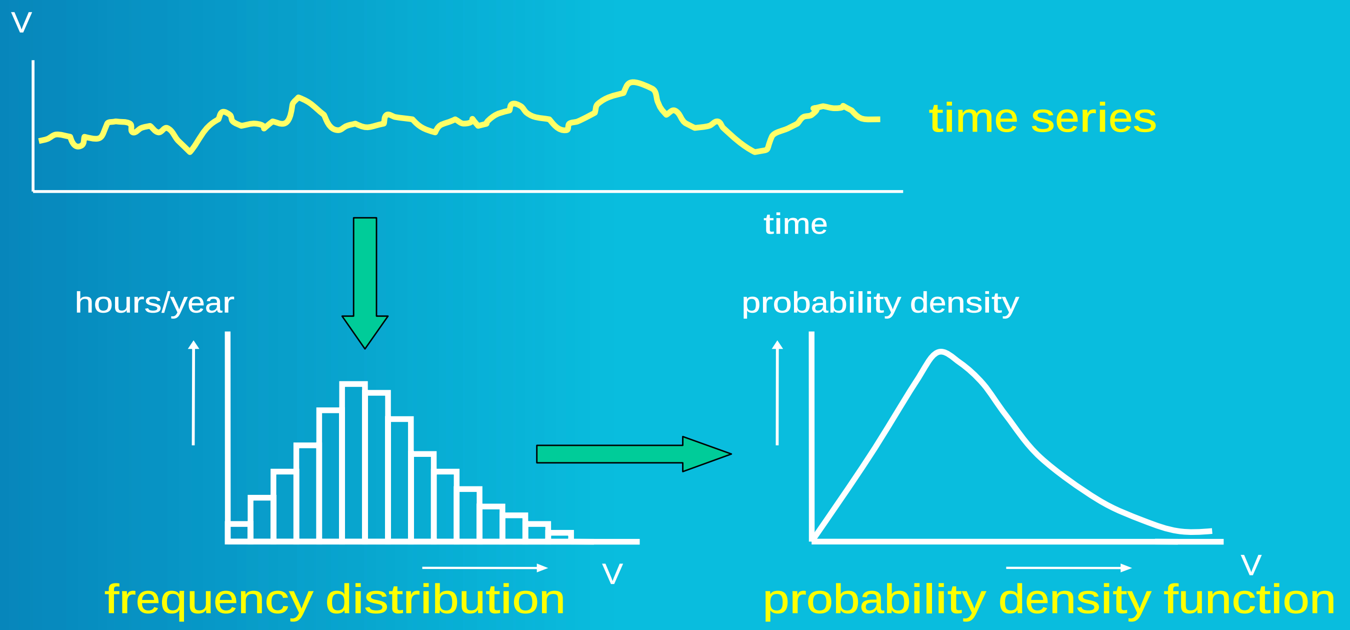
Variability of wind in space



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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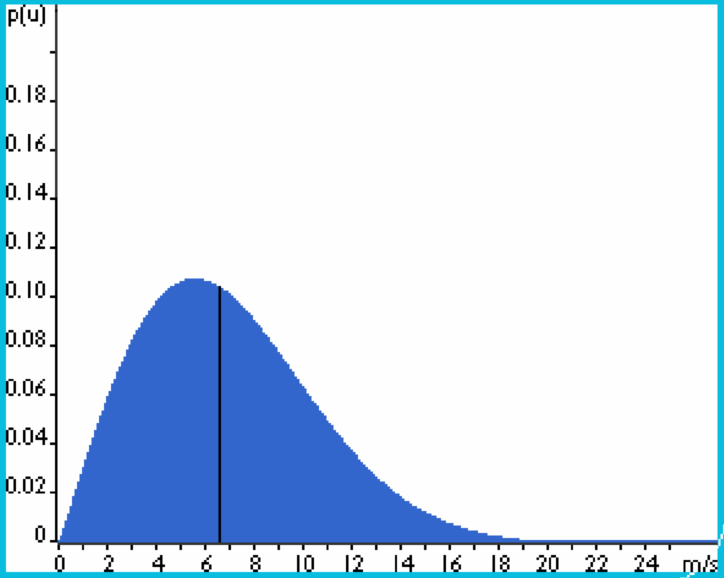
Mathematical modeling of wind speeds

- 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?

two basic options

	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”

Source: ALTENER

Wind statistics, II

- Measure – correlate – predict

reference meteostation
long term data and statistics

measurements at
location

simultaneous measurements

develop correlation

modify long term statistics

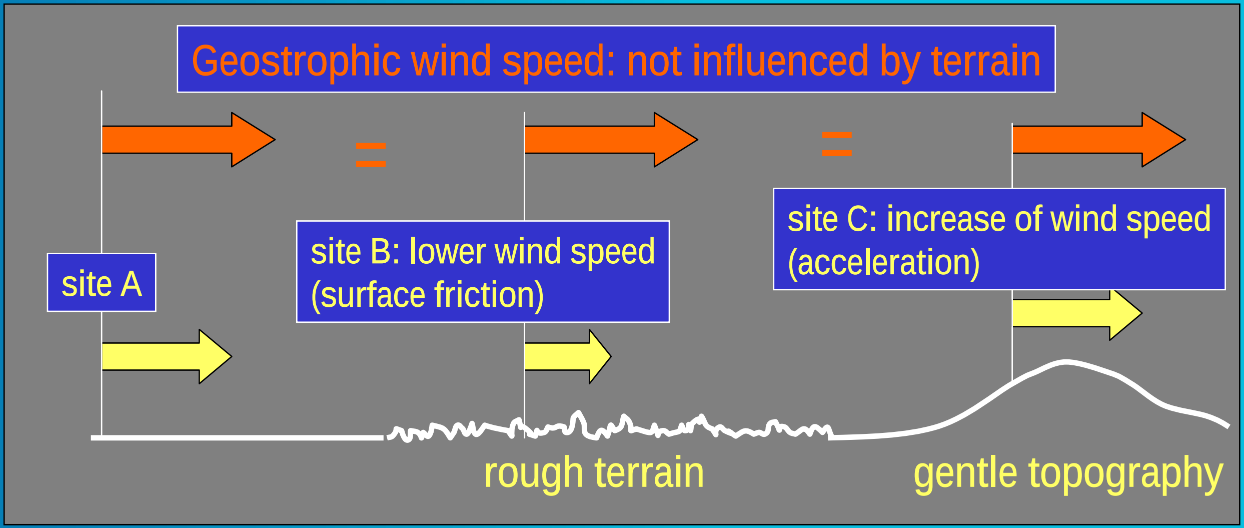
Source: ALTENER

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



Geostrophic wind speed: not influenced by terrain

site A

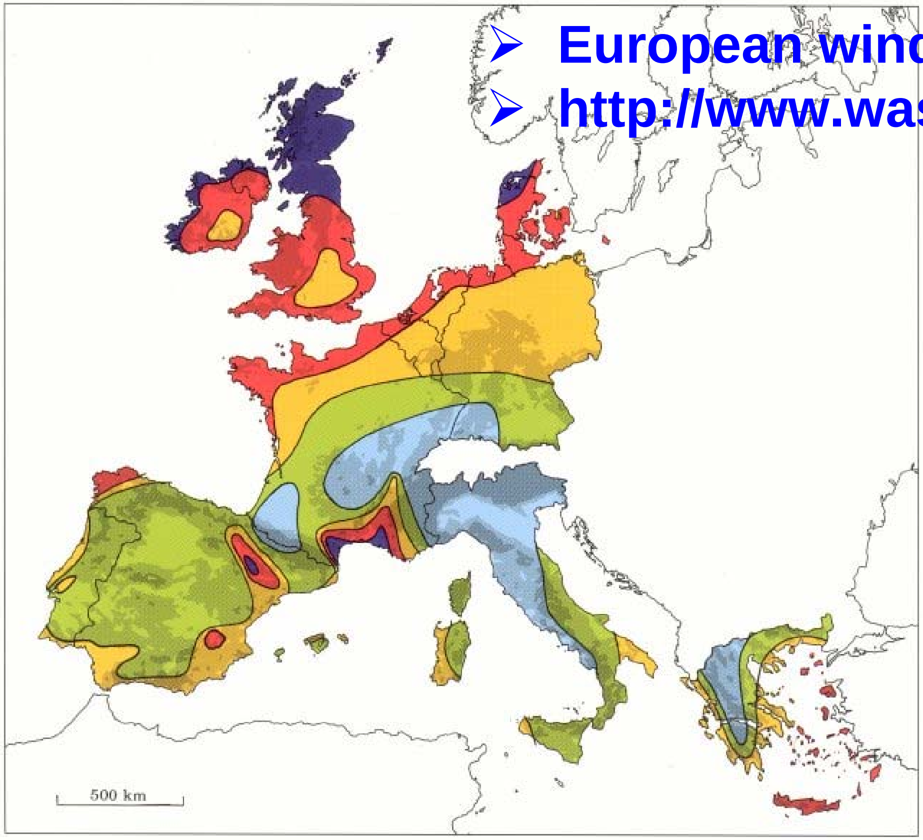
site B: lower wind speed (surface friction)

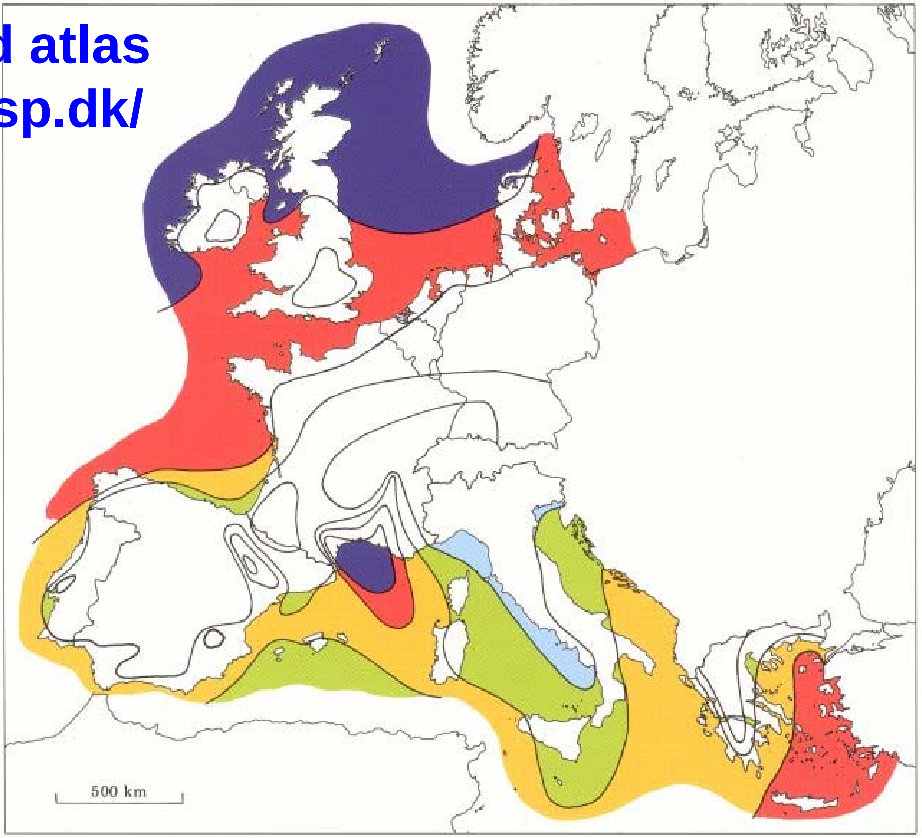
site C: increase of wind speed (acceleration)

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]	
	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$
🟪	> 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

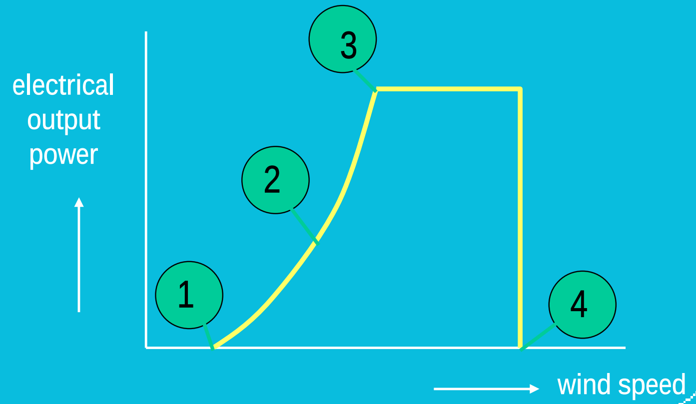
	10 m		25 m		50 m		100 m		200 m	
	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$	$\mathrm{m\,s^{-1}}$	$\mathrm{Wm^{-2}}$
🟪	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
🟥	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



RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

Wind energy production, II

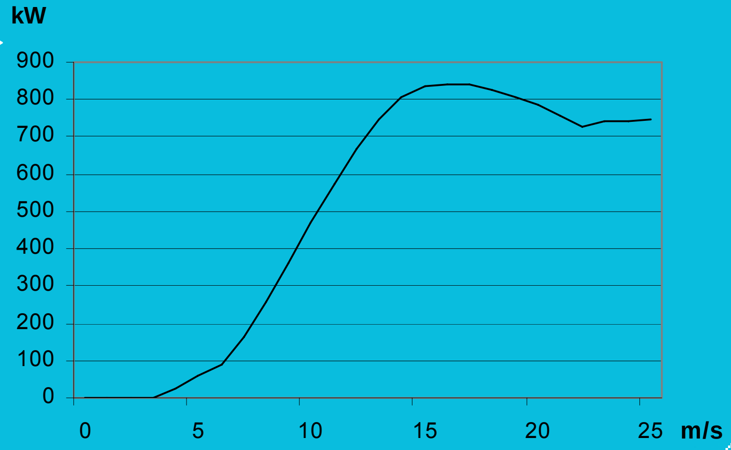
Electricity production

- 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

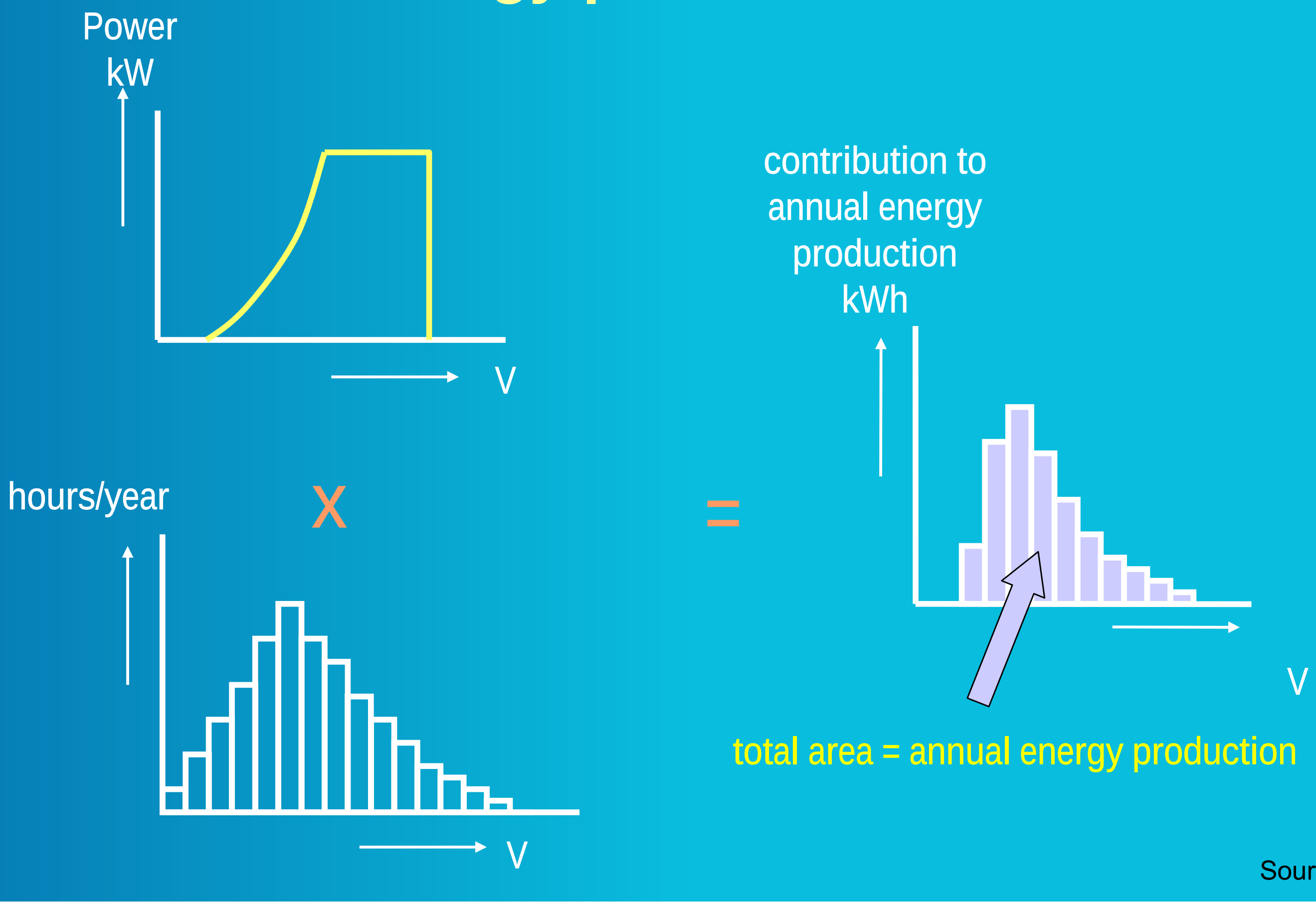
  at different wind speeds

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



Wind energy production, III

- **Assessment of energy production**



total area = annual 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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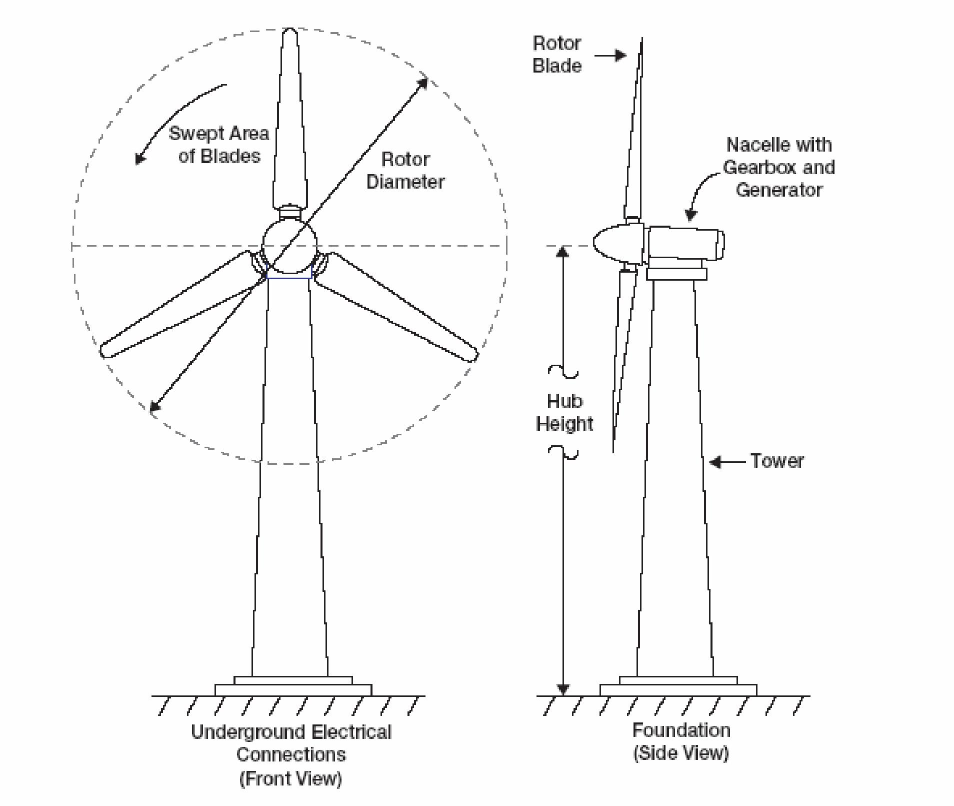
Wind turbine

- 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



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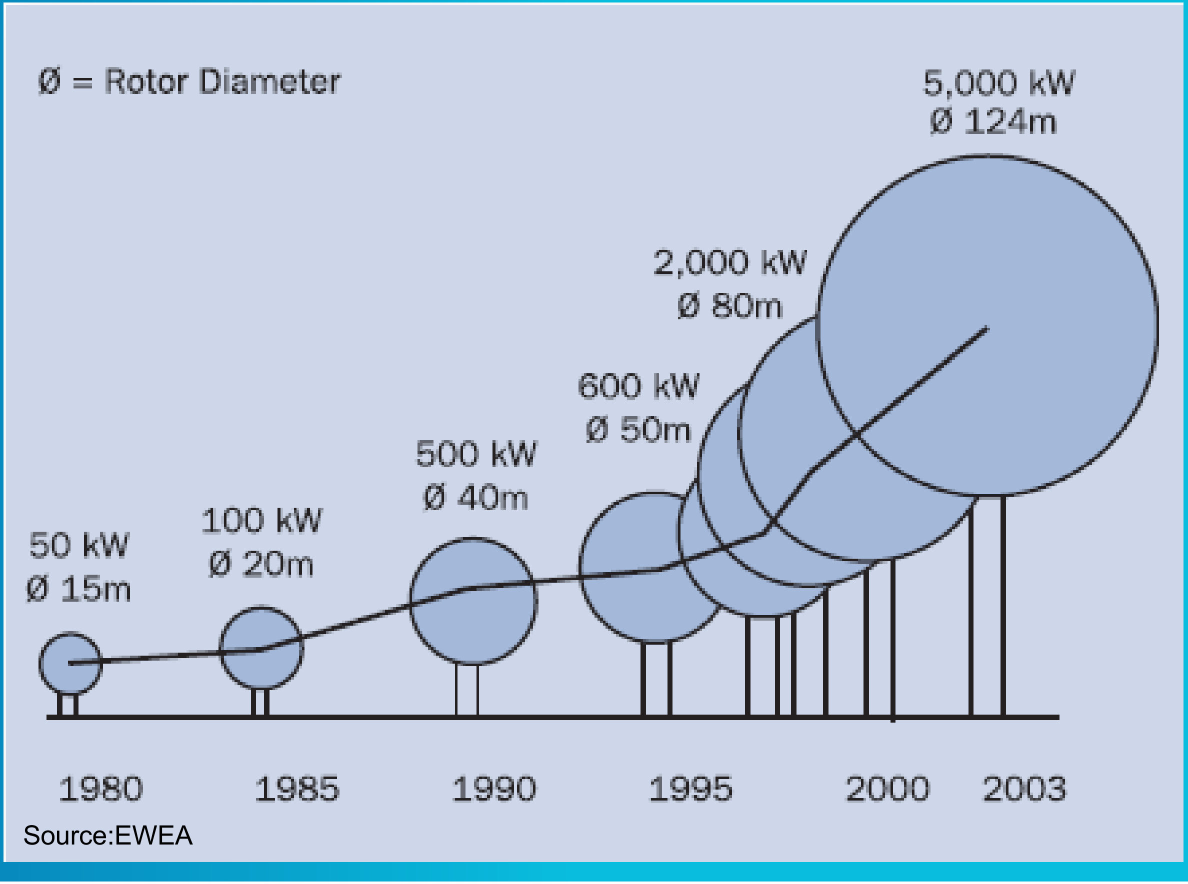
Wind turbine development

→ growth in size



Source:EWEA

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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

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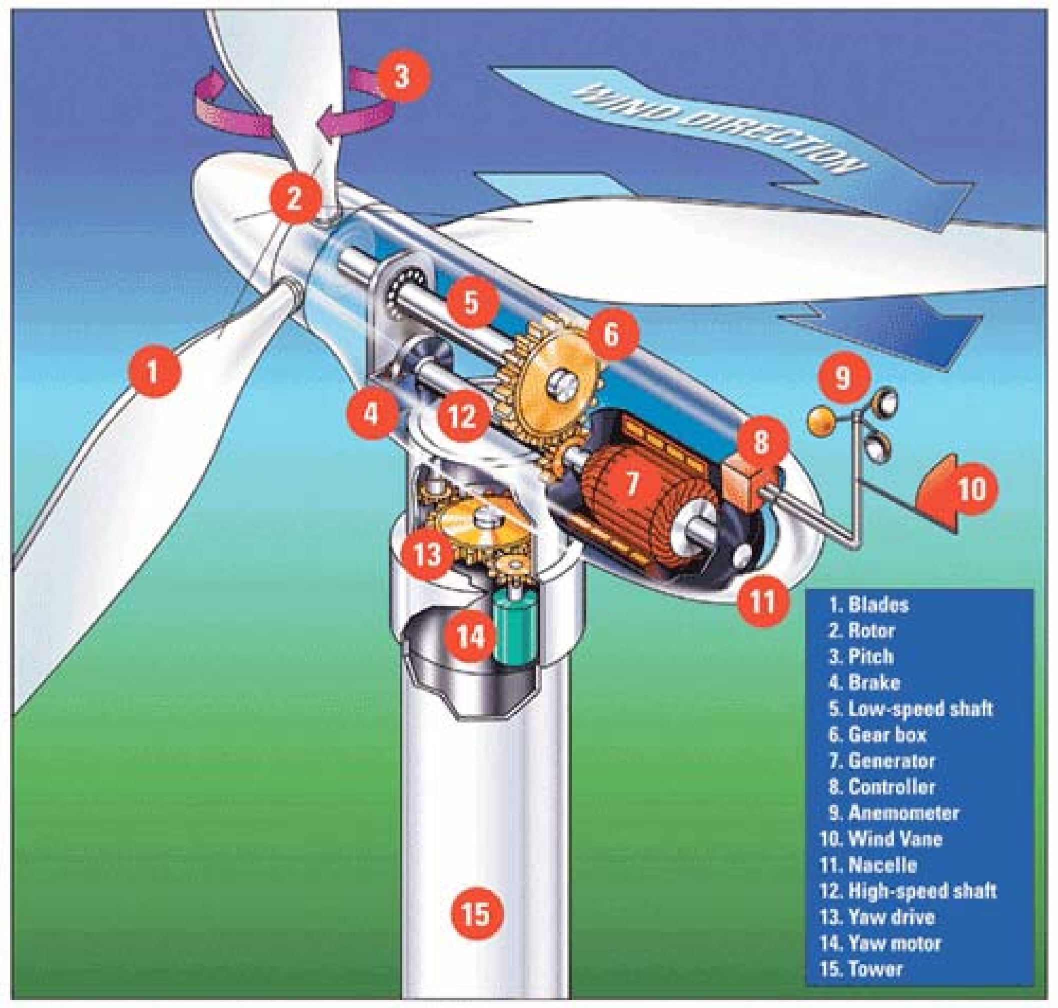
Wind turbine characteristics, IV

- 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

Wind turbine characteristics, IV



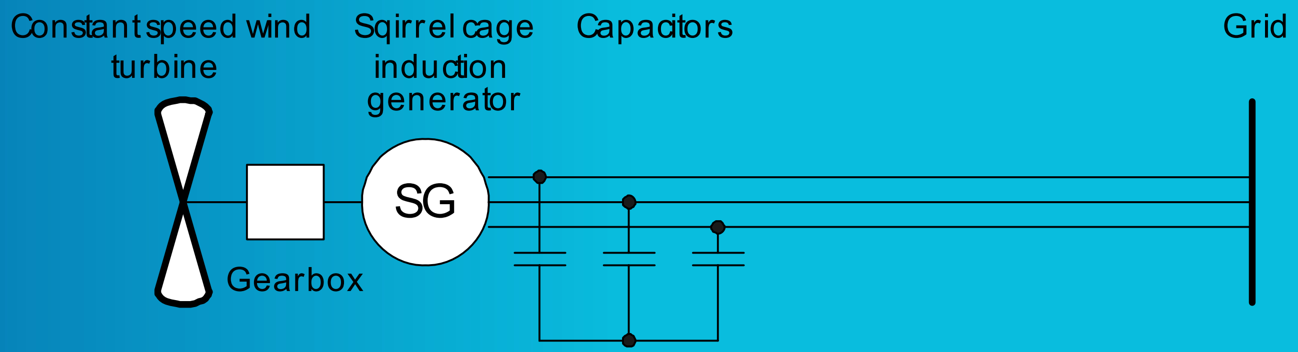
1. Blades
2. Rotor
3. Pitch
4. Brake
5. Low-speed shaft
6. Gear box
7. Generator
8. Controller
9. Anemometer
10. Wind Vane
11. Nacelle
12. High-speed shaft
13. Yaw drive
14. Yaw motor
15. Tower

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

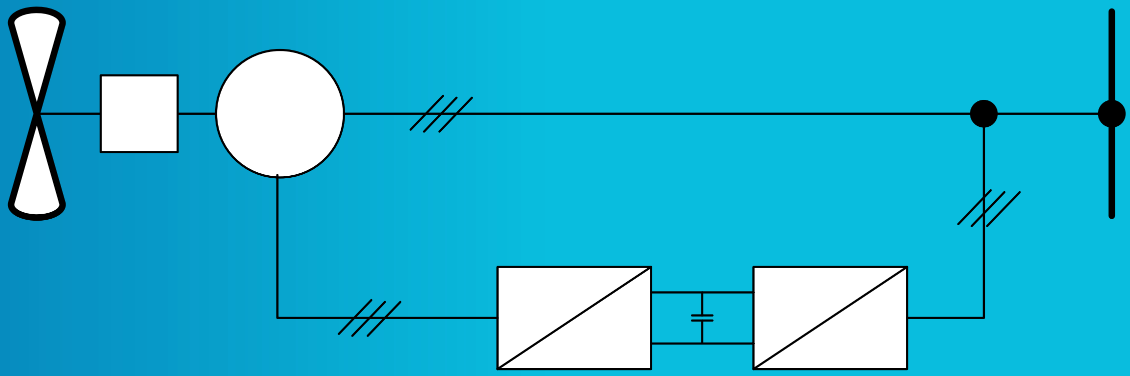
➢ Squirrel-cage induction generator system



- 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

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

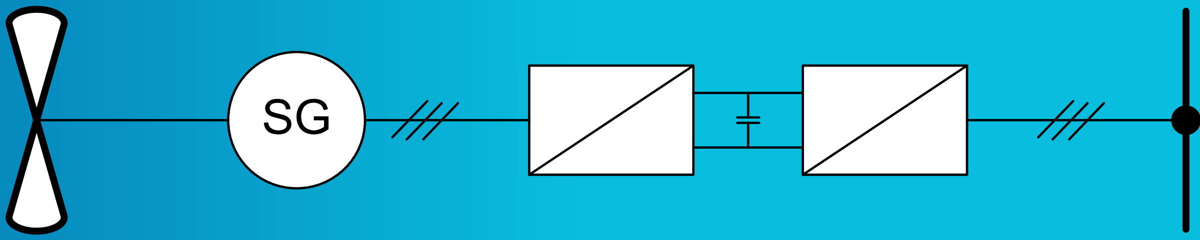
Variable speed wind turbine

Doubly fed induction generator

IG

Wind generator concepts, IV

➢ Direct drive synchronous generator

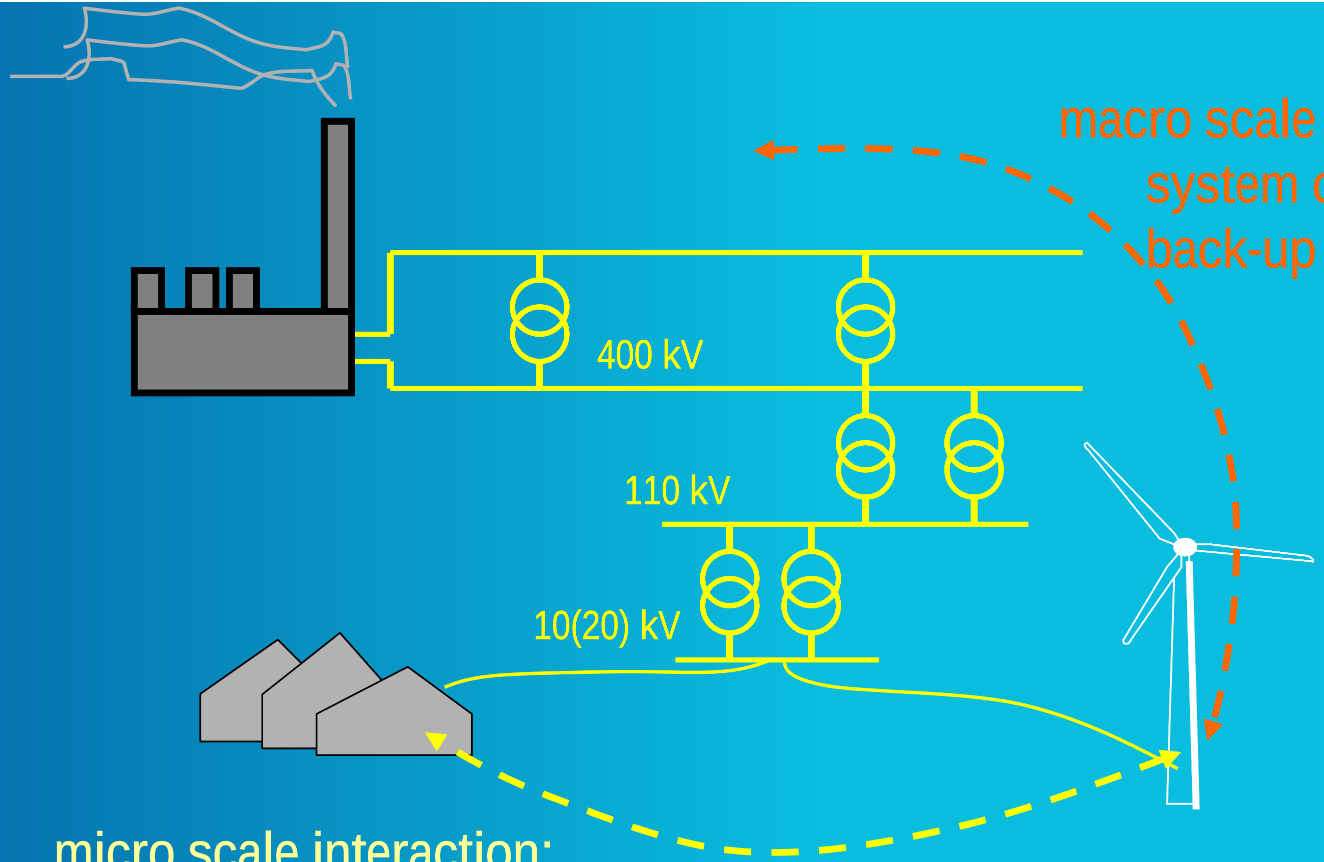


- turbine and generator are directly coupled, without gearbox
- generator used in such systems is high-pole synchronous generator designed for low speed – large generator, thus large nacelle
- solution is in direct drive concept but with single stage gear box with low ratio – lower number of poles required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

Variable speed wind turbine

Direkt-drive synchronous generator

Integration into power system



macro scale interaction:
system controllability
back-up requirement

⇩

limits to
wind power
penetration

micro scale interaction:
- grid variations affects turbine generator
- turbine influence on consumers, flicker etc

⇨ criteria for grid properties

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

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

Economics of wind power plants

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**

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)

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	[€]

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

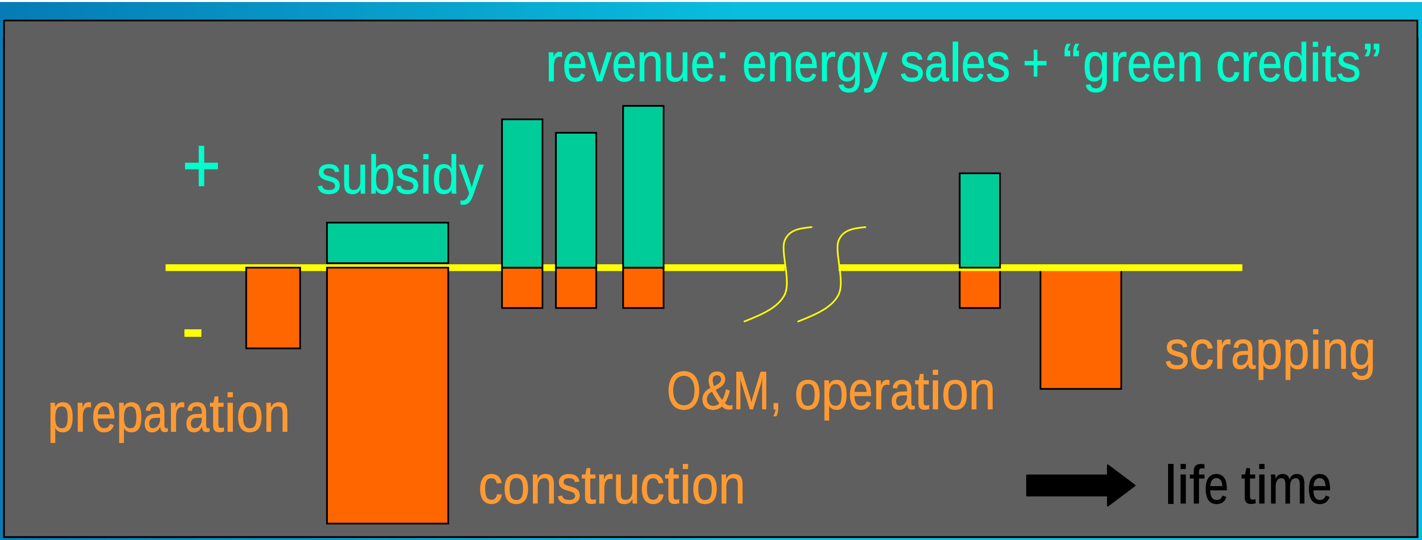
Project economics basics, V

- **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!

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

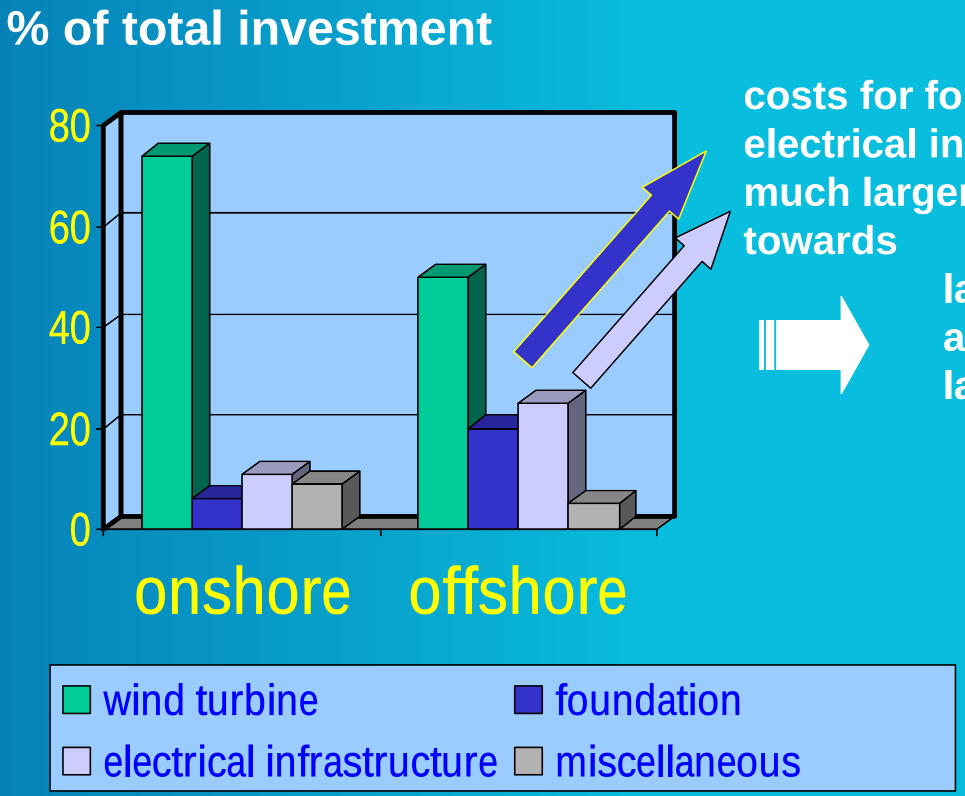
Wind power project expenditures

- 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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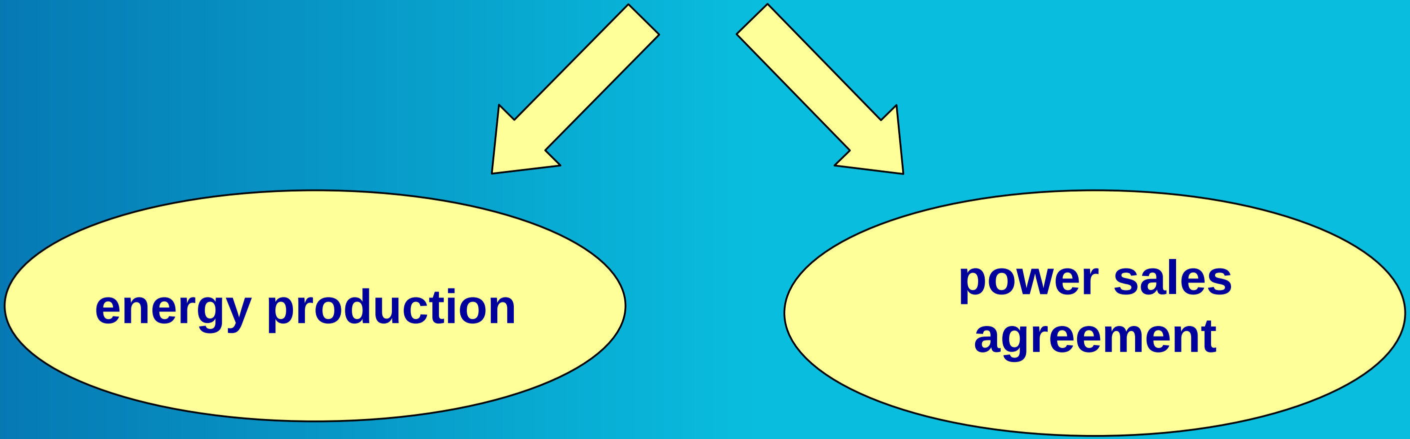
Contract: INCO-CT-2004-509205

Wind power project revenues



energy production

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

power sales agreement

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

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Contract: INCO-CT-2004-509205

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!

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

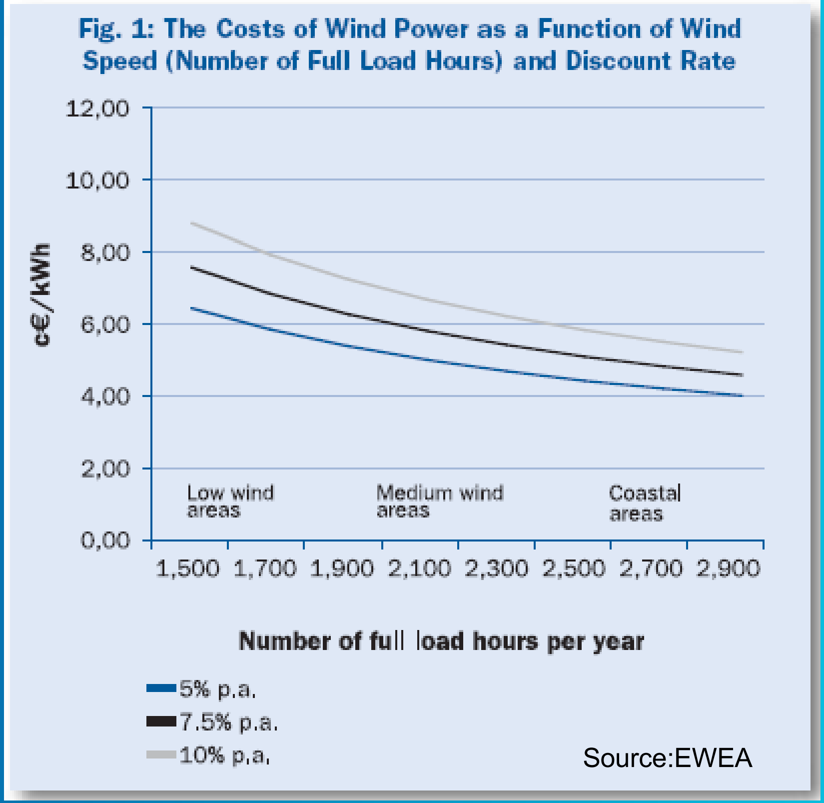


Fig. 1: The Costs of Wind Power as a Function of Wind Speed (Number of Full Load Hours) and Discount Rate

Source:EWEA

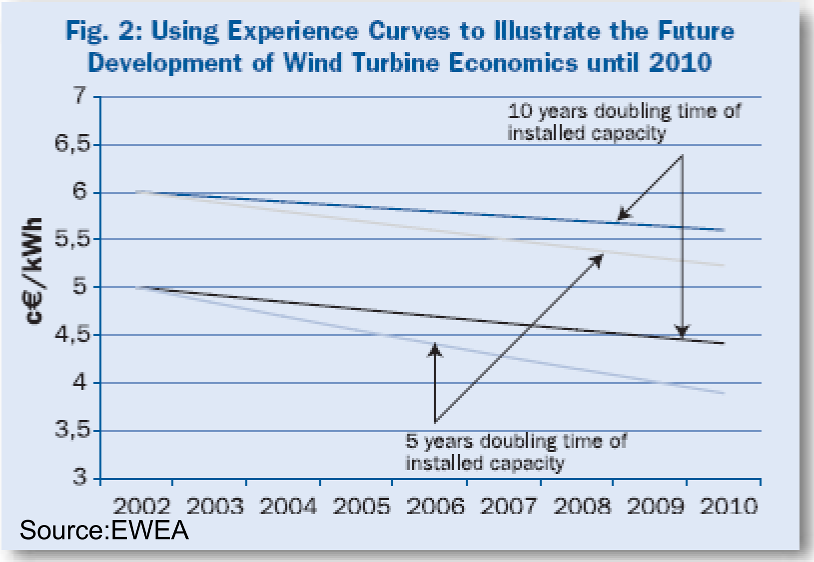
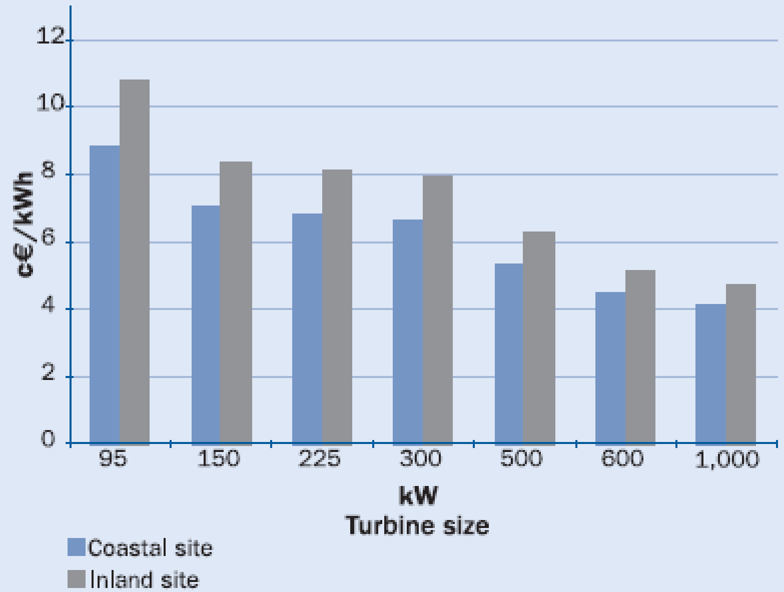


Fig. 2: Using Experience Curves to Illustrate the Future Development of Wind Turbine Economics until 2010

Source:EWEA

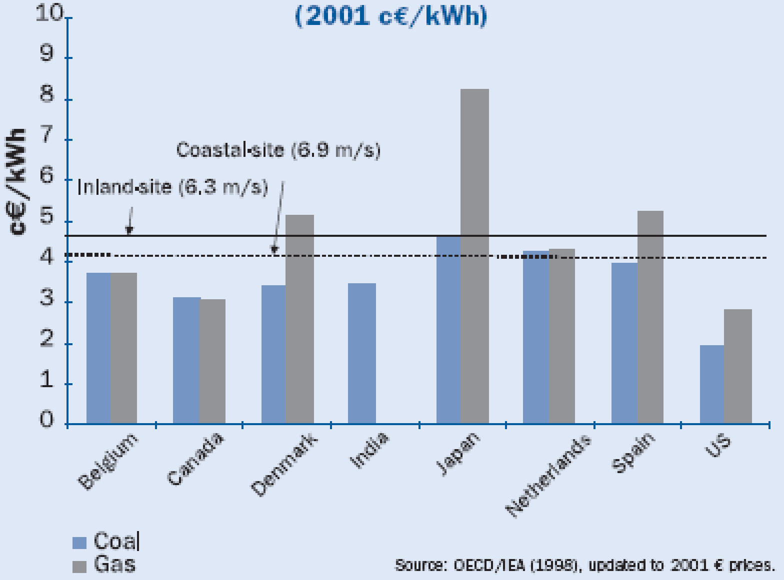
Generating cost of wind power, III

Fig. 3: Total Costs of Wind Power (c€/kWh, Constant 2001 Prices) by Turbine Size



Source:EWEA

Fig. 4: Projected Costs of Conventional Power (2001 c€/kWh)



Source: OECD/IEA (1998), updated to 2001 € prices.

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	900.000
Project documentation	750.000
Preparation civil engineering work	4.065.000
Equipment, transportation, instalment, etc.	36.784.000
Cable connection 10 kV and 35 kV	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

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

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**

Further reading

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

European Wind Energy Association (EWEA)

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

Environmental impacts of wind power plants

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

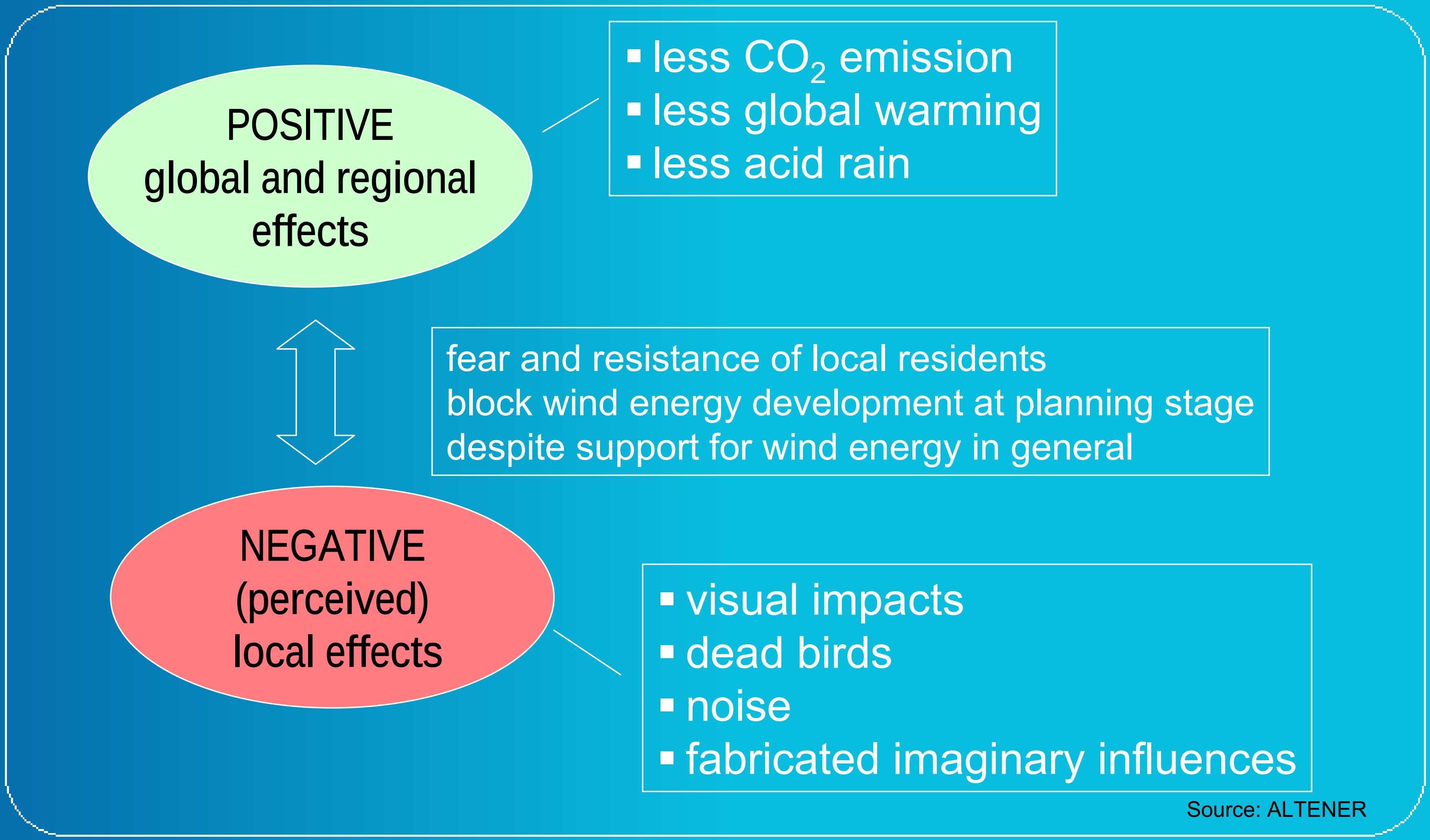
Content of lectures

- 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

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

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

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

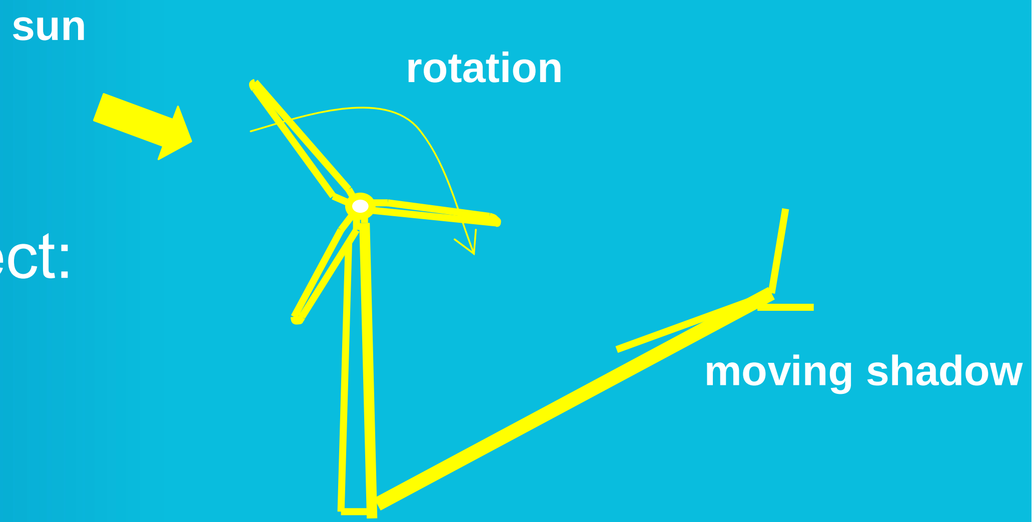
Remedies:

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

landscape architecture to carefully integrate wind farm into landscape

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

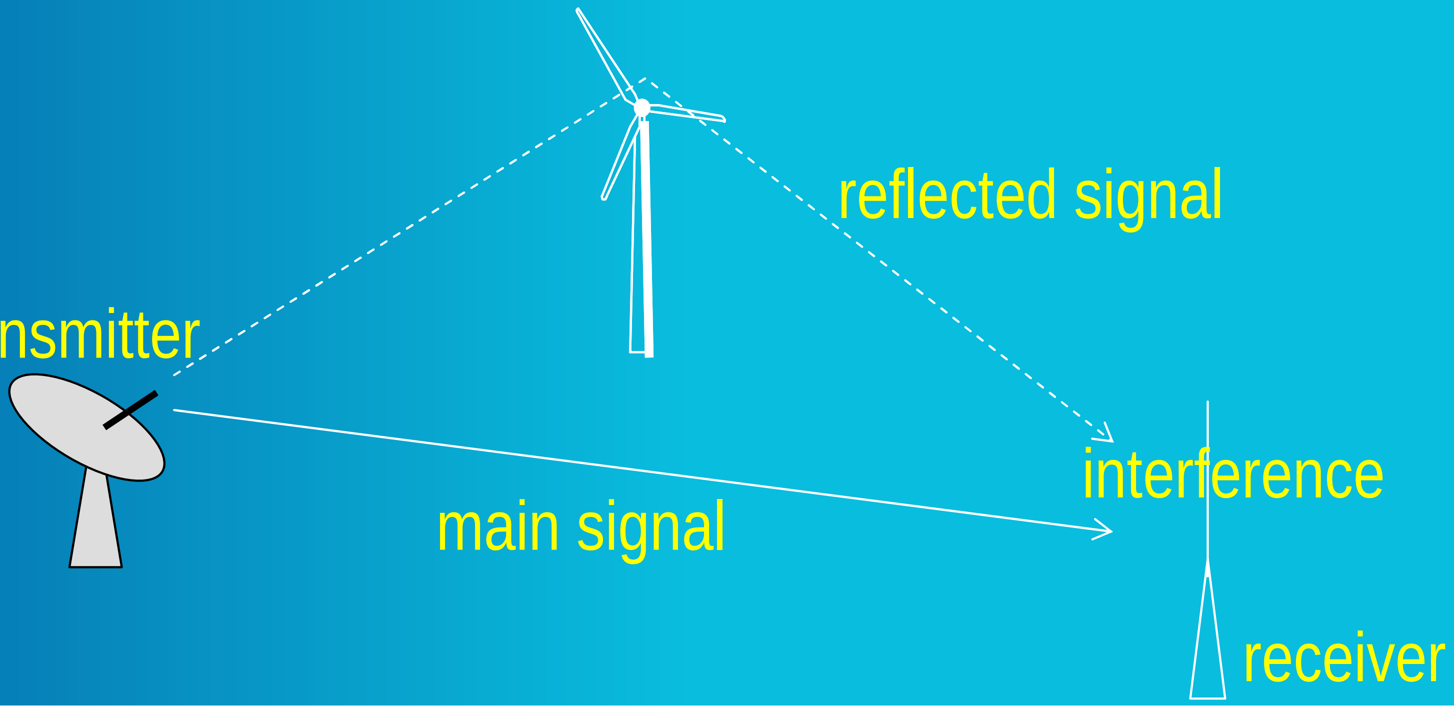


Nuisance, III

- 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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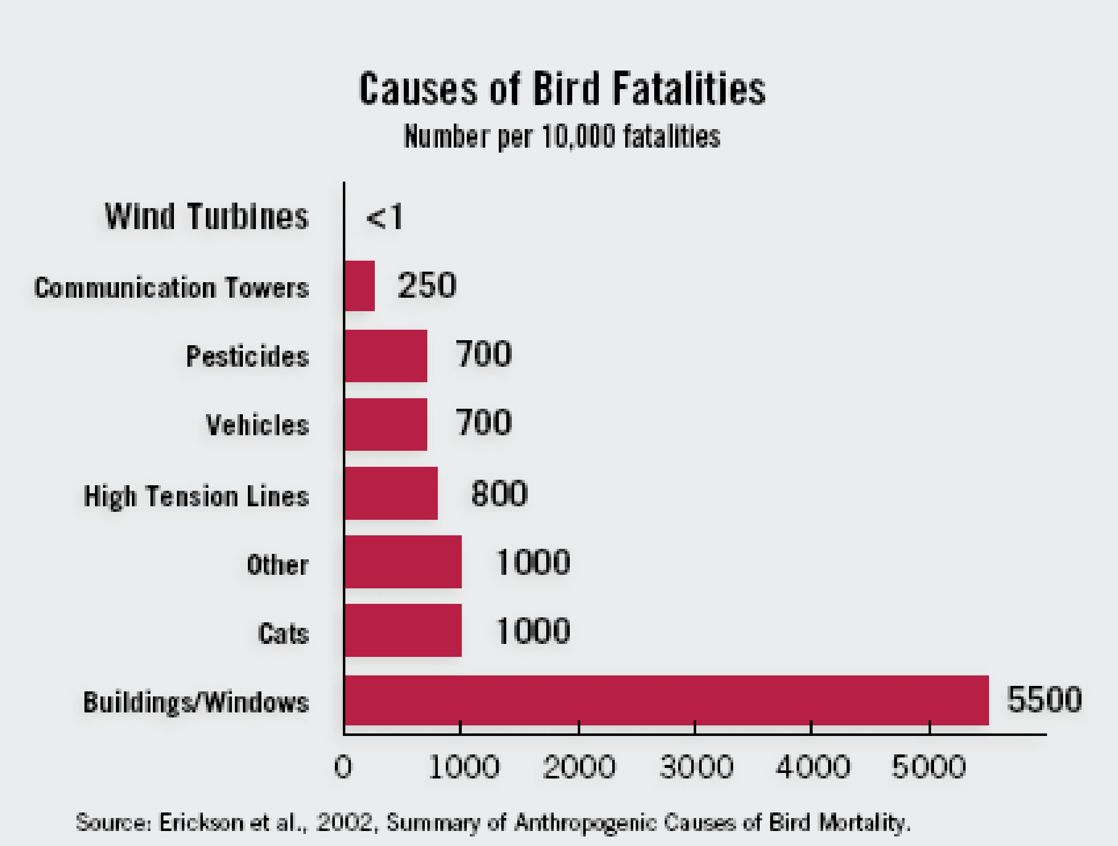
Ecological effects

- 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



Causes of Bird Fatalities

Number per 10,000 fatalities

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

Other interesting complaints

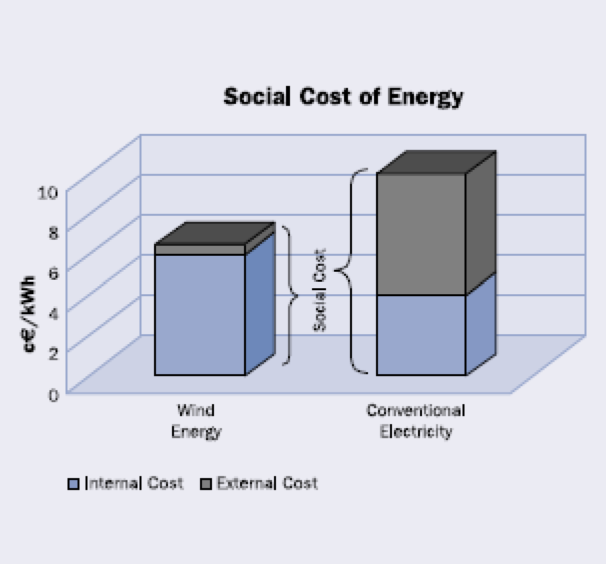
- wind turbines are dangerous
- horses are frightened
- wind turbines cause headaches
- promote lice on potato's and disturb agriculture

NON ARE TRUE!

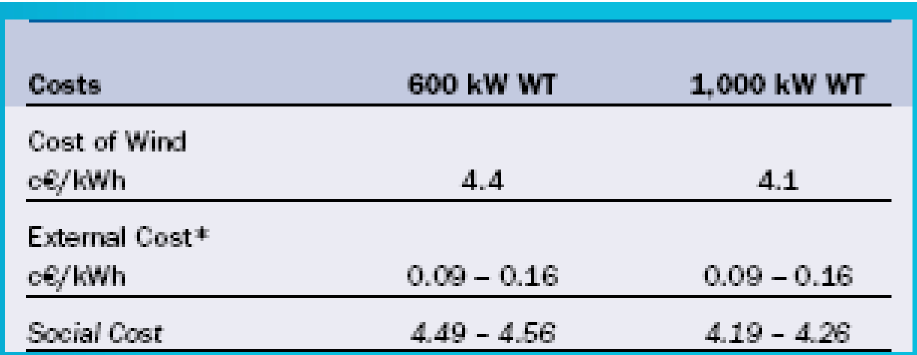
External costs

> “ ***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).

External costs, II

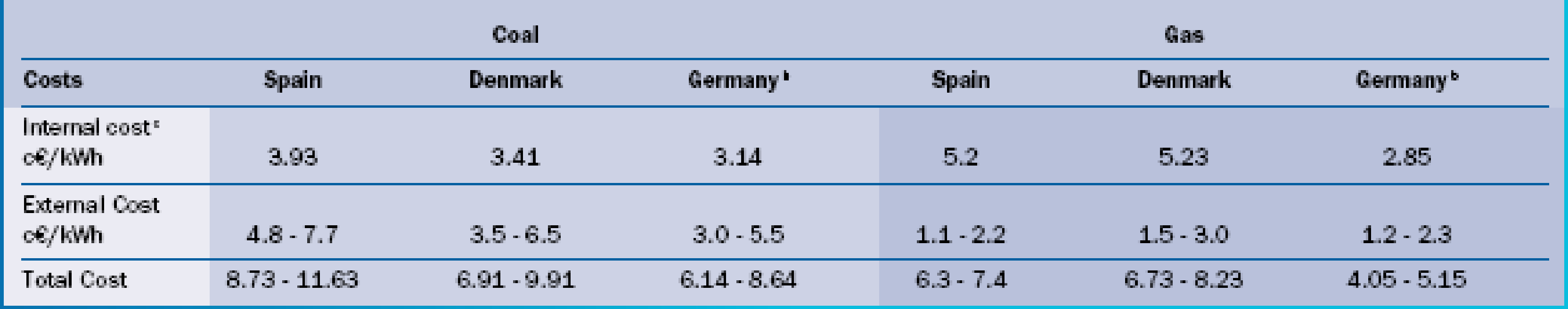


Source:EWEA



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

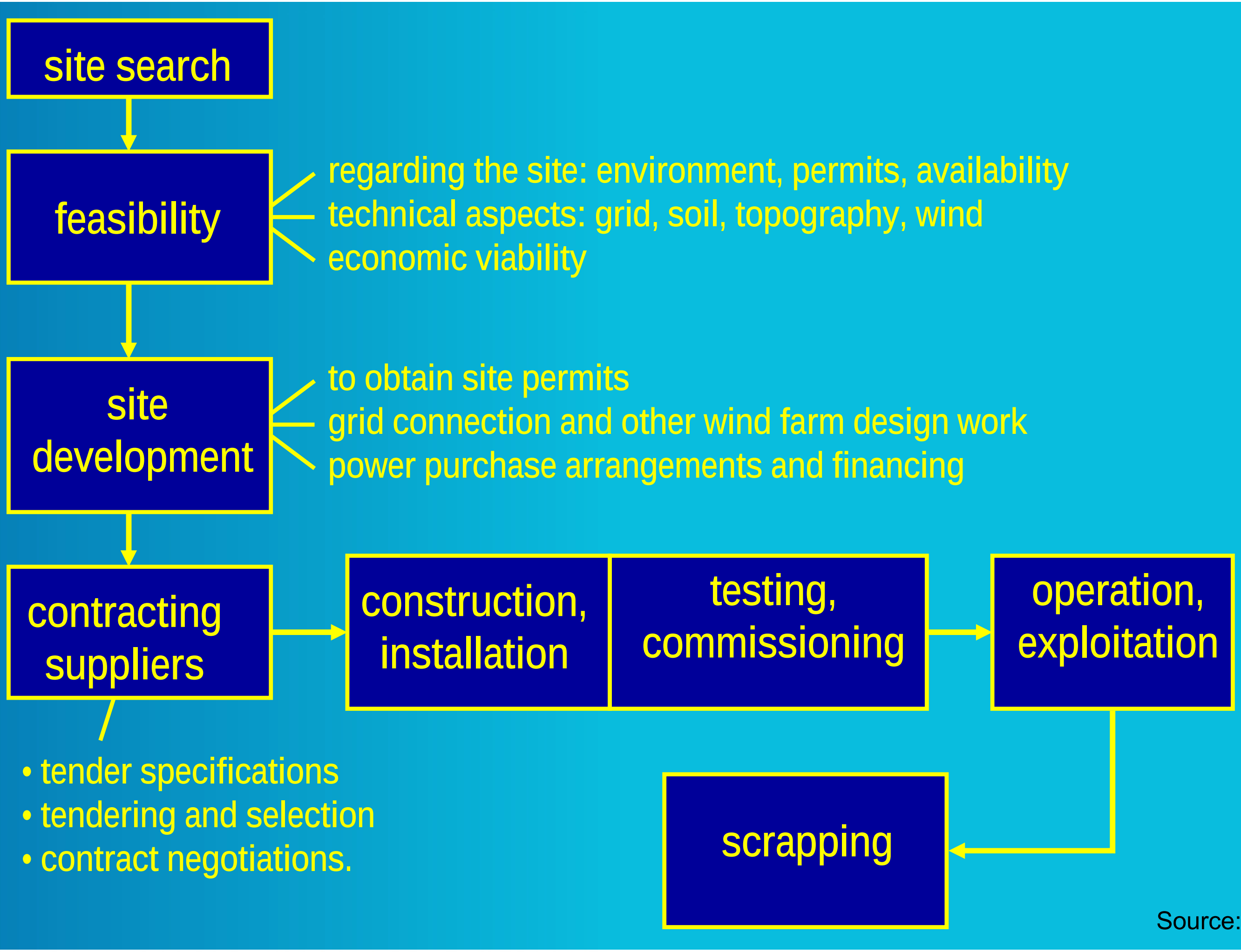
European Wind Energy Association (EWEA)

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

Implementation of wind power projects

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

Wind farm cycle



site search

feasibility
- regarding the site: environment, permits, availability
- technical aspects: grid, soil, topography, wind
- economic viability

site development
- to obtain site permits
- grid connection and other wind farm design work
- power purchase arrangements and financing

contracting suppliers
- tender specifications
- tendering and selection
- contract negotiations.

construction, installation

testing, commissioning

operation, exploitation

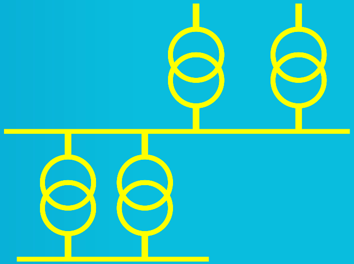
scrapping

Source: ALTENER

Feasibility study

is site available ?

technical feasible ?



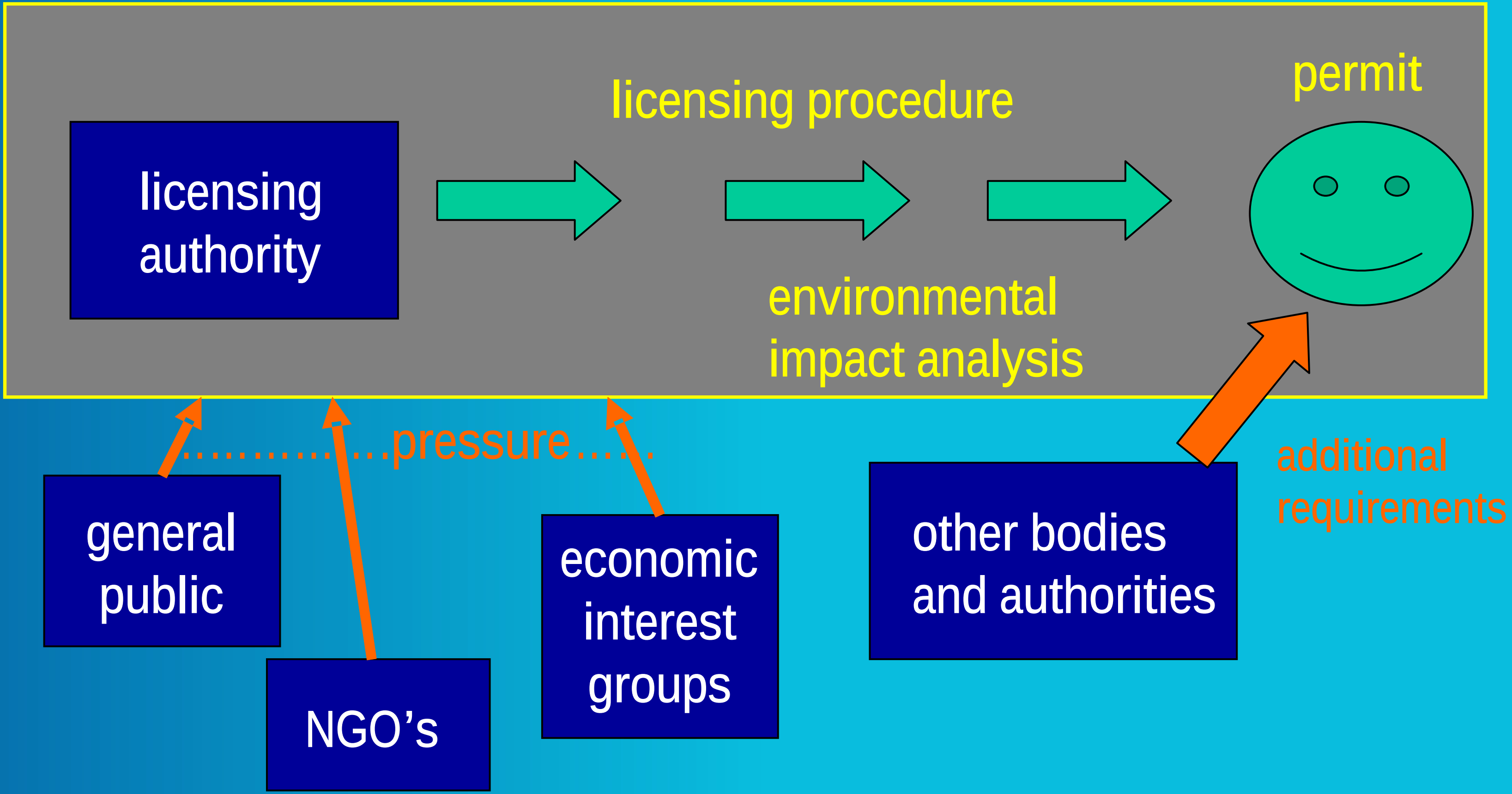
economic feasible ?

YES

proceed with site development

Source: ALTENER

Site development



licensing authority

licensing procedure

permit

environmental impact analysis

…………….pressure……..

general public

NGO's

economic interest groups

other bodies and authorities

additional requirements

Source: ALTENER

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

Construction

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

Conclusion:
Benefits from wind energy use

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/

Thank you for your attention!

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Wind energy

Classroom Exercises

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

Exercise 1

- Wind turbine is used for powering electric motor of a water pump, which has a rated power 100 kW. Average wind speed is 5 m/s. What is the minimal required radius of the wind turbine? Assume air density is 1.225 kg/m^3 and maximal Betz coefficient 0.59.

Exercise 2

- The wind turbine diameter is 100 m. Wind turbine reaches nominal power at wind speed 11 m/s and it doesn't operate when wind speed is less then 5 m/s or higher then 25 m/s. How much energy would wind turbine produce if following data are assumed:
  - 45 % of time wind speed is below minimal
  - 10 % of time wind speed is above maximal
  - 25 % of time wind speed is 8 m/s
  - 20% of time wind speed is between 11 m/s and 25 m/s
  - Air density is 1.22 kg/m^3
  - Betz coefficient 0.45

Exercise 3

- Wind power project analysis using RETScreen software
- http://www.retscreen.net/
- Suggested case study: Grid connected windfarm (available for download – assignment 04)

Exercise 3

- Site data:
  - 6.2 m/s at 30 m height
  - 20 MW wind farm, 300 kW wind turbine
  - replacement 50 % coal and 50 % large hydro

- Financial data:
  - inflation rate 2.5%, discount rate 12%
  - project lifetime 25 years
  - feed-in tariff 4.16 MU/kWh, escalates 5% annually (MU stands for “money unit”)
  - debt financing 75 %, debt term 7 years, interest rate 14 %
  - income tax 35 %
  -
- **Task: perform financial evaluation of a wind power project!**

GEOTHERMAL ENERGY

by

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

Centre for Renewable Energy Sources

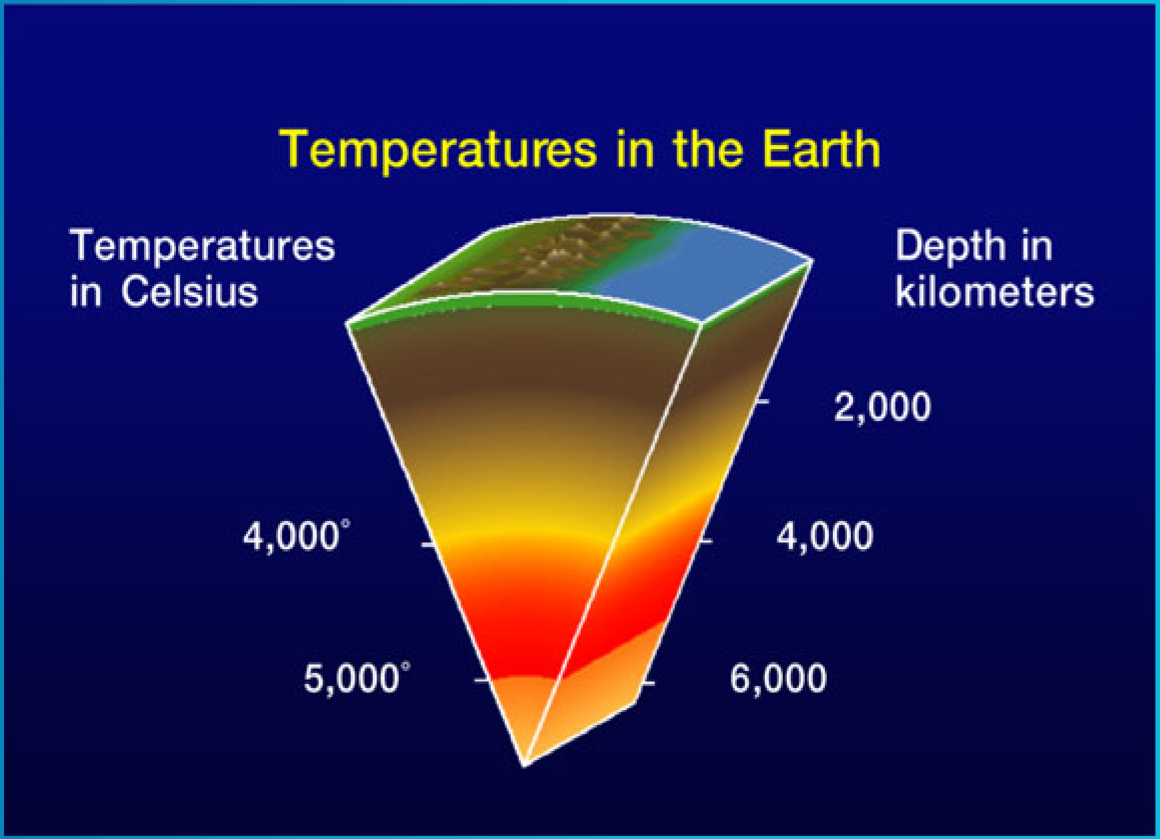
July 2006

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

Geothermal energy : The Reliable Renewable

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

Geothermal Energy is the Heat of the Earth interior



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Contract: INCO-CT-2004-509205

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 Powerstations

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

Power production Technology

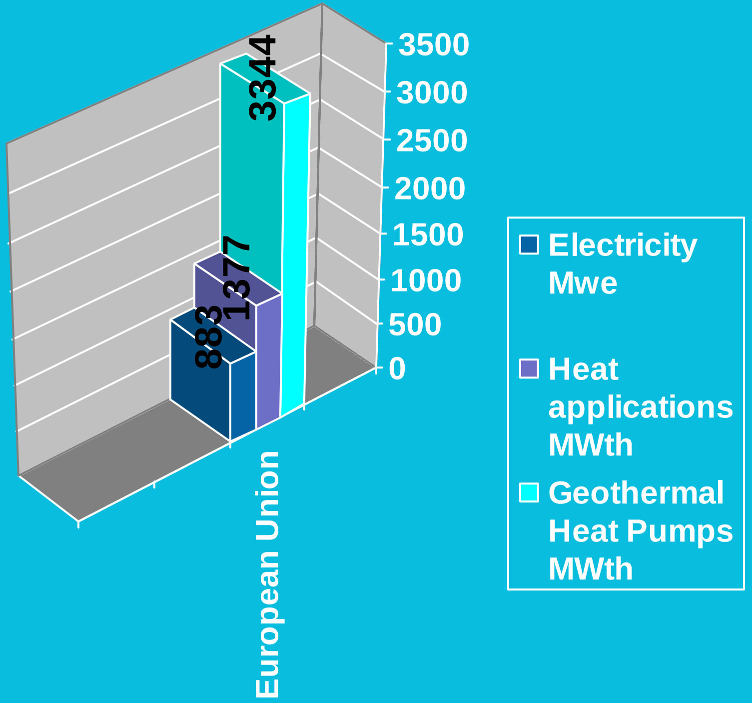
Sixth Framework Programme, Sixth Framework Programme, DG Research, International Cooperation
Contract: INCO-CT-2004-509205

Drilling rig view

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

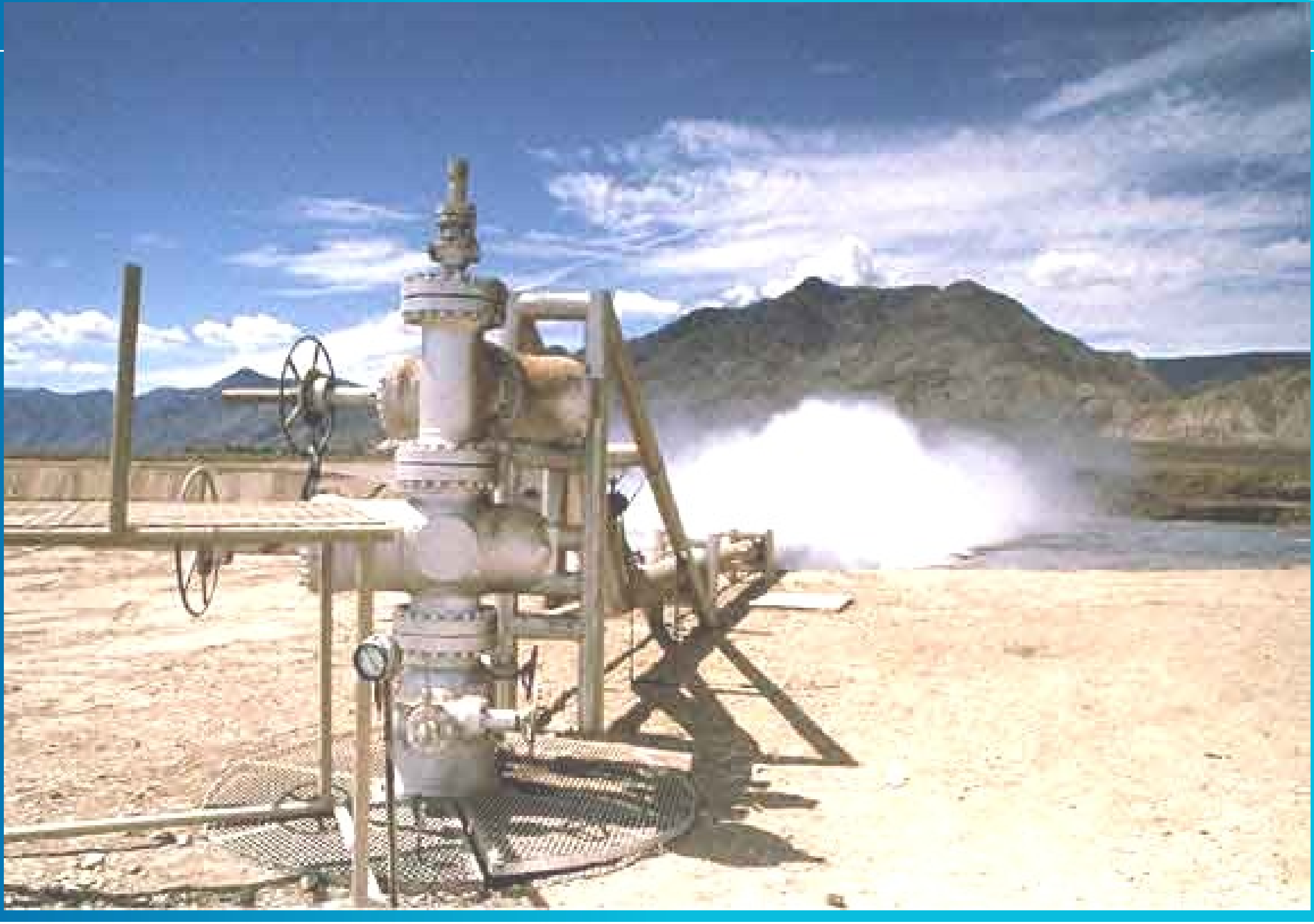
Geothermal Energy applications in the E.U.

- Electricity Production
- Heat utilization
- Geothermal Heat Pumps



Geothermal Powerstation view

High-enthalpy (temperature) drilling



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From Bertani 2005

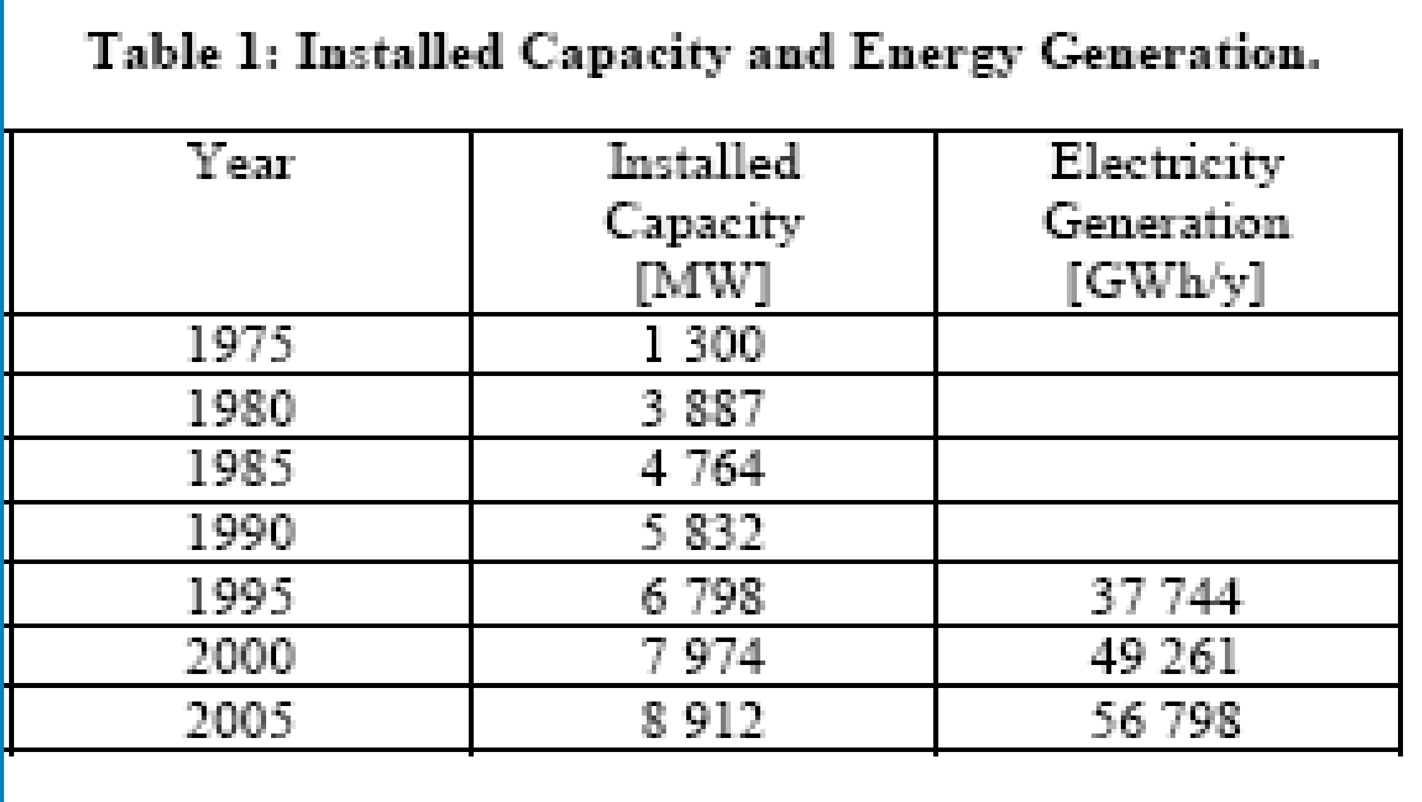
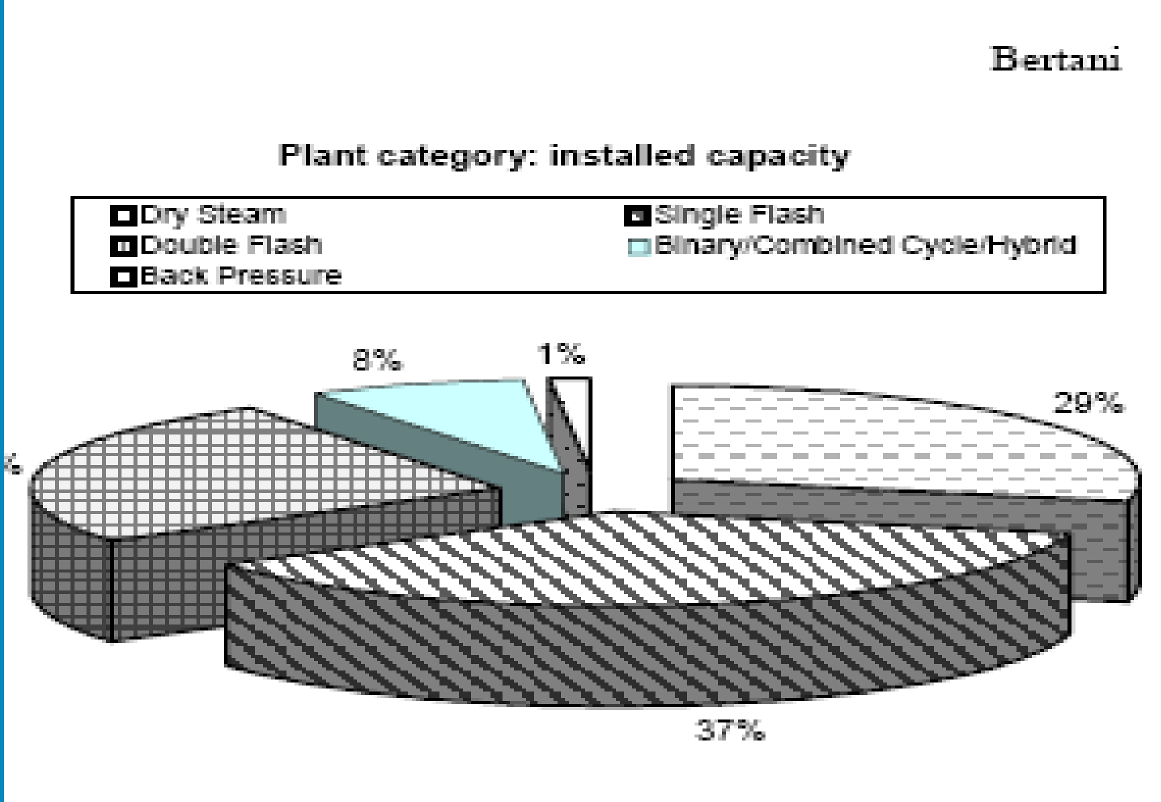


Table 1: Installed Capacity and Energy Generation.

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

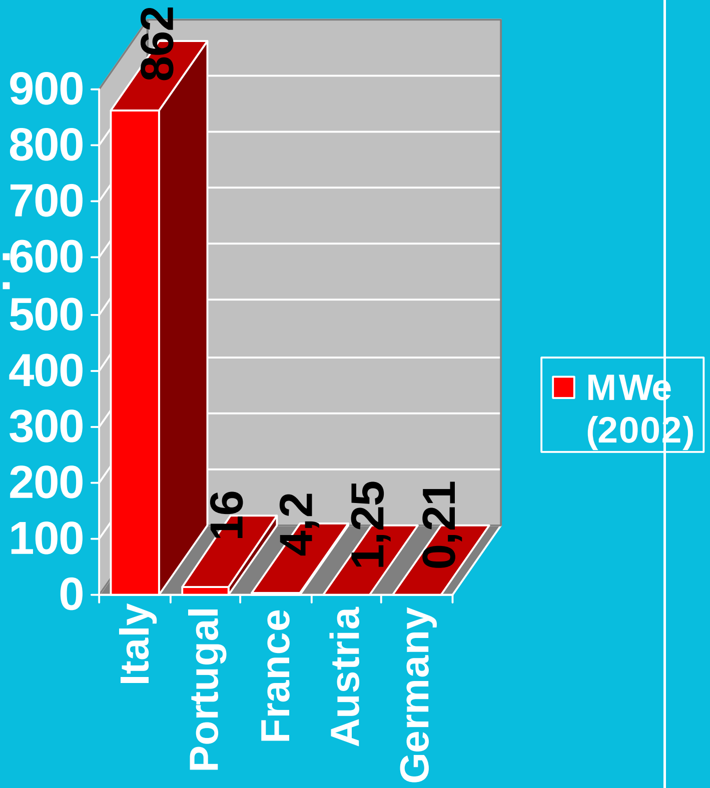

Bertani
Plant category: installed capacity
Dry Steam
Single Flash
Double Flash
Binary/Combined Cycle/Hybrid
Back Pressure
8%
1%
29%
37%

Electricity Production

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

- Operation and Maintenance cost:
  2 – 3 %

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



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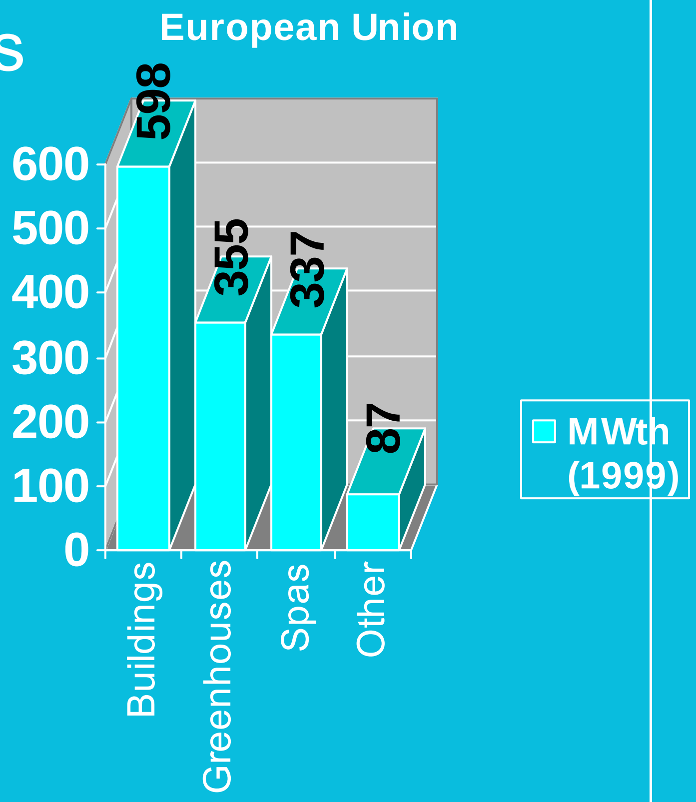
Thermal applications (I)

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



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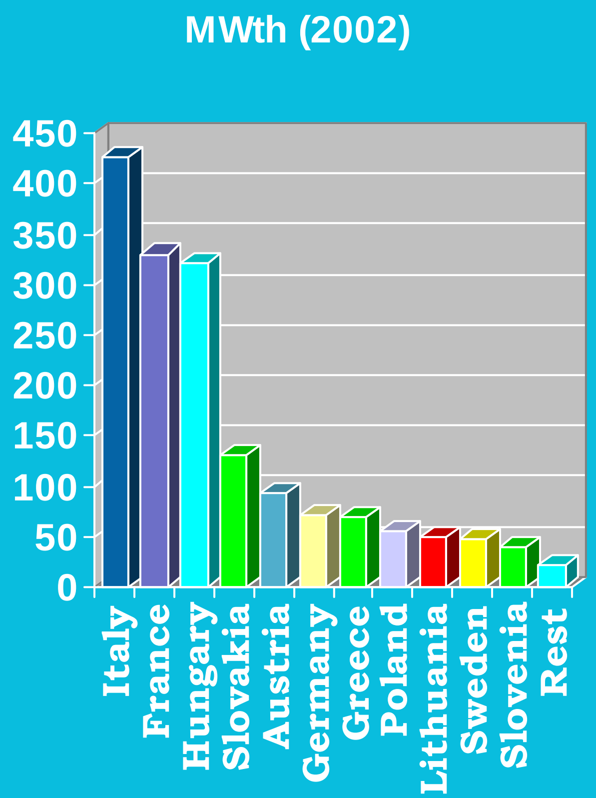
Thermal applications (II)

- Capital cost:
  200 – 1400 € / kW(th)
- Operation and Maintenance cost:
  2 – 3 %
- Energy cost:
  0,005 – 0,035 € / kWh(th)



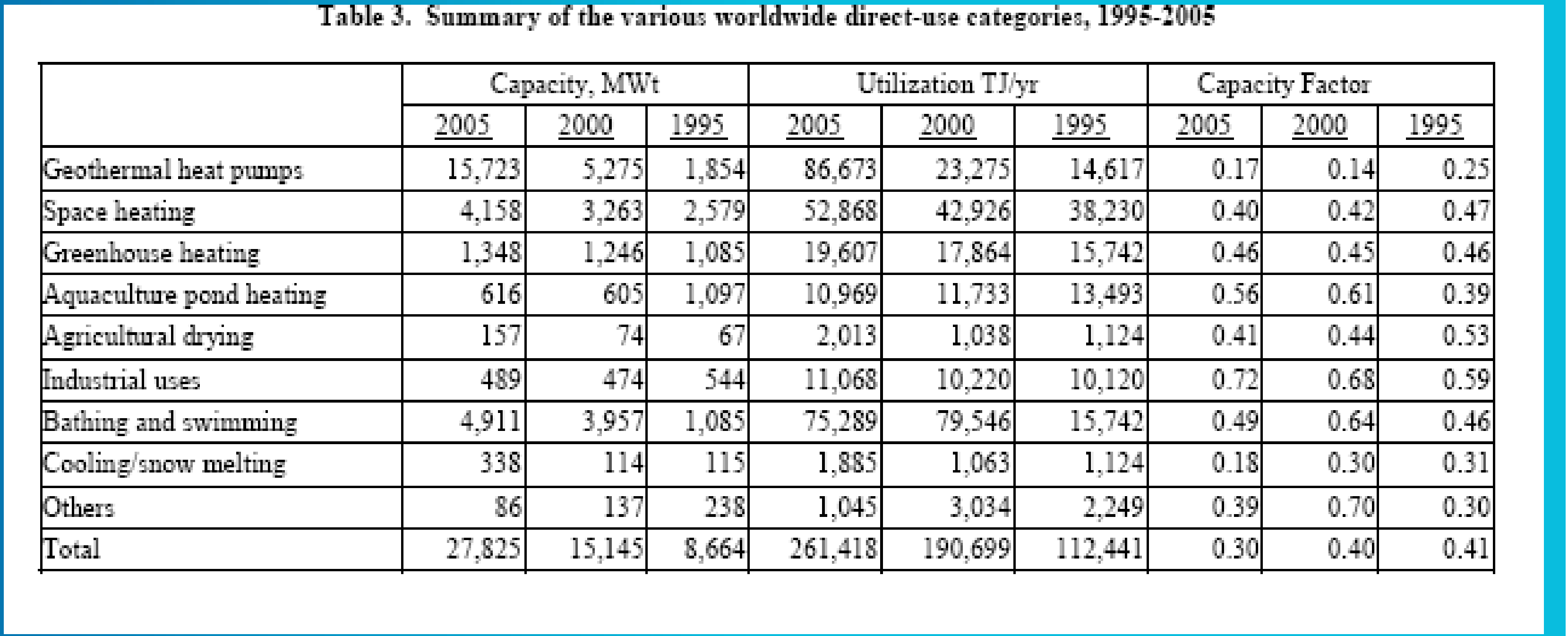


Table 3. Summary of the various worldwide direct-use categories, 1995-2005

	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

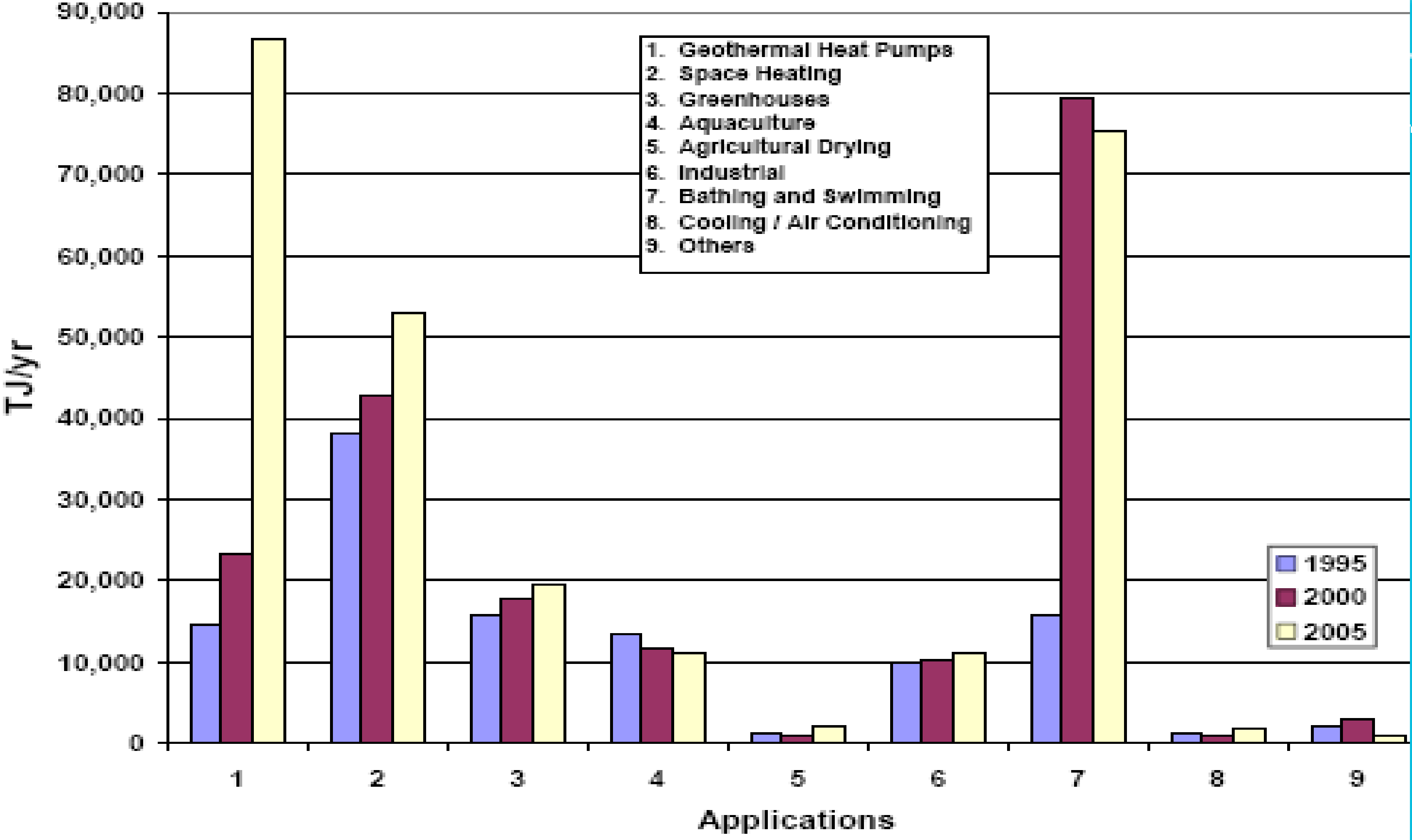


Figure 1: Comparison of worldwide energy use in TJ/yr for 1995, 2000 and 2005.

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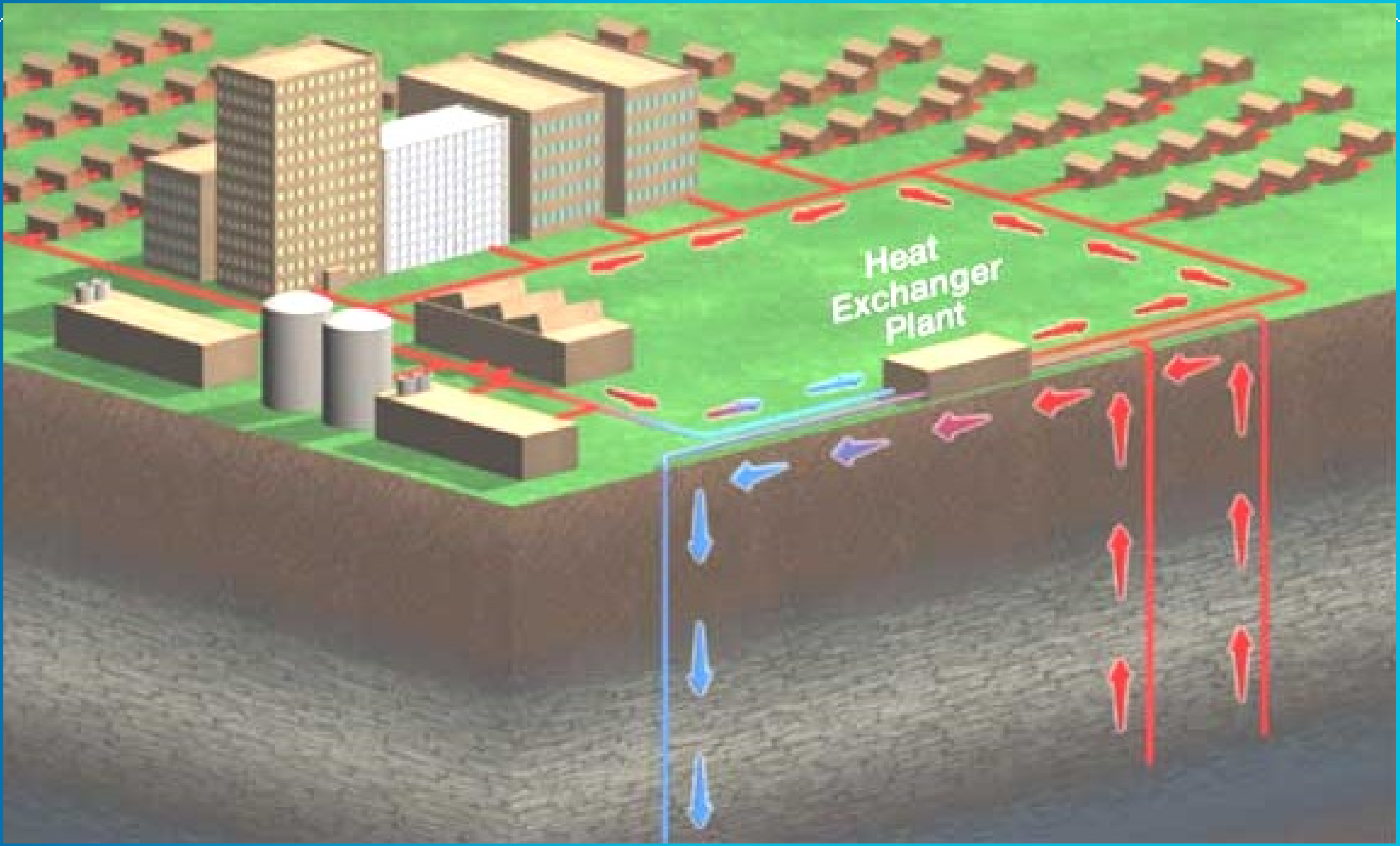
District-Heating



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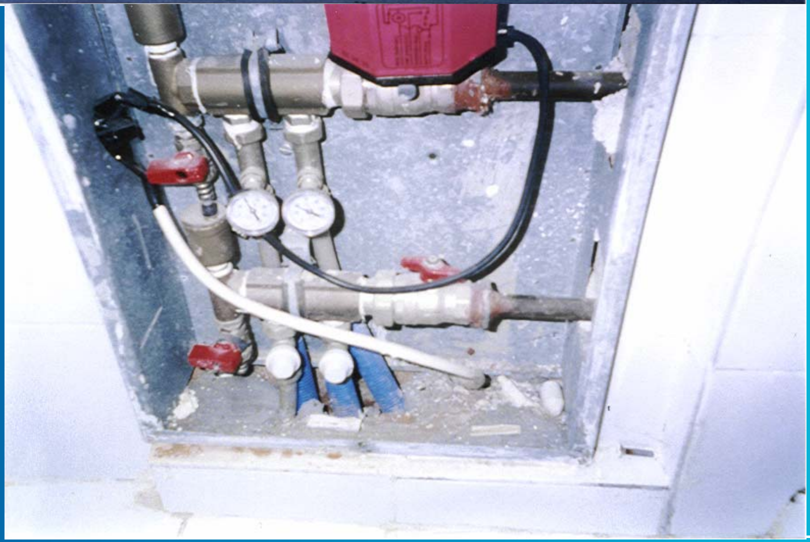
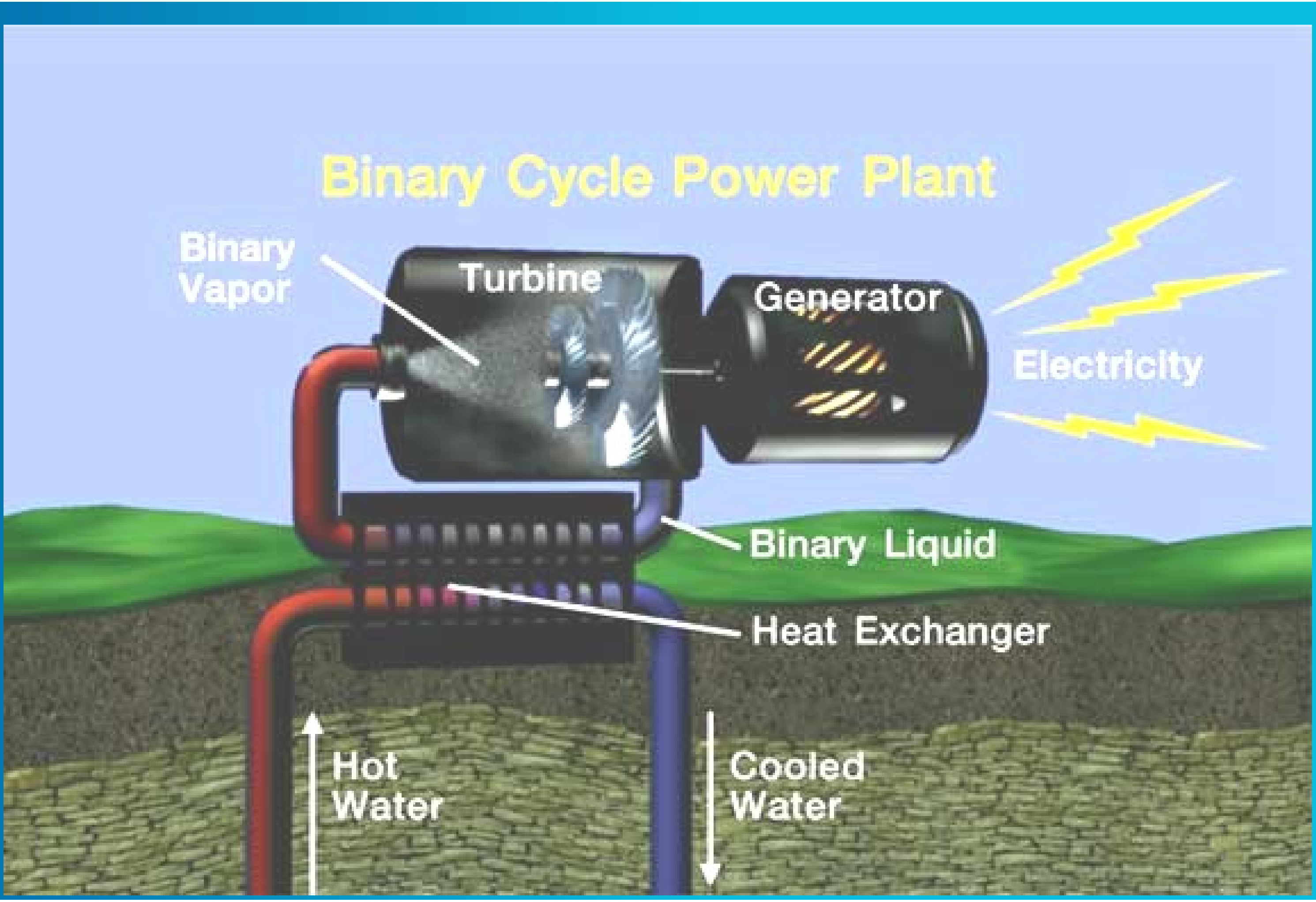
Traianoupolis-spas system specifications

- Borehole ~60m³/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

Traianoupolis-spas hotel heating



Power-production by use of an Organic substance or Ammonia



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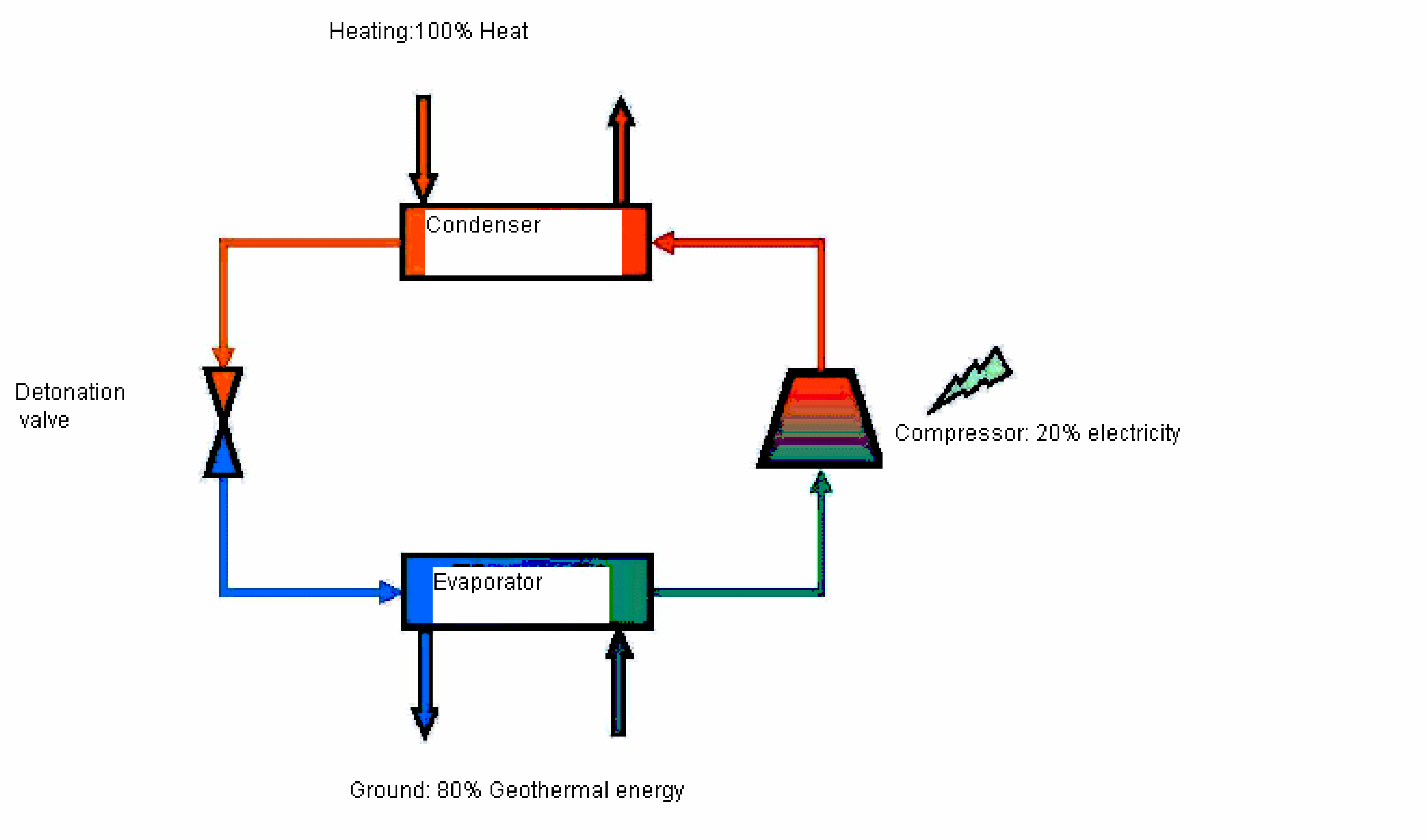
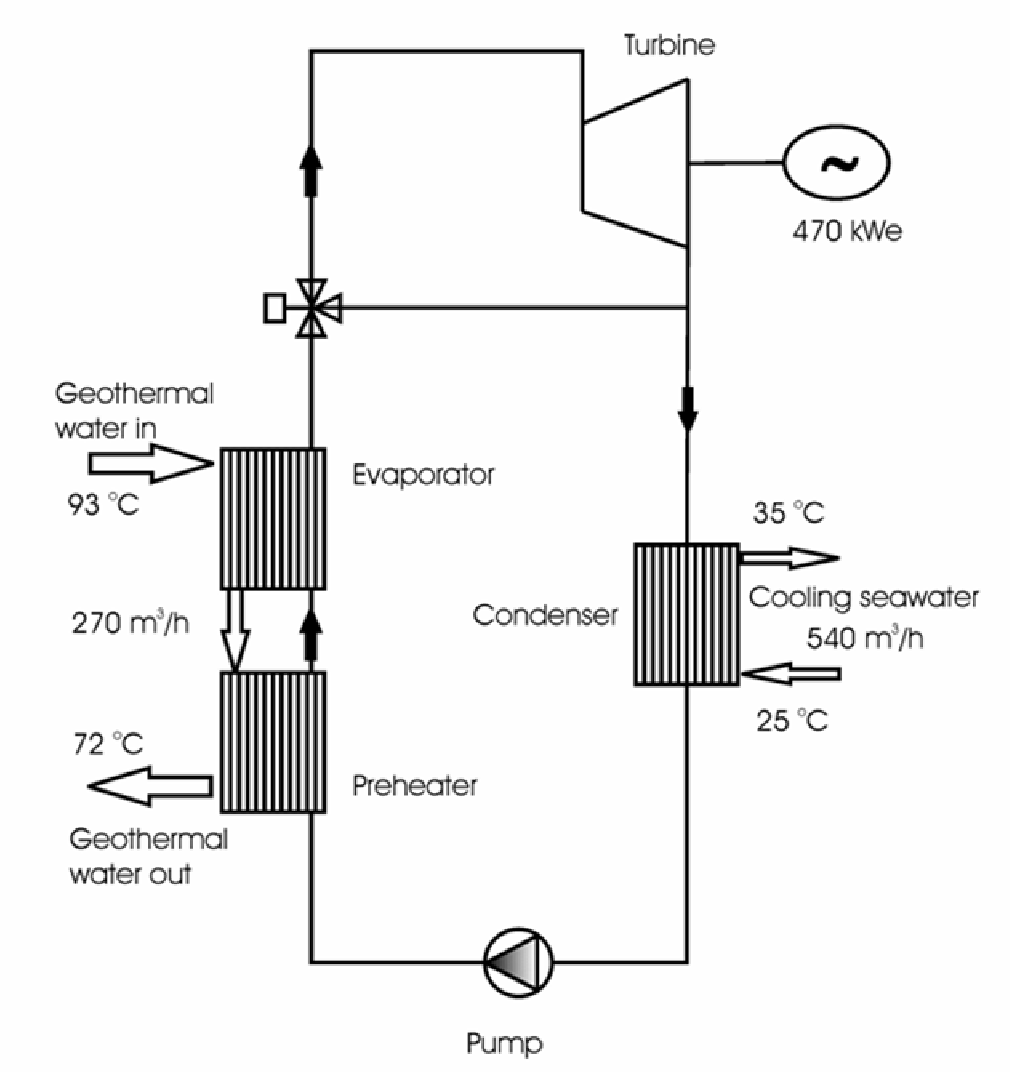
Operation principle



Operation principle



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Kimolos desalination unit

Photo 1: The desalination unit

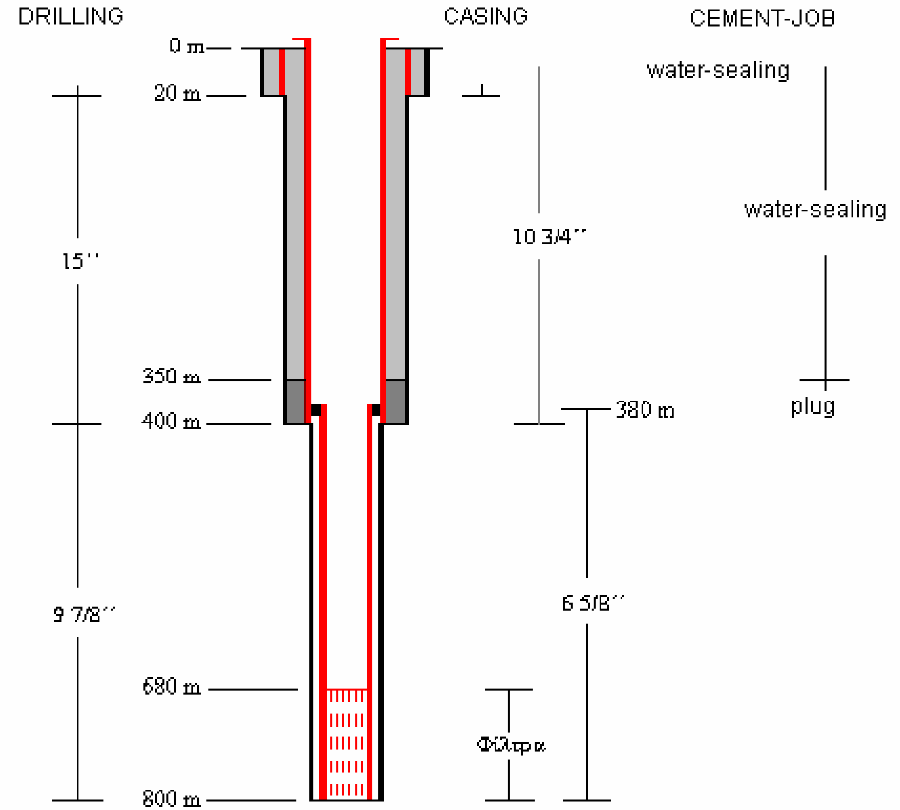
Heating of Greenhouses

Fish farming

SPA's

Drilling-rig view

Borehole section



GEOTHERMAL BORE-HOLE OF SALONICA AIRPORT "MACEDONIA"

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)

Geothermal Heat Pumps (I)

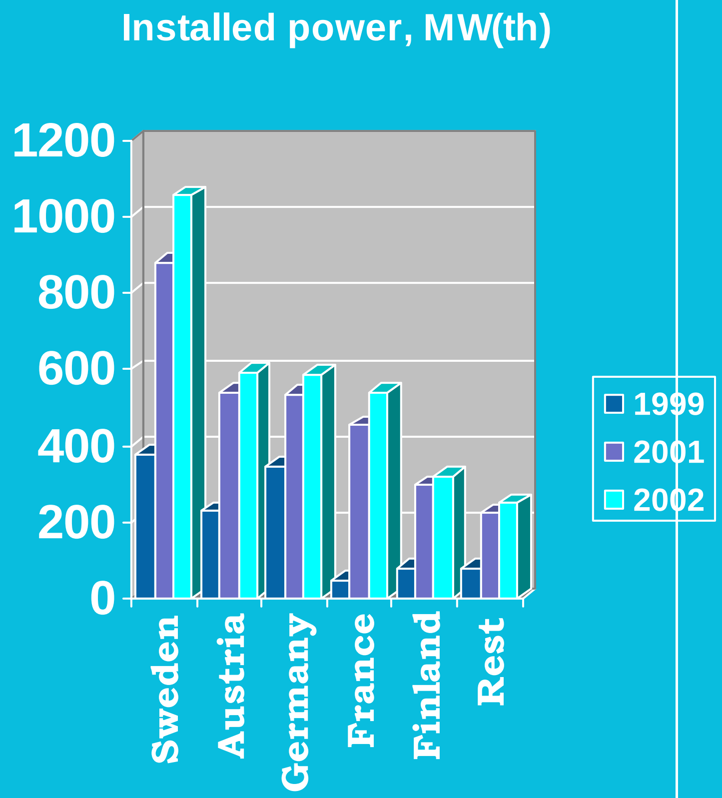
- Shallow Geothermal energy (t < 25 ºC):
  - Heating & cooling
    with water-cooled heat pumps

Geothermal Heat Pumps (II)

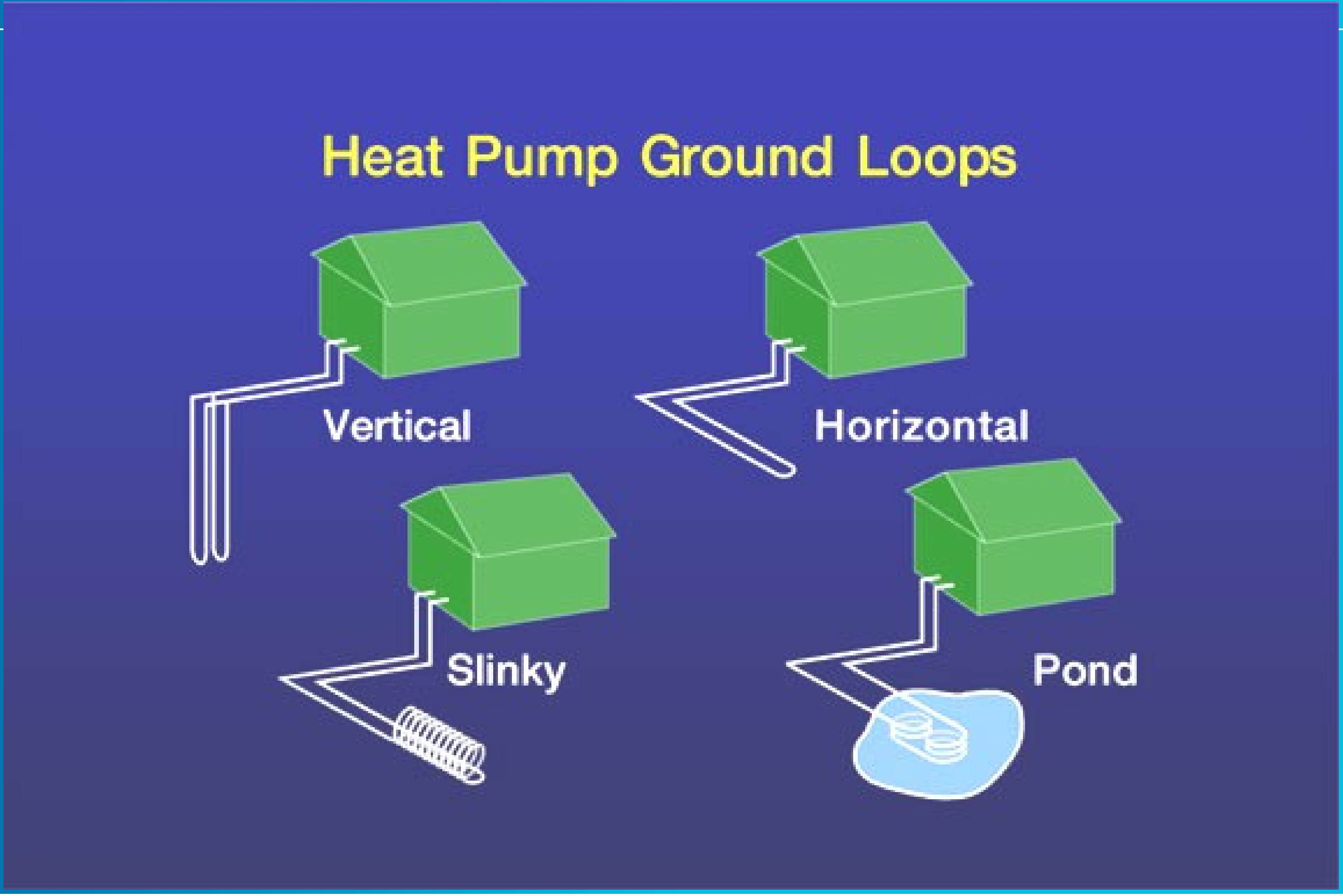
- Capital cost:
  600 – 1800 € / kW(th)

- 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)


Installed power, MW(th)

Underground heat pumps arrangement



Horizontal Earth Heat Exchanger (HEHE) Technology

Borehole Heat Exchanger (BHE) Technology

Underground Heat exchanger Technology

Pylaia Town-Hall system specifications

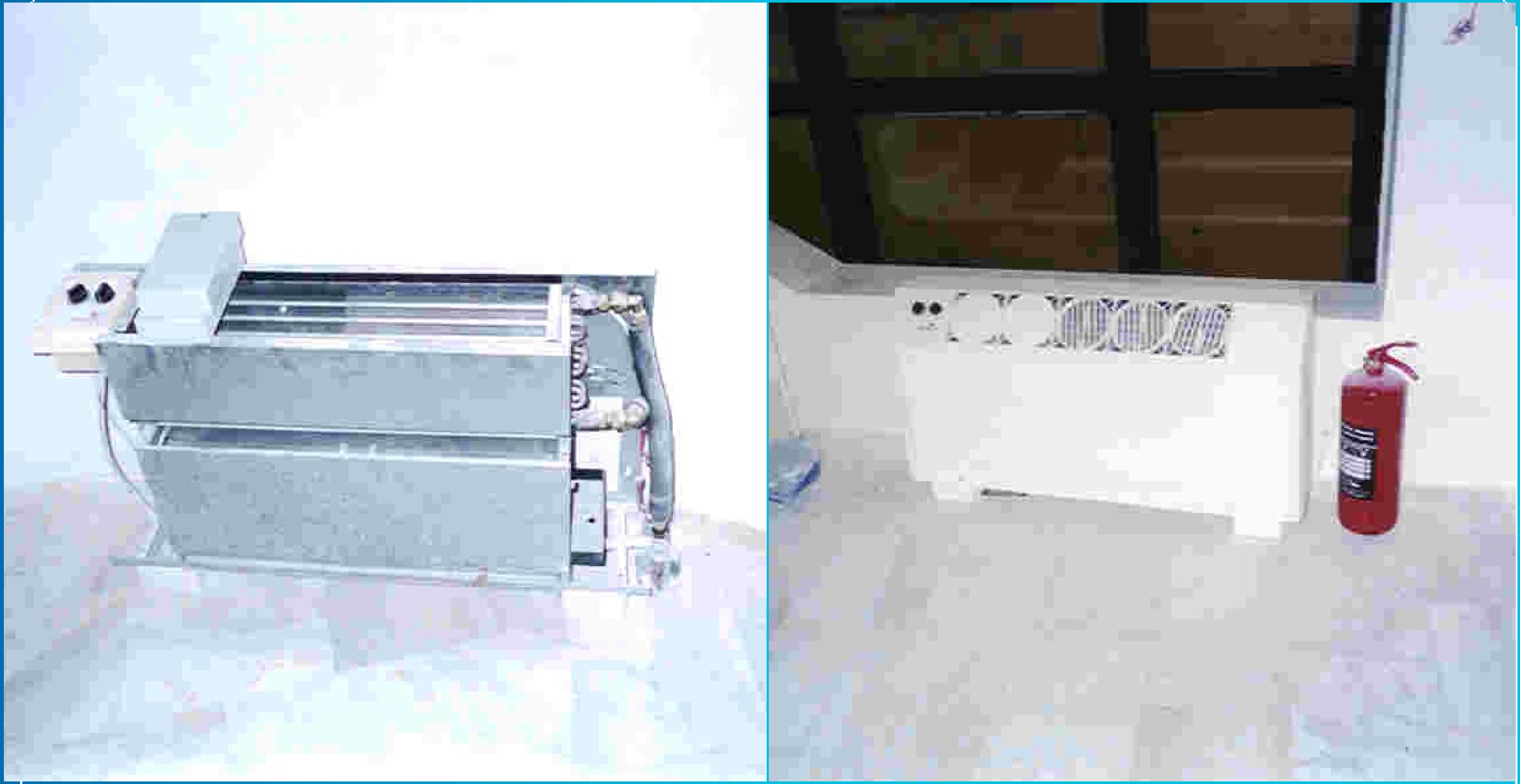
- 21 6’’ boreholes
- 80 m deep
- U-tube , Φ 40
- 10 Water-source HPs
- 155 kWth & 215 kWC
- Fan-coils
- Central AHU

Heat Pumps in Pylaia Townhall

NTUA Building

- Borehole of 280 m, 35 m³/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

Fan-coil in Pylaia Townhall



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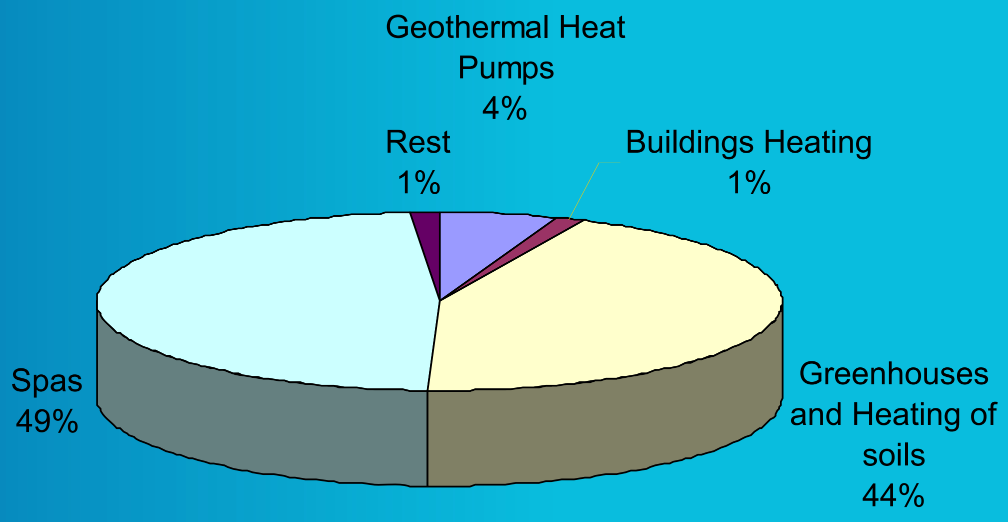
European Public-law Centre

- 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

Geothermal Energy applications in Greece (2005): 74 MW



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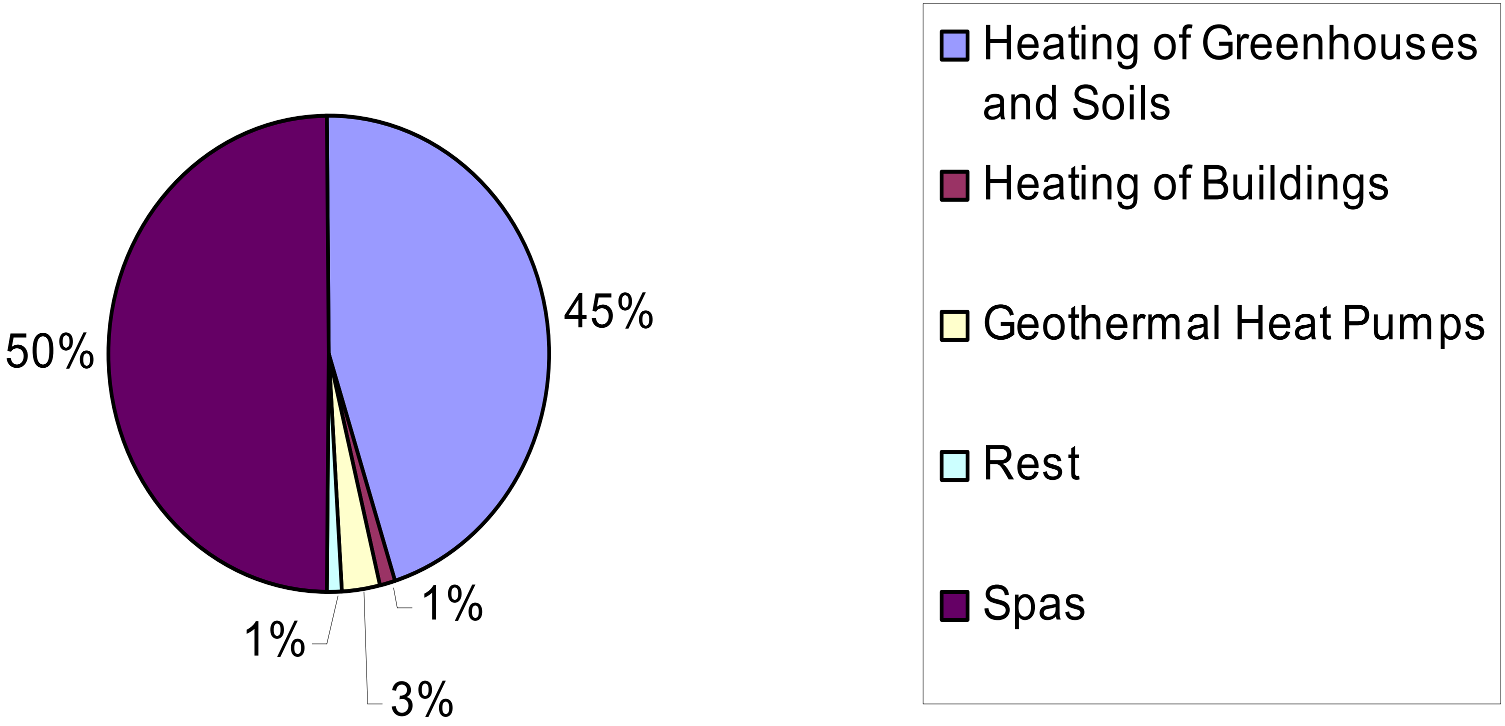
Geothermal Energy applications in Greece (2001): 71 MW



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Economic aspects of RES

Borut Del Fabbro

Competitiveness of RES

- RES are usually not competitive with fossil fuels
- The price of fossil fuels does not include the costs of externalities:
  - CO2 emissions cause global warming
  - Other pollution (SO2, 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

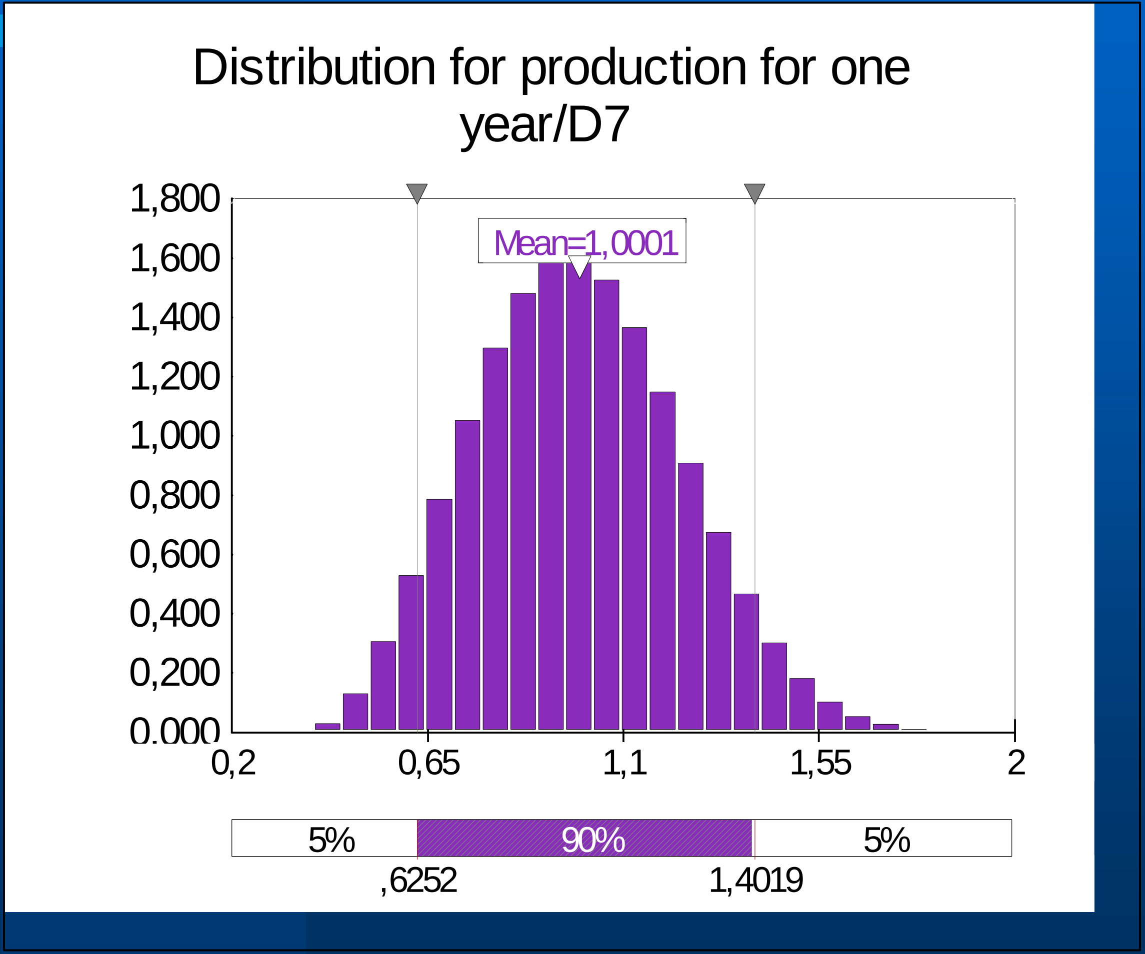
Breakeven prices for RES

	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

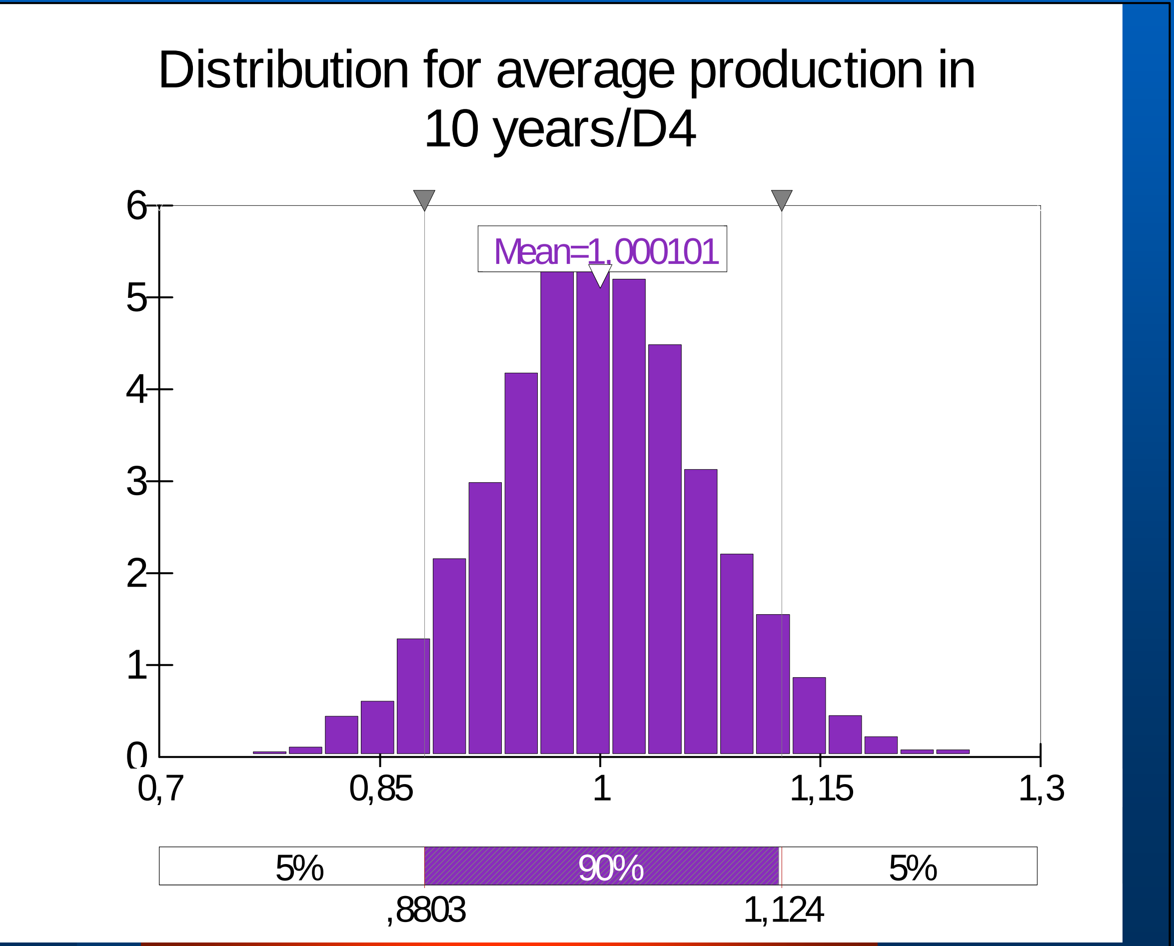
Production uncertainty



Distribution for production for one year/D7

%tile	Value
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”


Distribution for average production in 10 years/D4

%tile	Value
5%	88%
10%	91%
15%	92%
20%	94%
25%	95%
30%	96%
35%	97%
40%	98%
45%	99%
50%	100%
55%	101%
60%	102%
65%	103%
70%	104%
75%	105%
80%	106%
85%	108%
90%	110%
95%	112%

Thank you very much
for your attention!

Electricity Market: a Case of Market Power in GENCO

Prof. Dr. Robert Golob
Prof. Dr. Andrej Gubina

Faculty of Electrical Engineering
University of Ljubljana, Slovenia

Fojnica, Bosnia and Herzegovina, 17.-21. July 2006

Lecture Topics

1. What is Deregulation All About?
2. Power Market Overview
3. GENCO in Deregulated Environment
4. Power Market Simulator
5. Illustration: GENCO Case Studies

1. What is Deregulation All About?

Regulated vs. Deregulated System

Official Goals of Deregulation

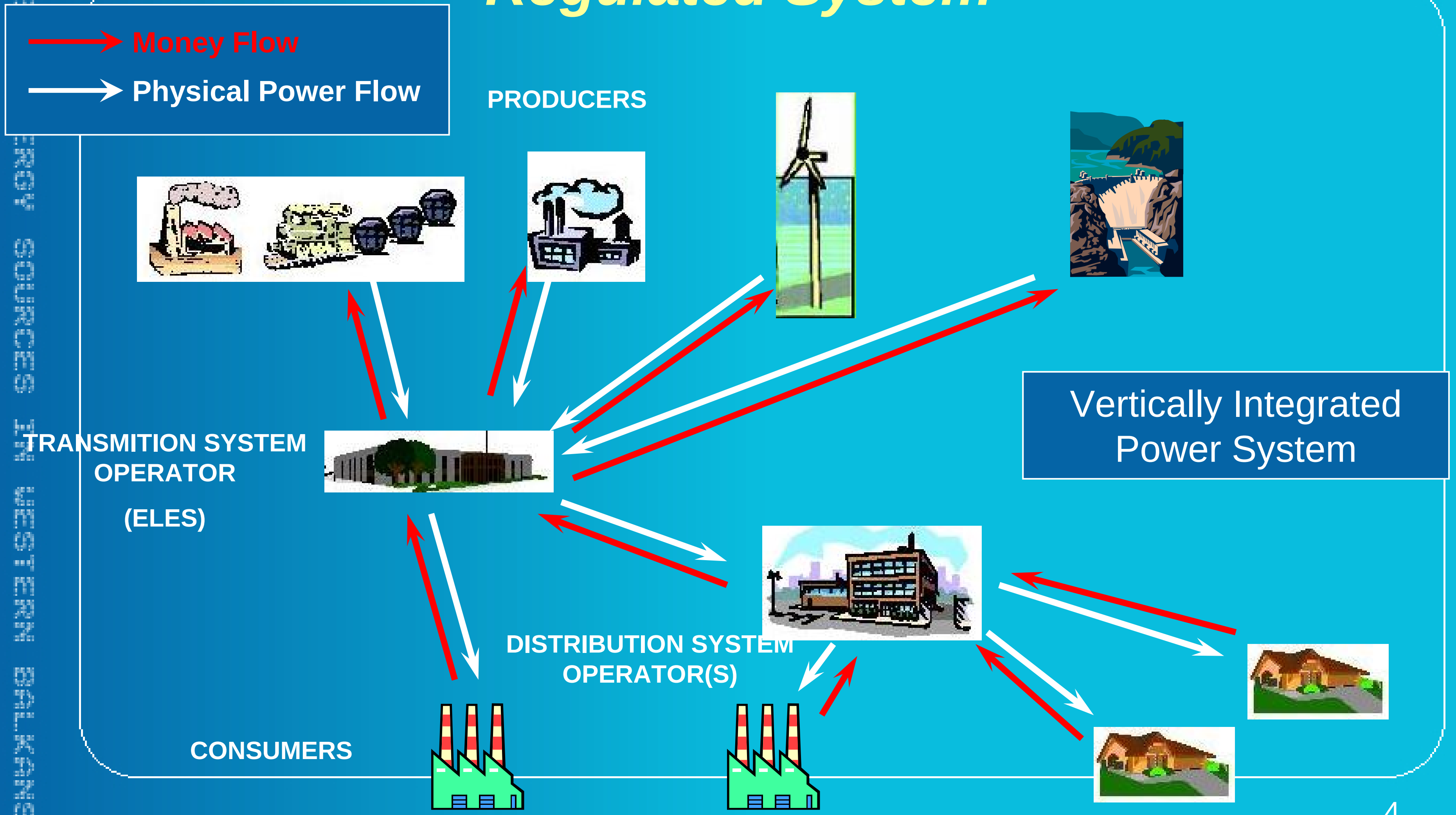
How Are This Goals Being Met?

Deregulation & Prices

So What Have We Learned?

What is Deregulation All About?

Regulated System



→ Money Flow

→ Physical Power Flow

PRODUCERS

TRANSMITION SYSTEM OPERATOR

(ELES)

DISTRIBUTION SYSTEM OPERATOR(S)

CONSUMERS

Vertically Integrated Power System

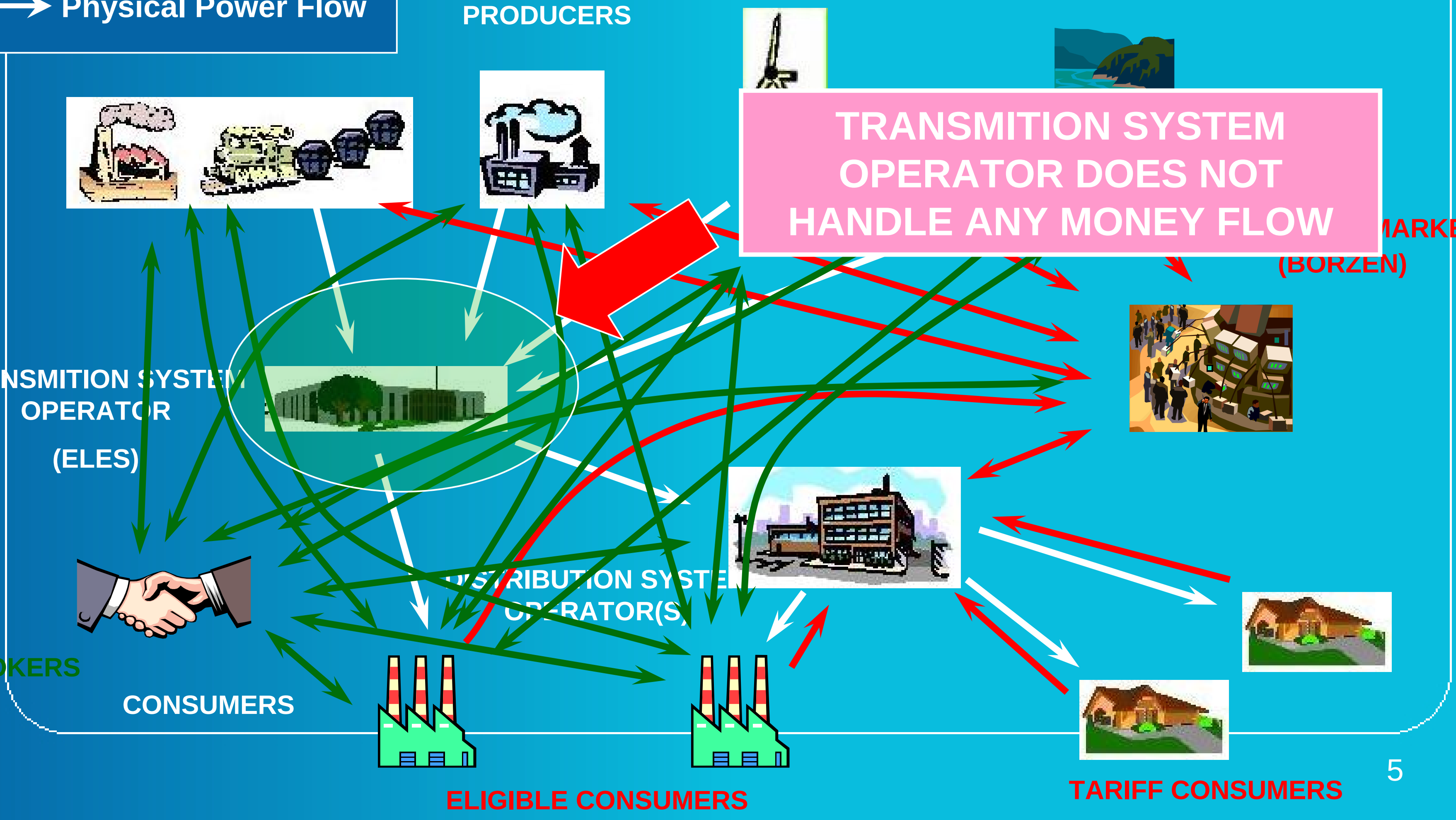
What is Deregulation All About?

Deregulated System

→ Money Flow

→ Money Flow

→ Physical Power Flow



PRODUCERS

TRANSMITION SYSTEM OPERATOR DOES NOT HANDLE ANY MONEY FLOW

MARKET
(BORZEN)

TRANSMITION SYSTEM
OPERATOR
(ELES)

DISTRIBUTION SYSTEM
OPERATOR(S)

BROKERS

CONSUMERS

ELIGIBLE CONSUMERS

TARIFF CONSUMERS

What We Have Learned

Official Goals of Deregulation

- Getting rid of vertically integrated monopolies
- Customer gets a right to choose
- Price / tariff reduction and alignment
- Entrance of new players and private capital
- Improving the efficiency of operation

What We Have Learned

How Are the Goals Being Met?

- **Deregulation:**

  (market) power has been transferred from transmission operators to generators

- **Liberalization:**

  due to lack of transparency (liquidity), the mobility of consumers stays rather low

- **Privatization:**

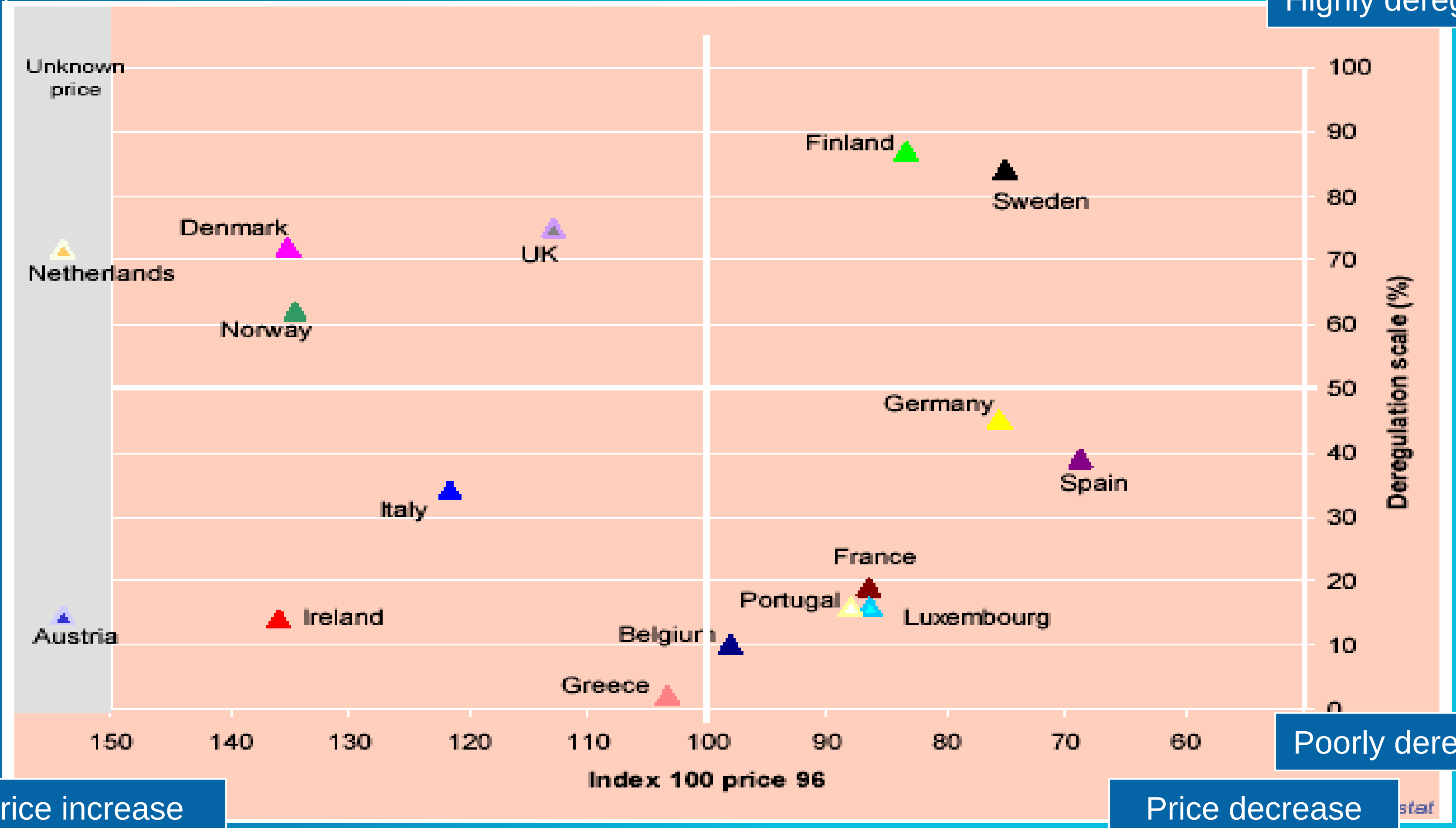
  large incumbents control the scene

- **Efficiency:**

  revenues are increasing and costs have been (drastically) decreased

What We Have Learned

Deregulation & Prices



Highly dereglated

Poorly dereglated

Price increase

Price decrease

What We Have Learned

So What Have We Learned?

- No unique solution and no guarantee that it will work
- Yet there are some extremely positive examples
- Liquidity of the markets – transparent price indicators are crucial
- The process is still evolving (continental Europe)
- Consolidation will mark the future outcomes

2. Power Market Overview

Situation in 1998

How Are This Goals Being Met?

Deregulation & Prices

So What Have We Learned?

Power Market Overview

Different Market Designs

- Two distinct trading mechanisms:
    - Central auction
    - Bilateral trading
- Central auction mechanism:
    - Simple central auction mechanism (without economic dispatch)
    - Highly complex auction mechanisms (based on unit commitment algorithms)
- Auction types:
    - Double-sided auction – demand side can be fully envolved
    - Single-sided auction – only supply can submit bids to the market
- Transmission & ancillary services:
    - Electricity trading is done independetly of transmission and ancillary services
    - The energy is traded with the transmission and ancillary service markets (usually leads to nodal or zonal pricing market models)

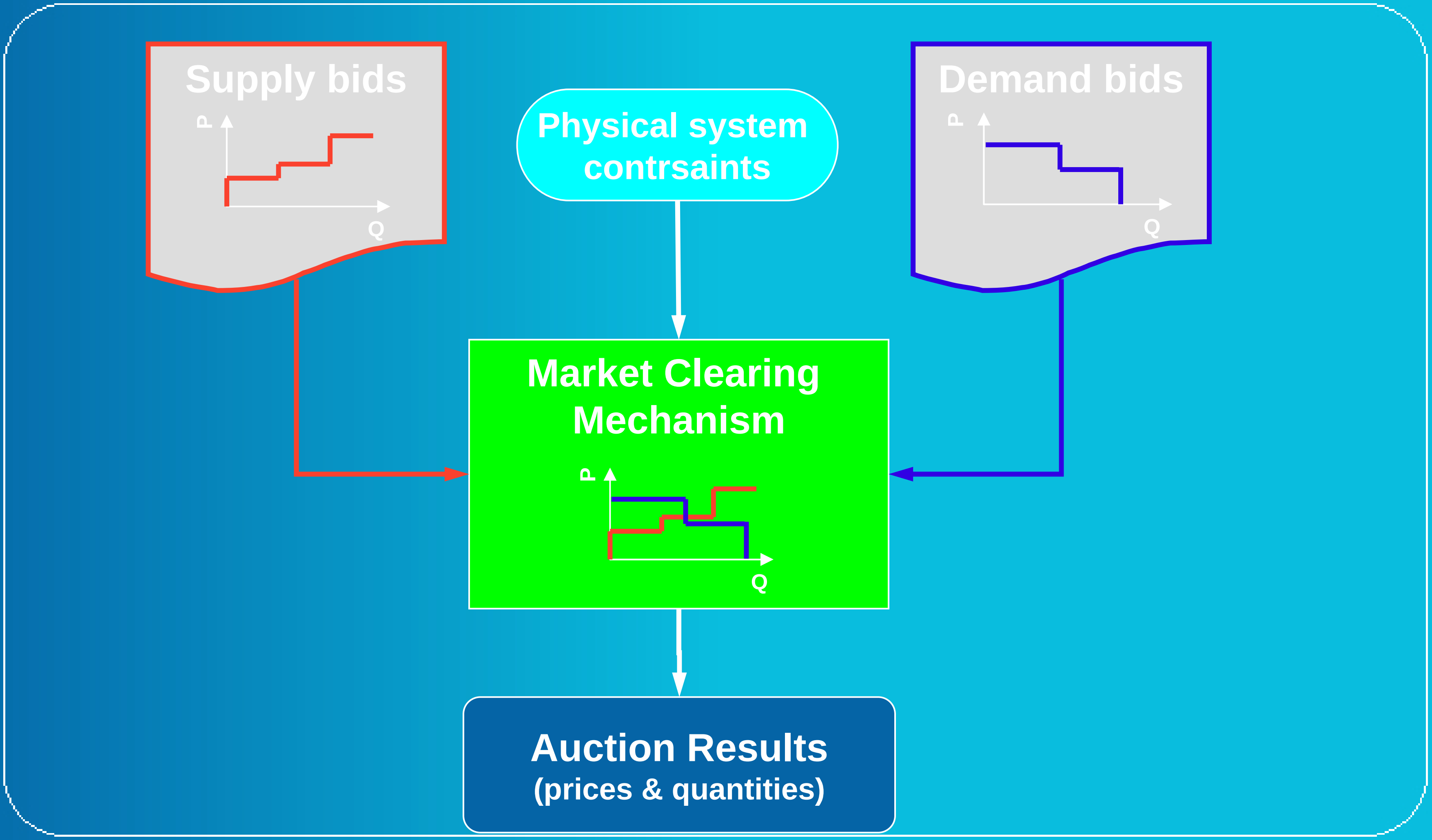
Power Market Overview

Day-Ahead Market

- Hourly bids.
- Central auction mechanism.
- Double-sided auction.
- 24 simultaneous auctions for next day period.
- Single Market Clearing Price (MCP) for all participants.
- Billateral trade is allowed.

Power Market Overview

Auction Design



Supply bids

Physical system contrsaints

Demand bids

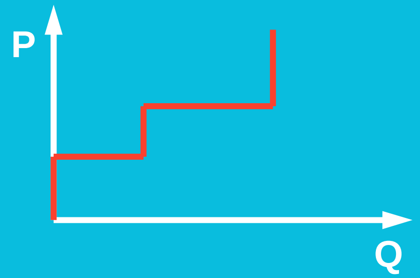
Market Clearing Mechanism

Auction Results
(prices & quantities)

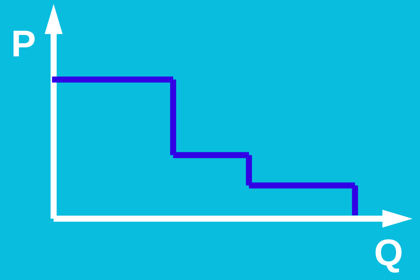
Power Market Overview

Bids

- All bids are “*Price / Quantity*” bids.
- Supply bids:
  - bids to sell energy
  - increasing or constant

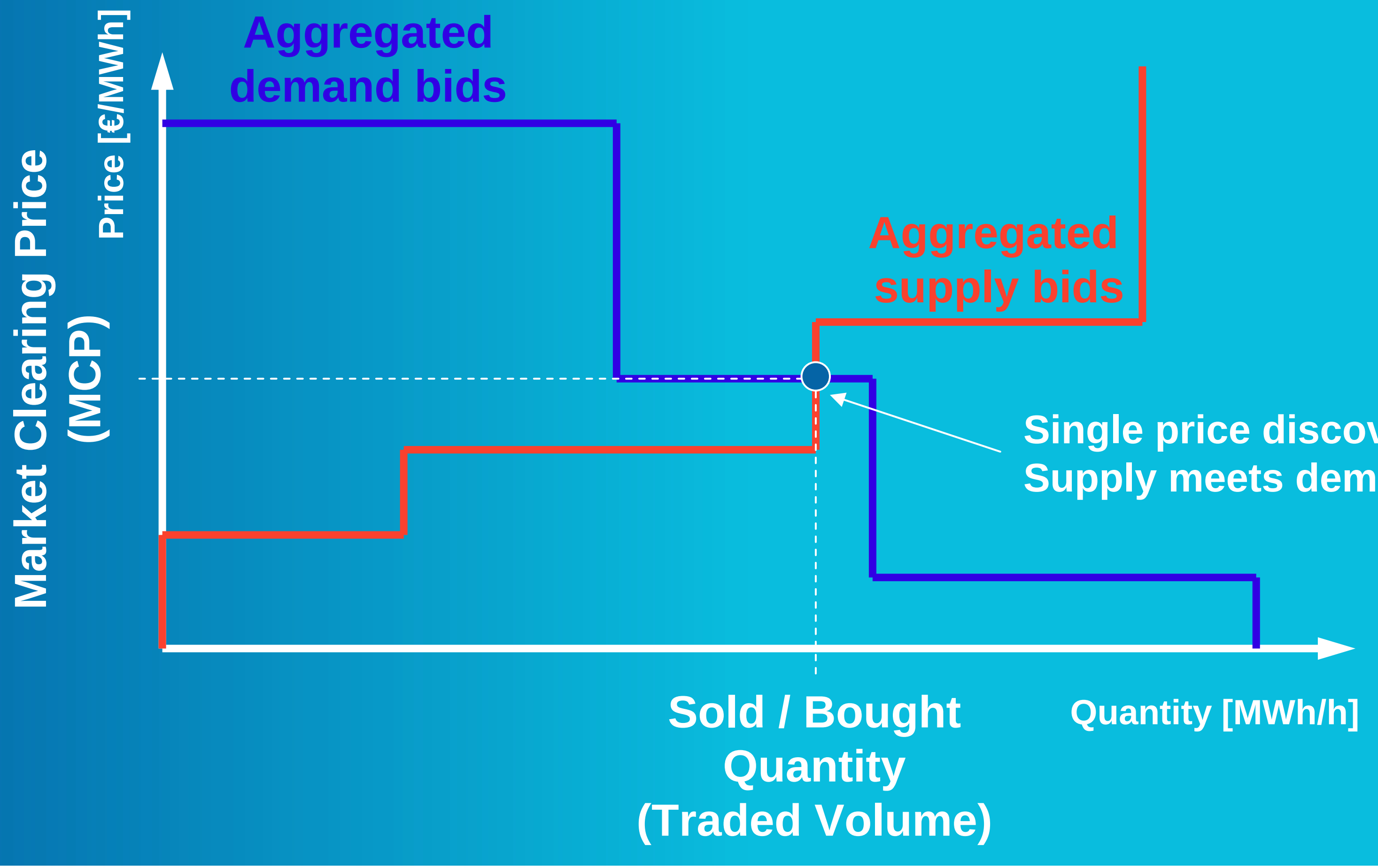


- Demand bids:
  - bids to buy energy
  - decreasing or constant



Power Market Overview

Market Clearing Mechanism



2. GENCO Overview

GENCO Types

Bids & Bidding Strategies

Scheduling

Billateral Trade

GENCO Overview

- Different types of GENCO’s:
  - Thermal (coal-fired, gas-fired, oil-fired)
    - Combined-cycle (CHP)
  - Hydro
    - Pumped storage
  - Nuclear
  - Alternative sources
    - Wind
    - Solar
    - ...
- Different types of strategies & market bids.

GENCO Overview

Basic Bid

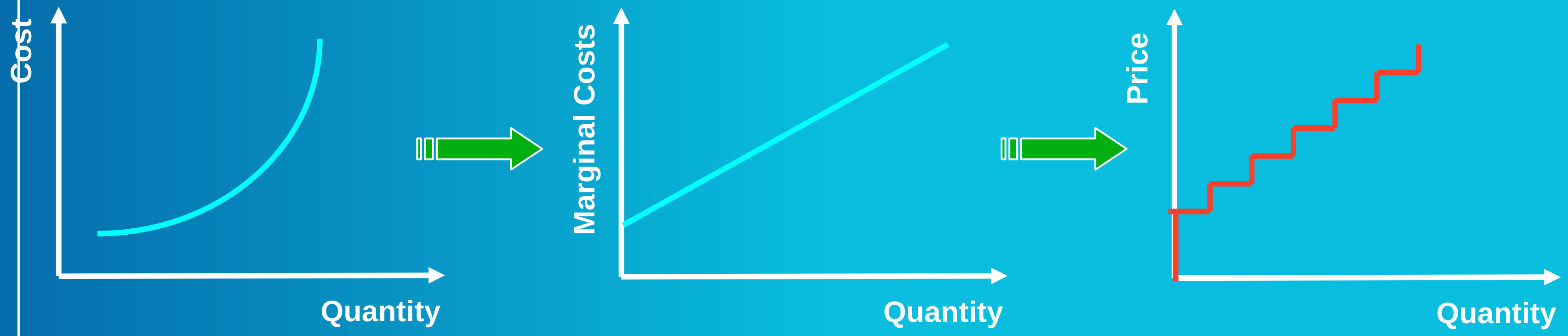
- Passive bid (strategy) – must-run bid:

- Bid for selling electricity by any price.
- Commonly used by hydro, nuclear and some types of thermal producers.

GENCO Overview

Bids & Bidding Strategies

- Thermal GENCO:
  - Marginal production cost bid:



Production cost curve:

$C = a + b*Q + c*Q^2$

Marginal production costs:

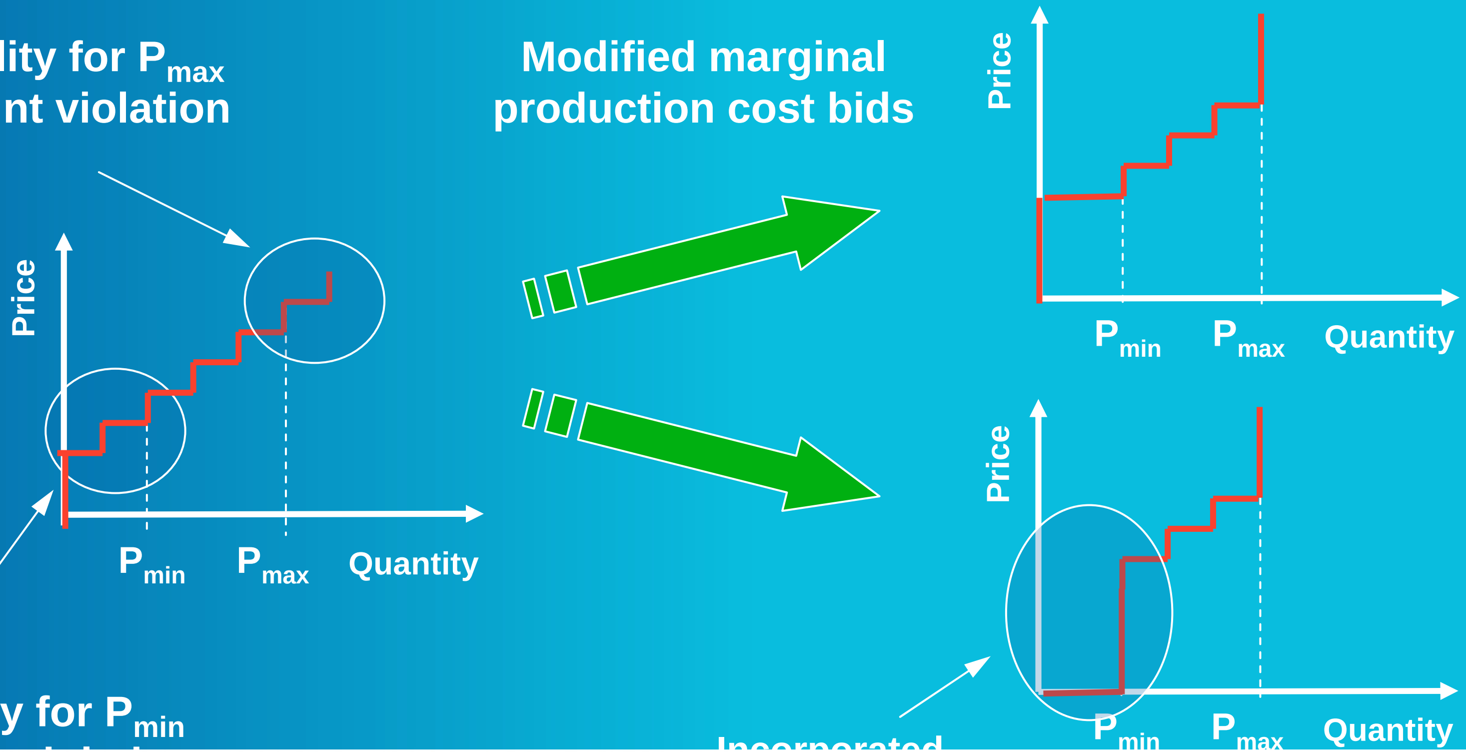
$$MC = \frac{dC}{dQ} = b + 2*c*Q$$

Marginal production cost bid

GENCO Overview

Bids & Bidding Strategies

- Thermal GENCO:
  - Incorporating technical constraints into bid – P_{min} & P_{max}:



Possibility for P_{max} constraint violation

Modified marginal production cost bids

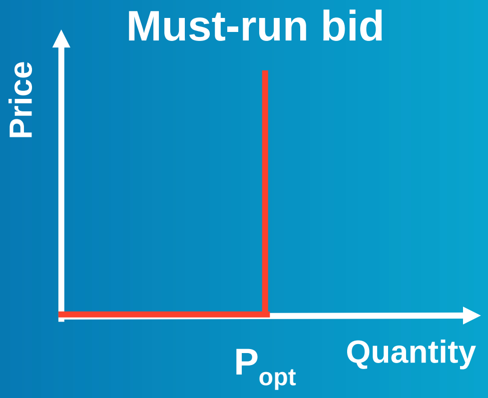
Possibility for P_{min} constraint violation

Incorporated must-run bid

GENCO Overview

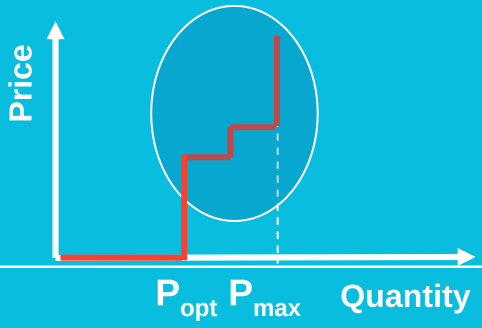
Bids & Bidding Strategies

- Hydro GENCO:
  - P_{opt} is optimisation problem variable
  - No marginal production costs



- P_{opt} is hydrology dependant
- Must-run bid ensures all available energy is sold and no spillage occurs

- If unit has water storage capacity large enough it can incorporate gaming into its bids:



GENCO Overview

Scheduling

- Combined GENCO:
  - It contains more than one unit (powerplant).
  - According to market rules it can submit a single bid for all its capacity.
  - After the auction only uniform price and combined quantity is known.
  - In fully liberalised market environment there is no central dispatching.
  - The problem of optimal unit comitment (UC) and economic dispatch (ED) remains within combined GENCO.
  - Different approaches to UC and ED can be used:
    - Classical optimization and hydro-thermal coordination techniques
    - Genetic algorithms, evolutionary computation, ...

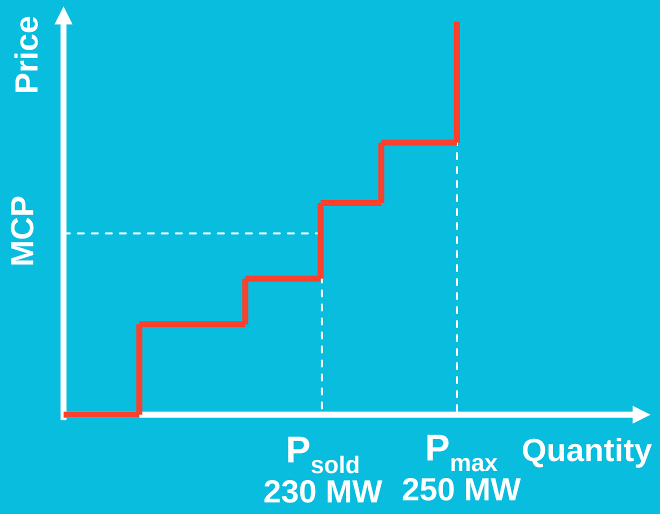
GENCO Overview

Scheduling

- Combined GENCO - example:
  - Contains several different type units:

Unit type	P_{min} [MW]	P_{max} [MW]	MC [€/MWh]
Hydro	0	50	0
Thermal (coal-fired)	70	130	30
Thermal (gas-fired)	20	70	60

- Submitted combined bid for single hour:



Sum of all available capacity within GENCO

- Final economic dispatch done by GENCO:

Unit type	P [MW]
Hydro	50
Thermal (coal-fired)	130
Thermal (gas-fired)	50

In this simple example the ED is done by dispatching units in MC merit order.

3. GENCO in Deregulated Environment

General Overview

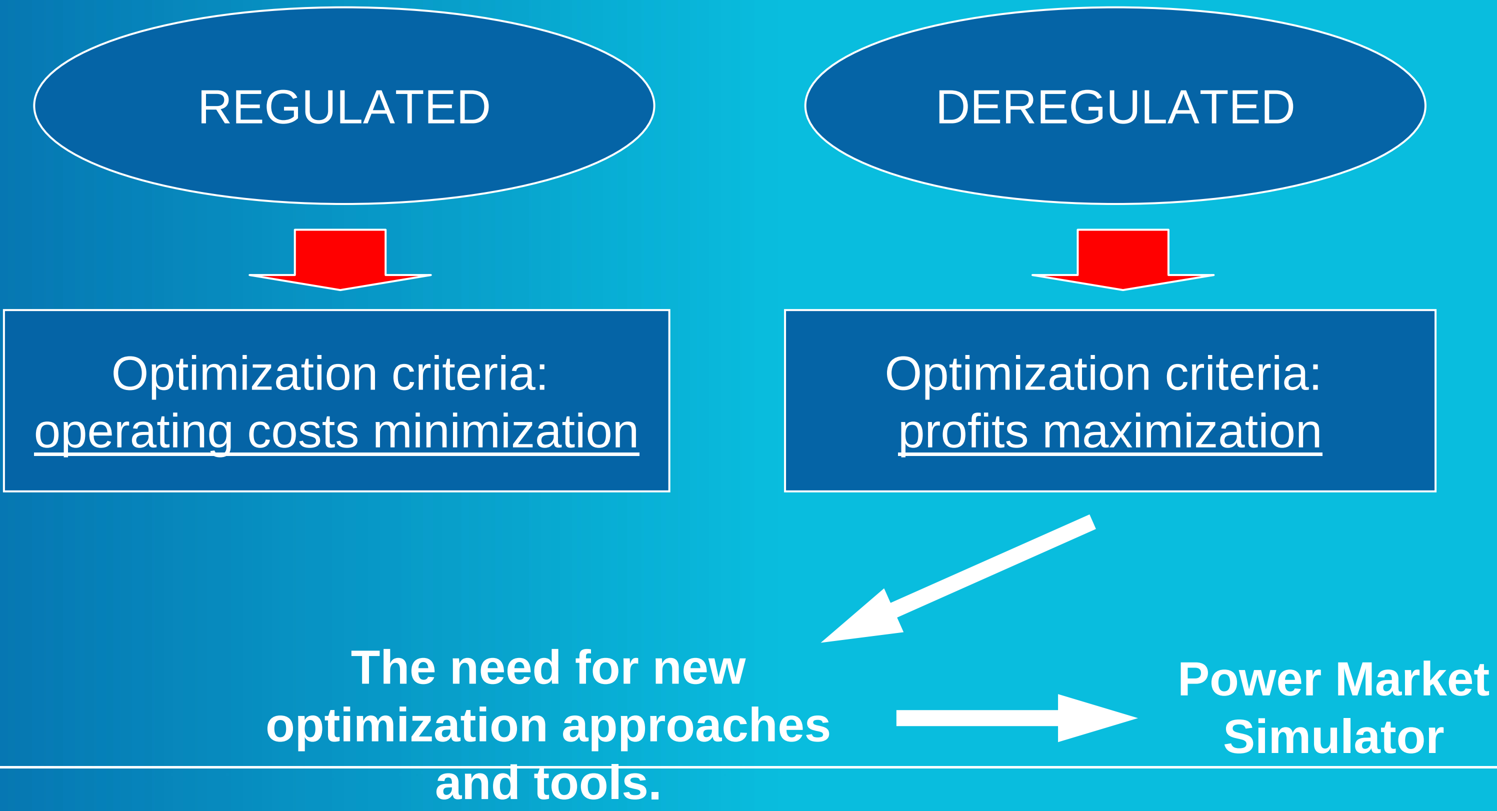
Power Market Simulator as Optimization Tool

Market Power

GENCO in Deregulated Environment

General Overview

- Significant shift in optimization criteria:



REGULATED

Optimization criteria:
<u>operating costs minimization</u>

DEREGULATED

Optimization criteria:
<u>profits maximization</u>

The need for new optimization approaches and tools.

Power Market Simulator

GENCO in Deregulated Environment

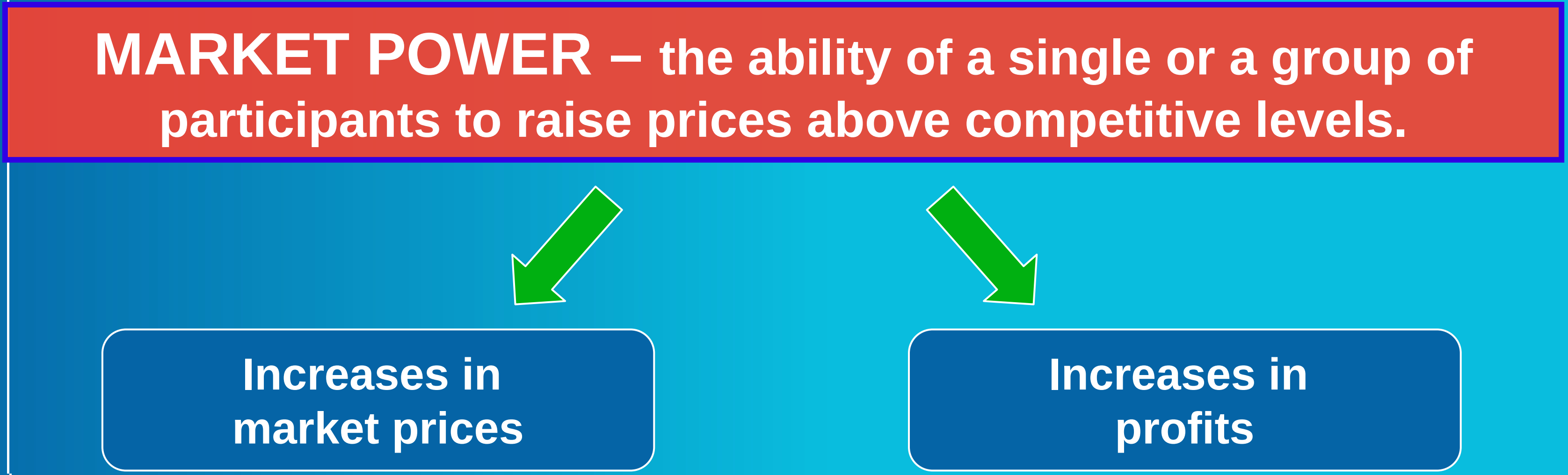
Power Market Simulator as Optimization Tool

- Bidding strategies optimization:
  - Power market simulator can be on of the tools used in optimal bidding strategy development for GENCO
  - With simulation of different scenarios and approaches the “optimal” bidding strategy can be found:
    - by simulating GENCO’s own different approaches and tactics
    - by modeling expected actions of the competition and reviewing impacts a suitable counter-action can be formed
    - by forecasting different trends (market prices, scheduled plant decomissions or openings, ...)

GENCO in Deregulated Environment

Market Power

- Due to the GENCO’s focus on profit maximization a high probability of market abuse exists.
- The posibility (probability) of market abuse is usually correlated with the GENCO’s market power.



MARKET POWER – the ability of a single or a group of participants to raise prices above competitive levels.

Increases in market prices

Increases in profits

GENCO in Deregulated Environment

Market Power - Detection

- Common indices:
  - Hirschmann-Herfindahl (HHI) Index:

$$HHI = 10000 \bullet \sum_{i=1}^{N} S_i^2$$

S_i – market share of producer *i*
N – number of producers in the system

- Static index
- Gives the level of concentration of production
- Lacks the information about possibility of market power abuse

- Lerner Index:

$$\theta = \frac{(P - MC)}{P} \bullet 100\%$$

P – market price
MC – short-term marginal costs of production

- Much more dynamic
- Troubles with obtaining “true” production short-term marginal costs

All indices share the low ability to detect participant’s abusive behavior patterns.

GENCO in Deregulated Environment

Market Power - Detection

- Power Market Simulator:
  - Ability to simulate “reference scenario”.
  - Possibilty of dynamic observations of prices, market shares, quantities, profits...
  - Ability to forecast market trends and impacts of different events (planned plant maintainance outage, plant decomission or opening,...)
  - Simulation tool can be extremely efficient in detecting possible participant’s abusive behavior patterns.

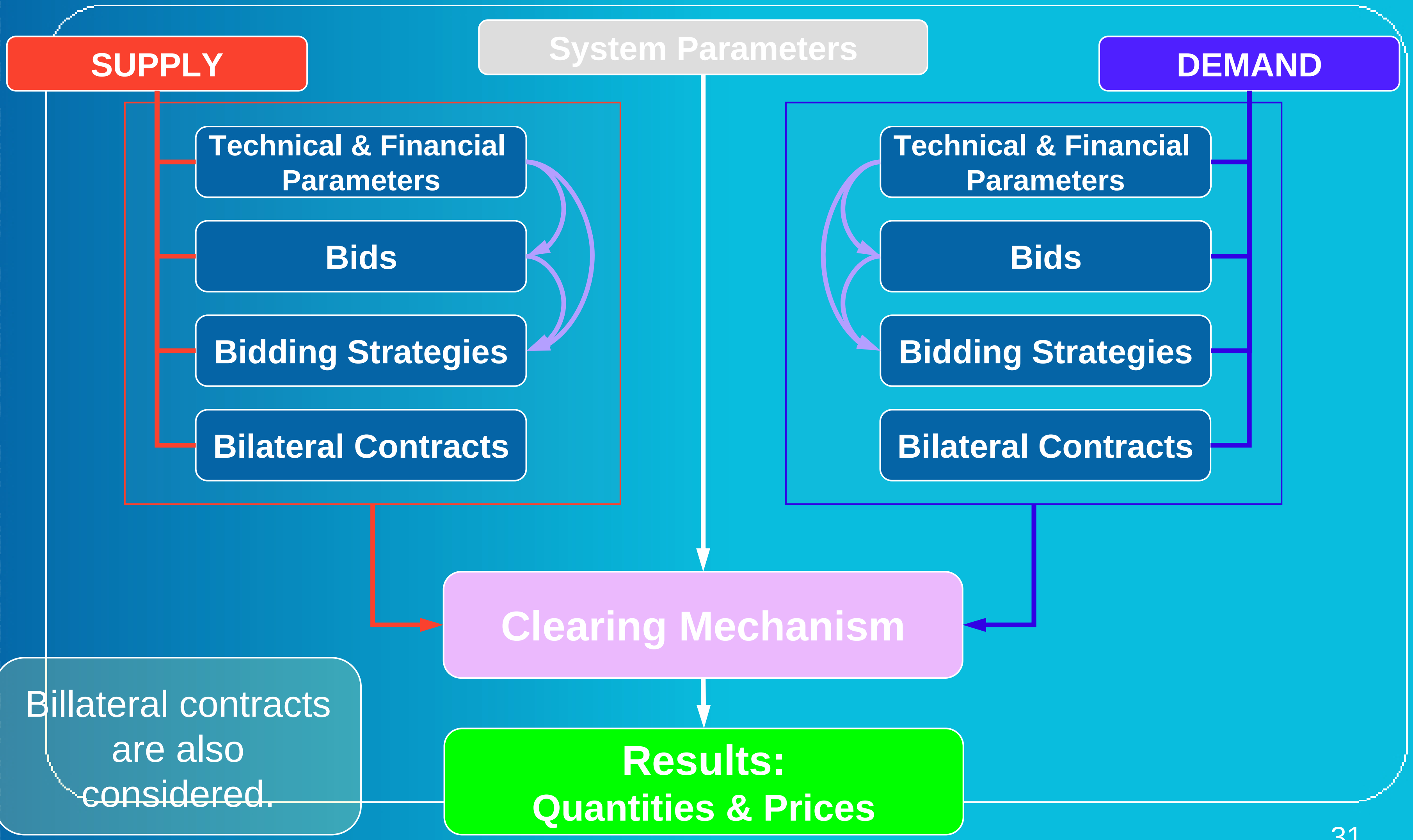
Power market simulator already used as a monitoring tool at Agency for energy – a market monitoring body in Slovenia.

4. Power Market Simulator

General Overview
Technical & Financial Parameters
Bids
Bidding Strategies
Bilateral Contracts
Clearing Mechanism
Results

Power Market Simulator

General Overview – Modelling of Day-Ahead Market



SUPPLY

System Parameters

DEMAND

Technical & Financial Parameters

Bids

Bidding Strategies

Bilateral Contracts

Technical & Financial Parameters

Bids

Bidding Strategies

Bilateral Contracts

Clearing Mechanism

Results:
Quantities & Prices

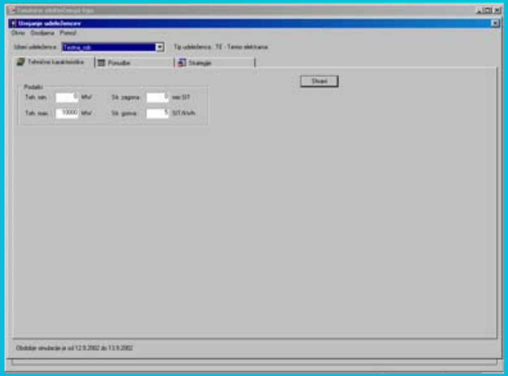
Billateral contracts are also considered.

Power Market Simulator

Technical & Financial Parameters

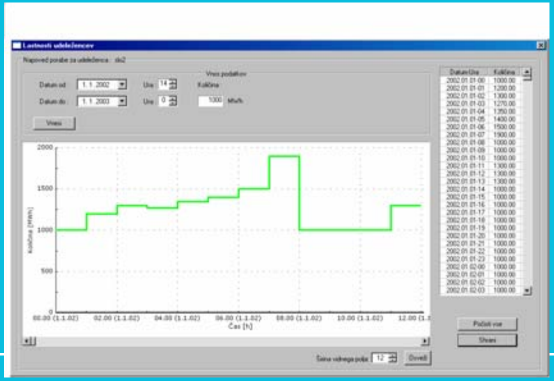
SUPPLY:

- Installed Capacity [MW]
- Start-up Costs (thermal units)
- Operating Costs (thermal units)
- Hydrology – reservoir inflow (hydro units)



DEMAND:

- Load curve
- Load forecast (short & long-term)

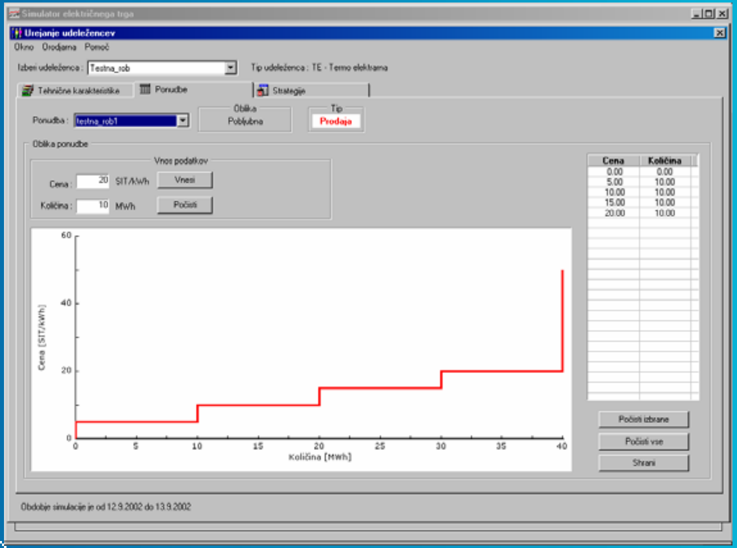


Power Market Simulator

Bids

- Bids are made of blocks of quantities and prices.

SUPPLY bid:
(bid for sale)

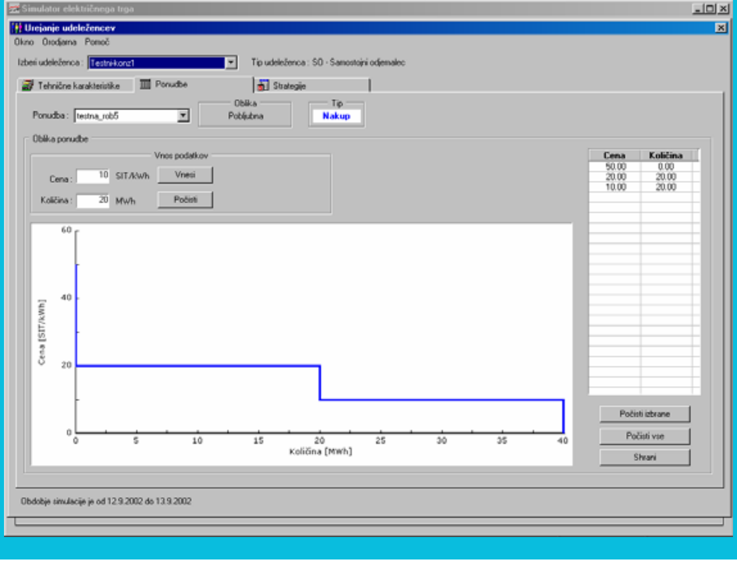


Izberi udeleženca : Testna_rob
Tip udeleženca : TE - Termo elektrarna
Ponudba : testna_rob1
Oblika: Poljubna
Tip: Prodaja
Oblika ponudbe
Vnos podatkov
Cena : 20 SIT/kWh
Količina : 10 MWh

Cena	Količina
0.00	0.00
5.00	10.00
10.00	10.00
15.00	10.00
20.00	10.00

Obdobje simulacije je od 12.9.2002 do 13.9.2002

DEMAND bid:
(bid for purchase)



Izberi udeleženca : Testni-konz1
Tip udeleženca : SO - Samostojni odjemalec
Ponudba : testna_rob5
Oblika: Poljubna
Tip: Nakup
Oblika ponudbe
Vnos podatkov
Cena : 10 SIT/kWh
Količina : 20 MWh

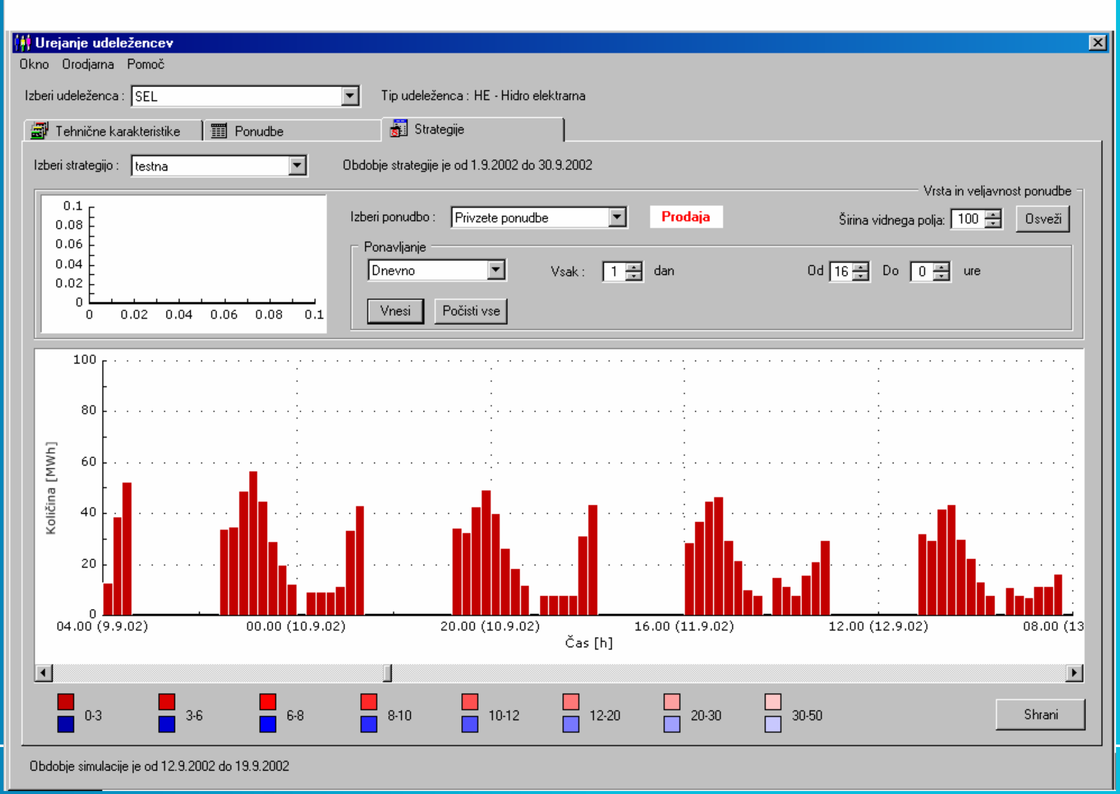
Cena	Količina
50.00	0.00
20.00	20.00
10.00	20.00

Obdobje simulacije je od 12.9.2002 do 13.9.2002

Power Market Simulator

Bidding Strategies

- Bidding strategy is basically a series of appropriate one-hour bids for corresponding number of simultaneous auctions.



Urejanje udeležencev

Izberi udeleženca : SEL

Tip udeleženca : HE - Hidro elektrarna

Izberi strategijo : testna

Obdobje strategije je od 1.9.2002 do 30.9.2002

Izberi ponudbo : Privzete ponudbe

Prodaja

Širina vidnega polja: 100

Ponavljanje: Dnevno

Vsak : 1 dan

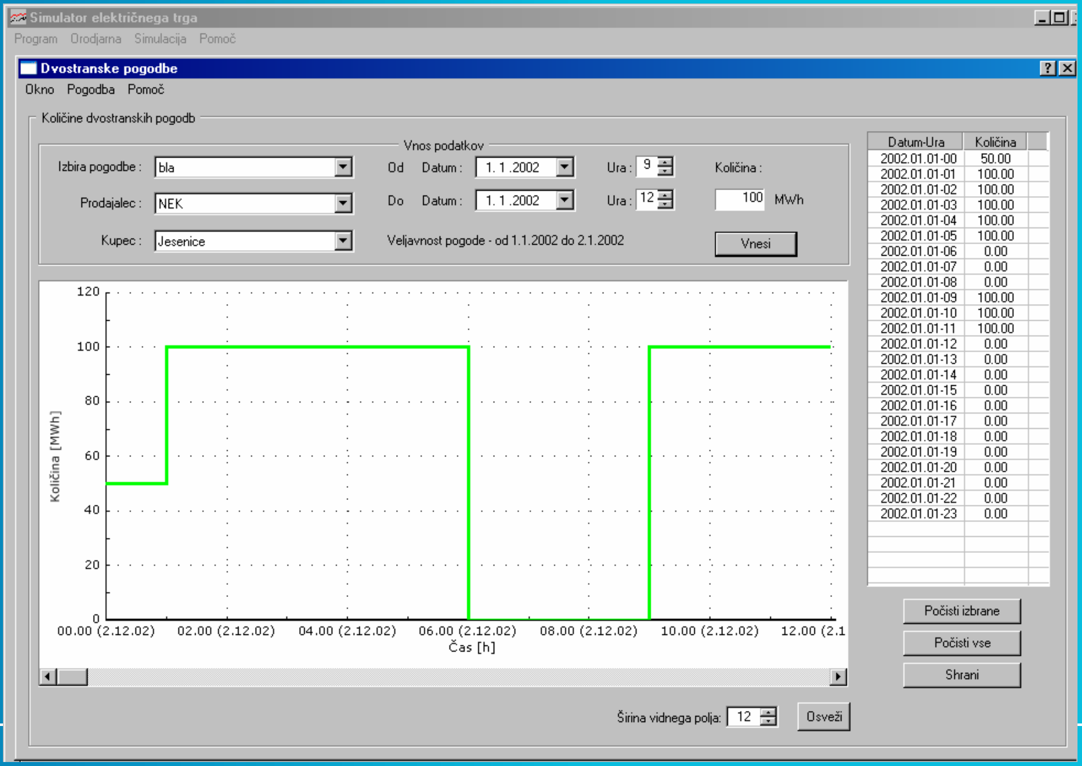
Od 16 Do 0 ure

Obdobje simulacije je od 12.9.2002 do 19.9.2002

Power Market Simulator

Bilateral Contracts

- Bilateral contracts are entered in the form of their load over time.
- The actual negotiated prices in bilateral contracts are unknown.



Izbira pogodbe : bla

Prodajalec : NEK

Kupec : Jesenice

Od Datum : 1. 1 .2002 Ura : 9

Do Datum : 1. 1 .2002 Ura : 12

Količina : 100 MWh

Veljavnost pogode - od 1.1.2002 do 2.1.2002

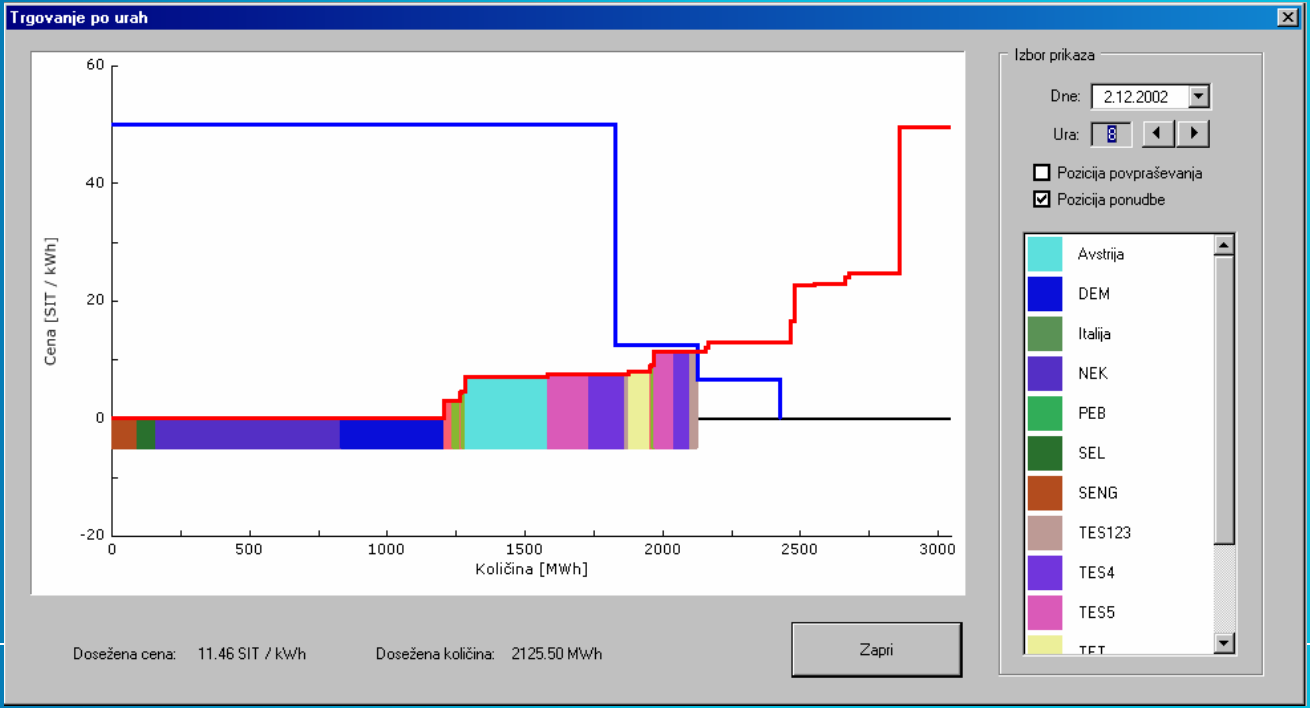
Datum-Ura	Količina
2002.01.01-00	50.00
2002.01.01-01	100.00
2002.01.01-02	100.00
2002.01.01-03	100.00
2002.01.01-04	100.00
2002.01.01-05	100.00
2002.01.01-06	0.00
2002.01.01-07	0.00
2002.01.01-08	0.00
2002.01.01-09	100.00
2002.01.01-10	100.00
2002.01.01-11	100.00
2002.01.01-12	0.00
2002.01.01-13	0.00
2002.01.01-14	0.00
2002.01.01-15	0.00
2002.01.01-16	0.00
2002.01.01-17	0.00
2002.01.01-18	0.00
2002.01.01-19	0.00
2002.01.01-20	0.00
2002.01.01-21	0.00
2002.01.01-22	0.00
2002.01.01-23	0.00

Širina vidnega polja: 12

Power Market Simulator

Clearing Mechanism

- Clearing mechanism mimics the actual clearing process on day-ahead power market.
- For each trading hour the *Market Clearing Price* (MCP) and quantities of bought/sold electricity are determined according to market rules.



Dne: 2.12.2002

Ura: 8

☐ Pozicija povpraševanja

☑ Pozicija ponudbe

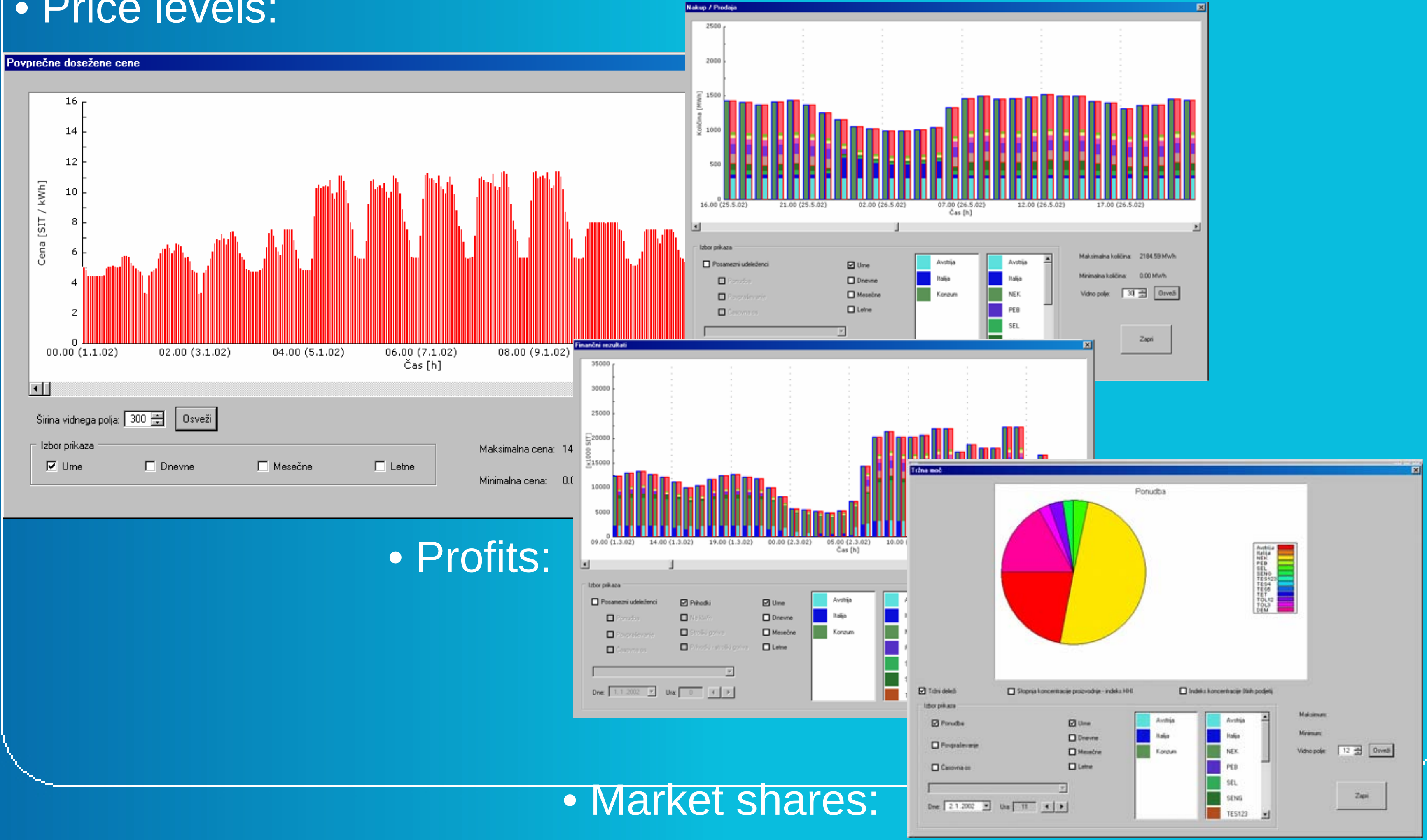
Dosežena cena: 11.46 SIT / kWh

Dosežena količina: 2125.50 MWh

Power Market Simulator

Results

- Price levels:
- Quantities:
- Profits:
- Market shares:



Povprečne dosežene cene

Širina vidnega polja: 300 Osveži

Izbor prikaza: ☑ Ure ☐ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 14

Minimalna cena: 0.(

Nakup / Prodaja

Maksimalna količina: 2184.59 MWh

Minimalna količina: 0.00 MWh

Vidno polje: 30

Finančni rezultati

Dne: 1.1.2002

Tržna moč

☑ Tržni deleži ☐ Stopnja koncentracije proizvodnje - indeks HHI ☐ Indeks koncentracije tržnih podjetij

Vidno polje: 12

Dne: 2.1.2002 Ura: 11

5. Case Studies

Abusive Behavior Illustration

Scheduled Outages Planning

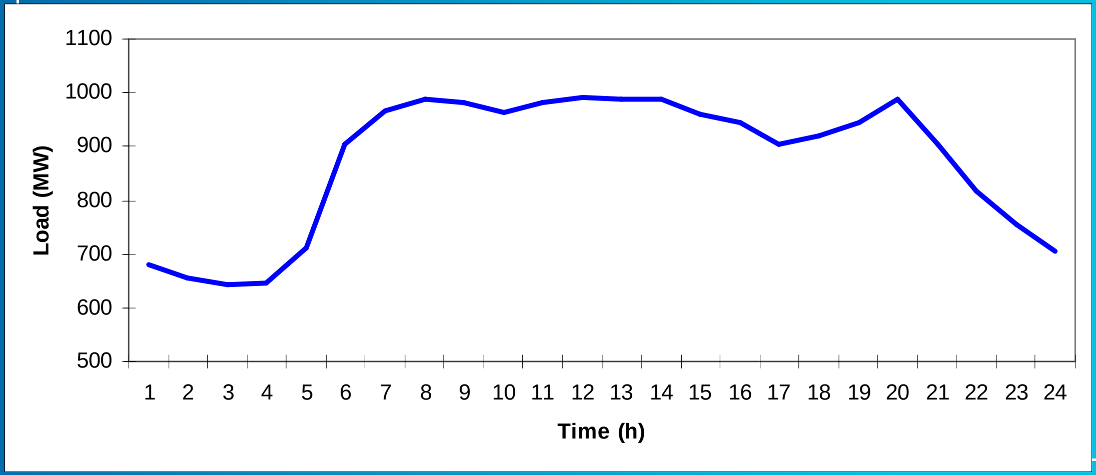
Pumped-storage Plant Operation

Case Studies

Abusive Behavior Illustration

- Test system characteristics:

Producer	Unit	Installed capacity [MW]	Unit’s marginal cost [c€/kWh]
A	**1**	300	1.74
	2	50	3.04
B	**1**	200	2.39
	2	150	2.83
	3	50	5.22
C	**1**	300	1.52
	2	100	5.65
	3	50	6.96

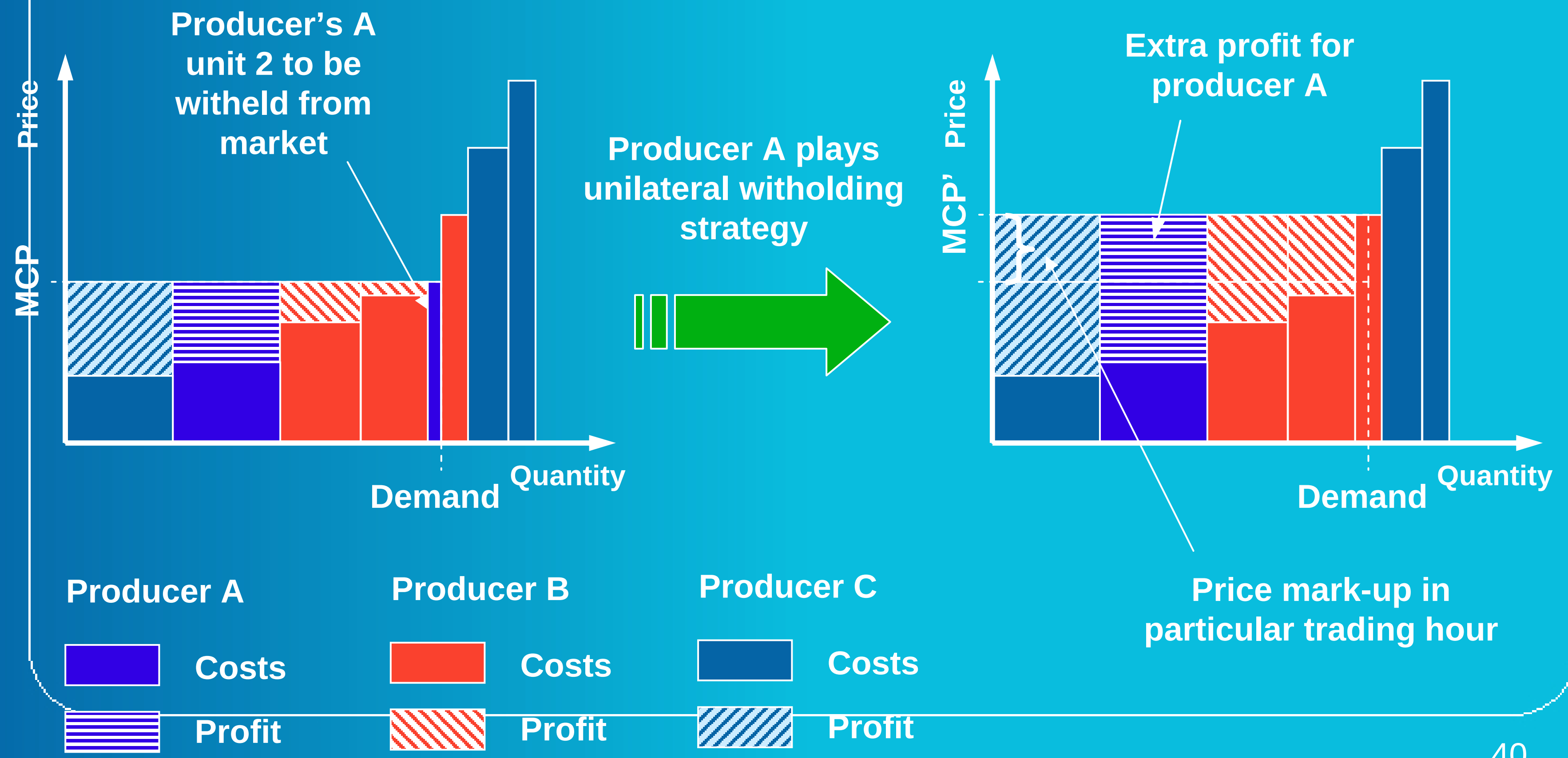


- Test system 24-hour inelastic demand diagram:

Case Studies

Abusive Behavior Illustration – Witholding Strategy

- Example of possible price manipulation by producer A in particular trading hour:



Producer's A unit 2 to be witheld from market

Producer A plays unilateral witholding strategy

Extra profit for producer A

Price mark-up in particular trading hour

Producer A
▇ **Costs**
▤ **Profit**

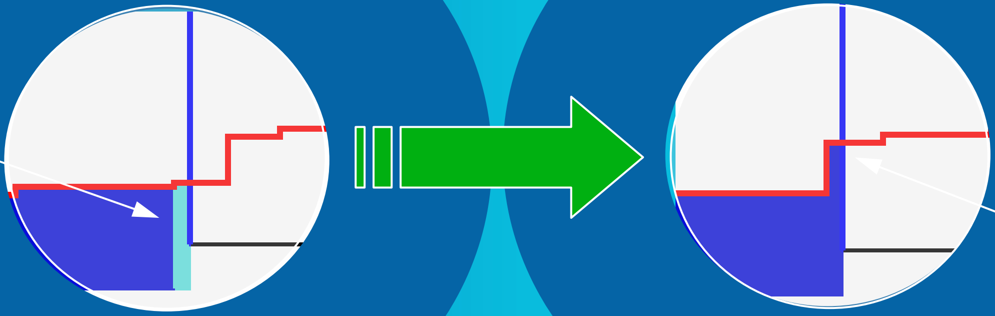
Producer B
▇ **Costs**
▧ **Profit**

Producer C
▇ **Costs**
▨ **Profit**

Case Studies

Abusive Behavior Illustration – Witholding Strategy

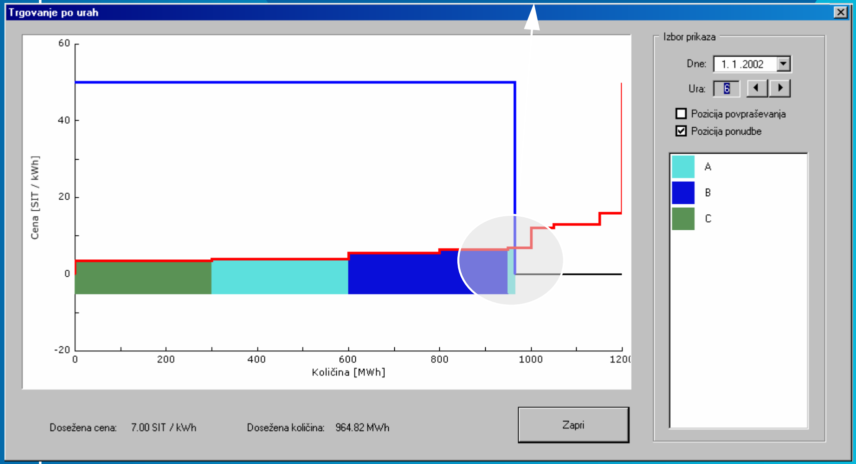
- A view from the simulator - 6th hour of the 24-hour period:



Producer's A unit 2 is to be witheld

Price mark-up in particular trading hour

Reference scenario



Dne: 1. 1 .2002

Ura: 6

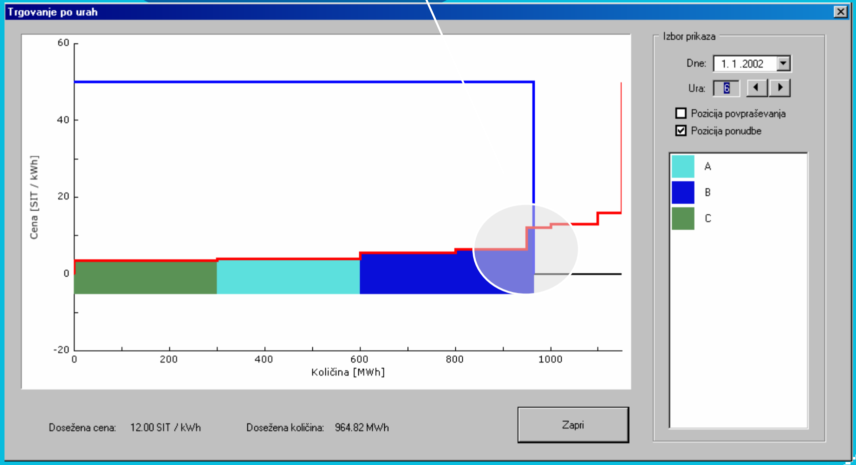
☐ Pozicija povpraševanja

☑ Pozicija ponudbe

Dosežena cena: 7.00 SIT / kWh

Dosežena količina: 964.82 MWh

Producer A is witholding



Dne: 1. 1 .2002

Ura: 6

☐ Pozicija povpraševanja

☑ Pozicija ponudbe

Dosežena cena: 12.00 SIT / kWh

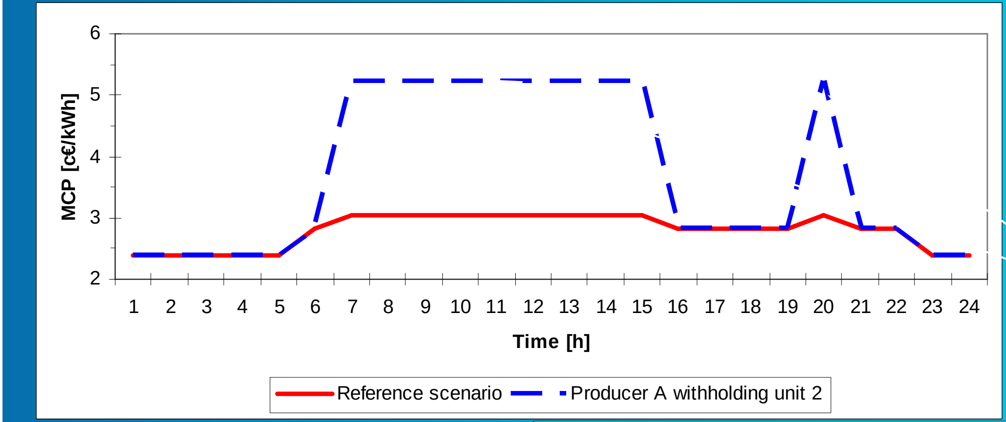
Dosežena količina: 964.82 MWh

Producer A	**Producer B**	**Producer C**
🟦	🟪	🟩

Case Studies

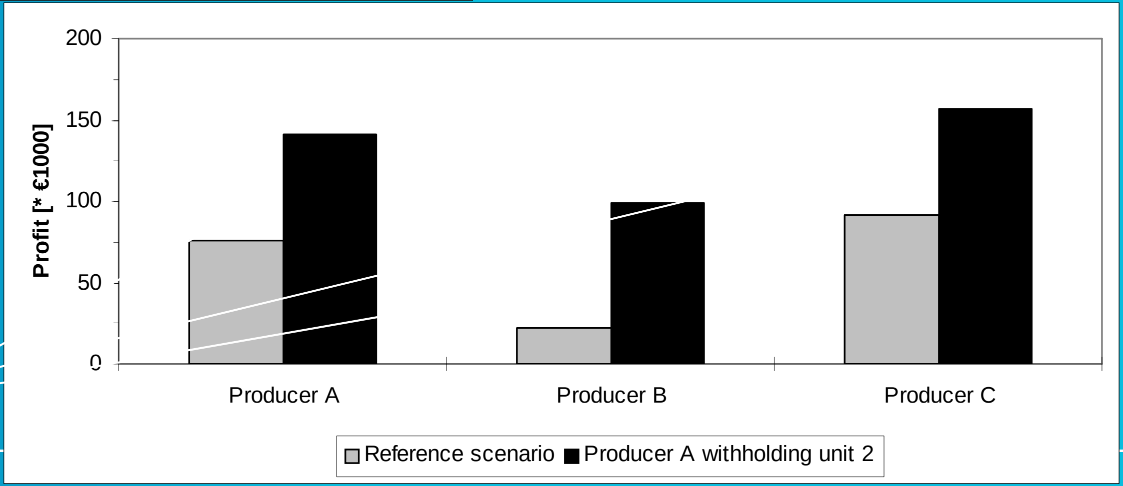
Abusive Behavior Illustration – Witholding Strategy

- Results:



- MCP levels during observed period.

Raised MCP levels as a result of Producer A abusive behavior.



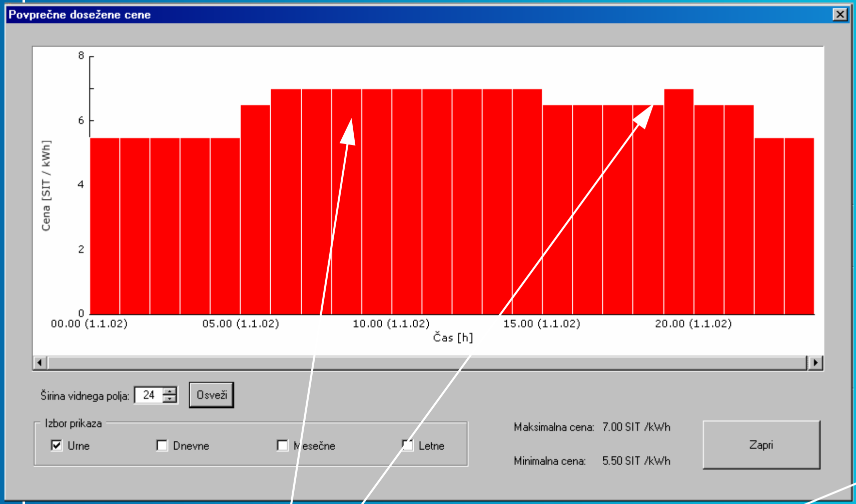
Raised profit levels as a result of Producer A abusive behavior.

Case Studies

Abusive Behavior Illustration – Witholding Strategy

- Results from Power Market Simulator:

Reference scenario



Povprečne dosežene cene

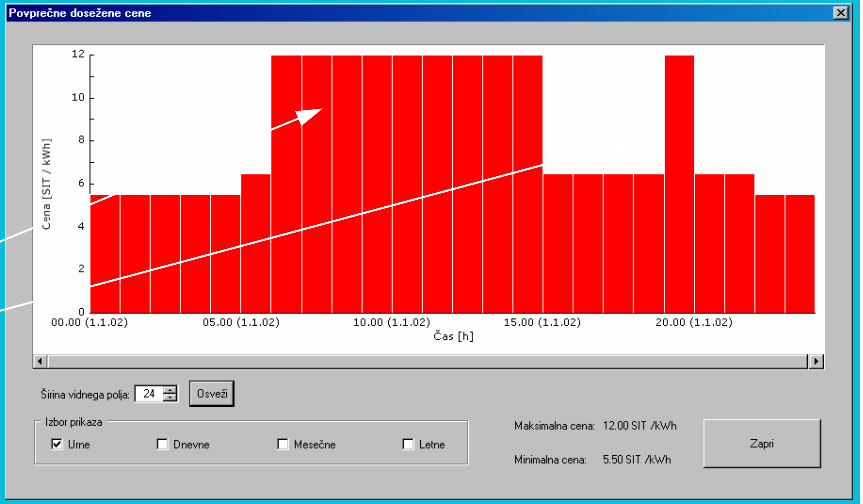
Širina vidnega polja: 24

Izbor prikaza
☑ Urne ☐ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 7.00 SIT /kWh

Minimalna cena: 5.50 SIT /kWh

Producer A is witholding



Povprečne dosežene cene

Širina vidnega polja: 24

Izbor prikaza
☑ Urne ☐ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 12.00 SIT /kWh

Minimalna cena: 5.50 SIT /kWh

Rised MCP levels as a result of Producer A abusive behavior.

Case Studies

Scheduled Outages Planning

- Test system:
  - Supply:

Nuclear producer is planning a 1 month maintenance outage.

Producer type	No. of producers	Combined installed capacity [MW]
Thermal (coal-fired)	7	857
Thermal (gas-fired)	1	386
Nuclear	1	337
Hydro	3	812
Total:	12	2392

- Demand:

  Peak demand: 1891 MW
  Base load: 692 MW
  Annual consumption: 11.3 TWh

- Neighbouring systems:

  2 neighbouring systems
  Maximum transfer capacity: 300 MW

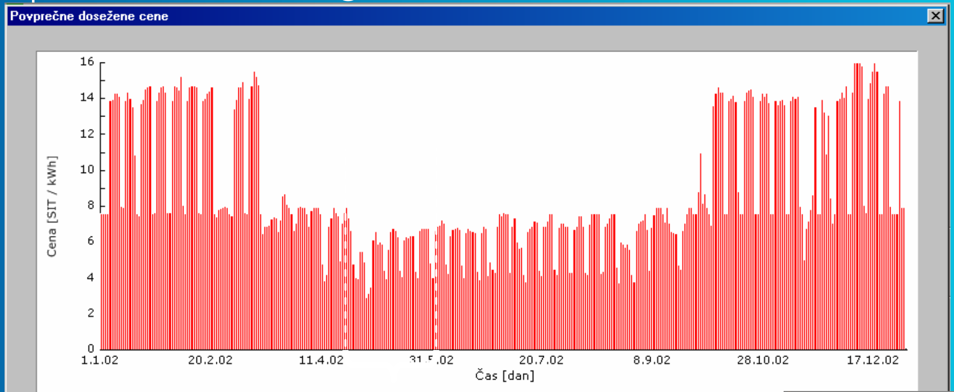
- Simulated period:

  1 year

Case Studies

Scheduled Outages Planning

Daily average prices
No scheduled outage



Širina vidnega polja: 500 Osveži

Izbor prikaza
☐ Ure ☑ Dnevne ☐ Mesečne ☐ Letne

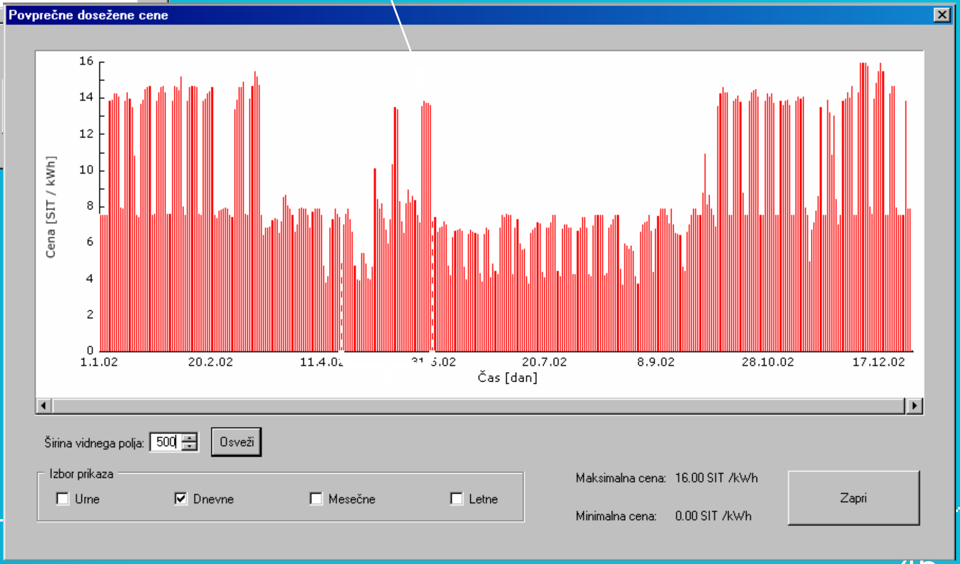
Maksimalna cena: 16.00 SIT /kWh

Minimalna cena: 0.00 SIT /kWh

Outage planned in May

Moderate price spikes as a result of outage in May.

Daily average prices
Scheduled outage in May



Širina vidnega polja: 500 Osveži

Izbor prikaza
☐ Ure ☑ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 16.00 SIT /kWh

Minimalna cena: 0.00 SIT /kWh

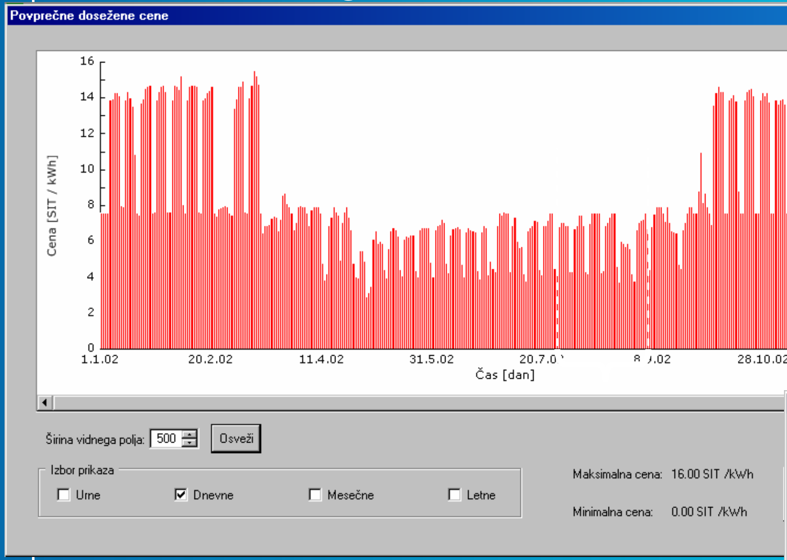
- Changes in prices:

Av. price levels	No outage [c€/kWh]	Outage [c€/kWh]
In May	2.40	3.87 (+61%)
Yearly	3.78	3.91 (+3%)

Case Studies

Scheduled Outages Planning – Uncoordinated Planning

Daily average prices
No scheduled outage



Širina vidnega polja: 500

Izbor prikaza: ☐ Urne ☑ Dnevne ☐ Mesečne ☐ Letne

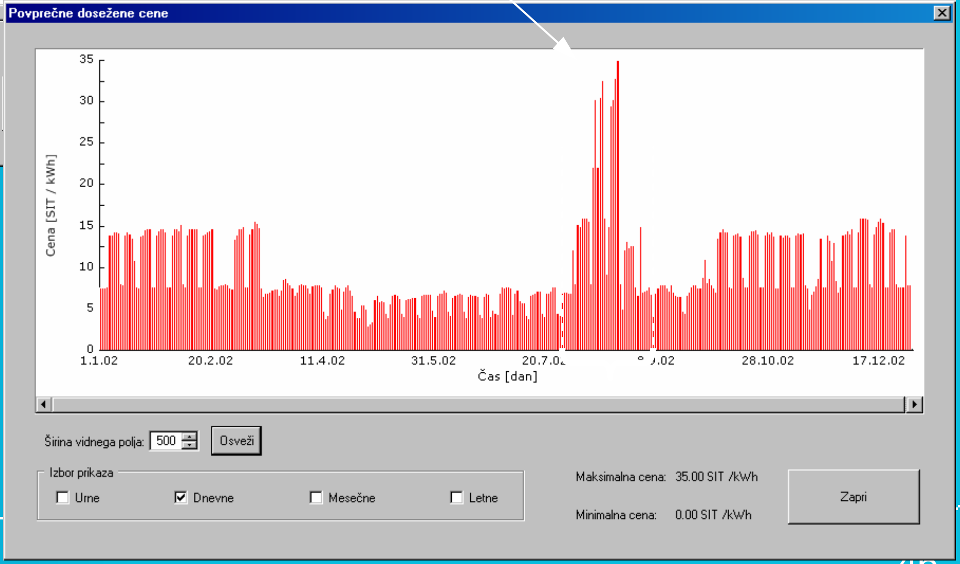
Maksimalna cena: 16.00 SIT /kWh

Minimalna cena: 0.00 SIT /kWh

Outage planned in August

<u>**Special event:**</u> **in August also one of the biggest thermal power plants consideres 1-month scheduled outage.** !

Daily average prices
Scheduled outage in August



Širina vidnega polja: 500

Izbor prikaza: ☐ Urne ☑ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 35.00 SIT /kWh

Minimalna cena: 0.00 SIT /kWh

- Changes in prices:

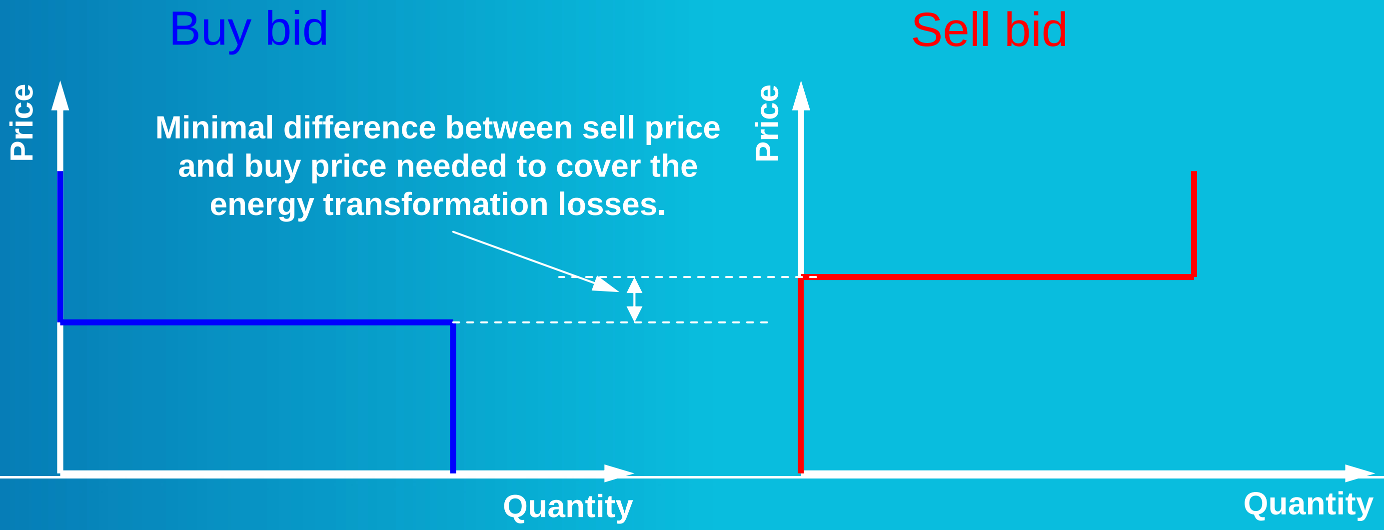
Av. price levels	No outage [c€/kWh]	Outage [c€/kWh]
In Aug.	2.63	7.47 (+184%)
Yearly	3.78	4.20 (+11%)

Case Studies

Pumped-storage Plant Operation

- Pumped-storage plant characteristics:
  - - Maximum production capacity: 50 MW
  - - Maximum consumption capacity: 50 MW
  - - Upper reservoir capacity: unlimited

- Bids submitted each trading hour:



Minimal difference between sell price and buy price needed to cover the energy transformation losses.

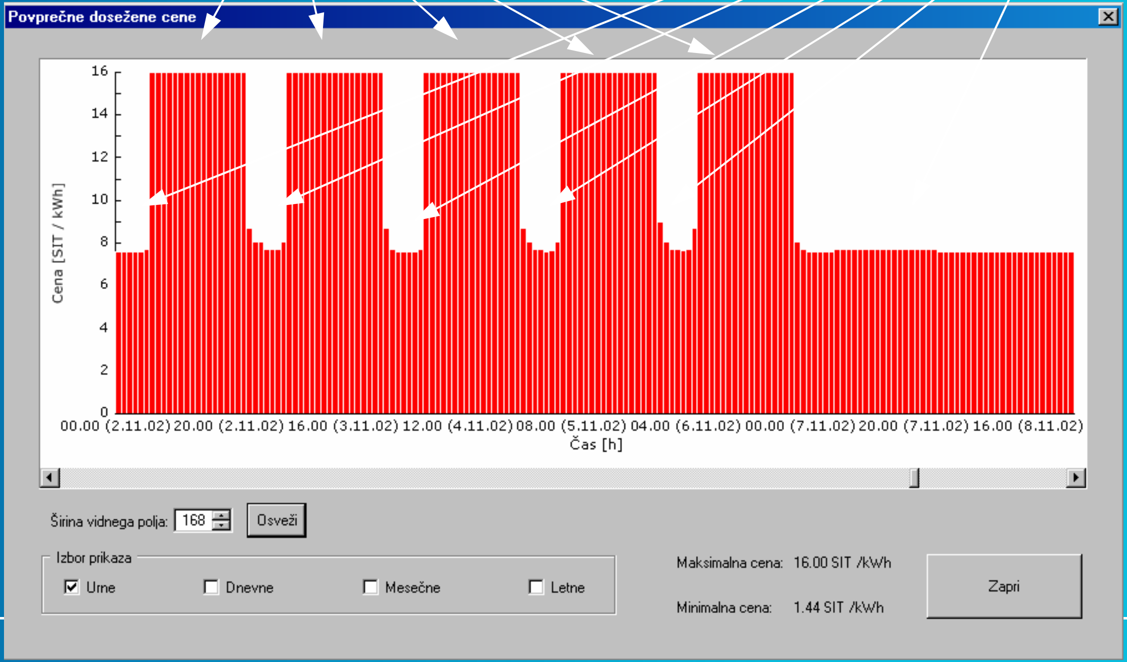
Case Studies

Pumped-storage Plant Operation

- Resulting price levels during observed period:

During work-day peak hours the electricity prices are high.

During work-day night hours and during the weekend the electricity prices are lower.



Širina vidnega polja: 168

Izbor prikaza

☑ Urne ☐ Dnevne ☐ Mesečne ☐ Letne

Maksimalna cena: 16.00 SIT /kWh

Minimalna cena: 1.44 SIT /kWh

Pumped-storage plant is taking advantage of such periodic price fluctuations.

Case Studies

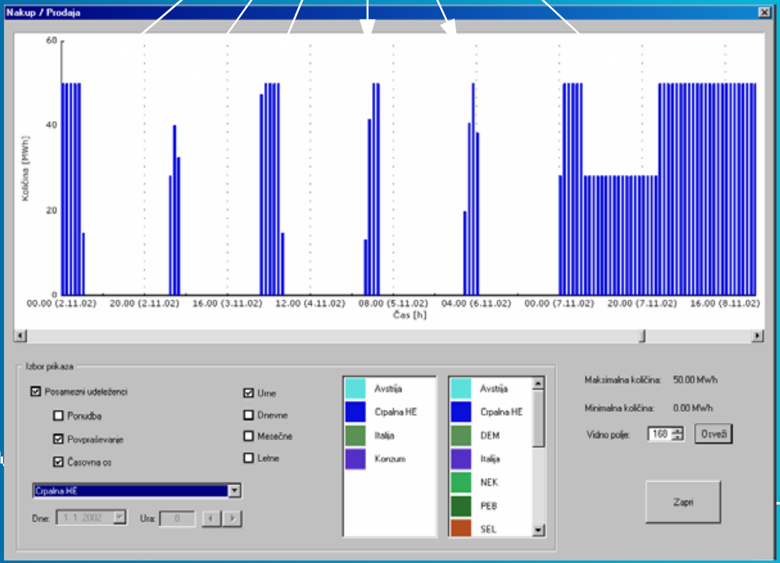
Pumped-storage Plant Operation

- Simulation results (1 week period):

During work-day night hours and during the weekend the energy is consumed for pumping water into upper reservoir.

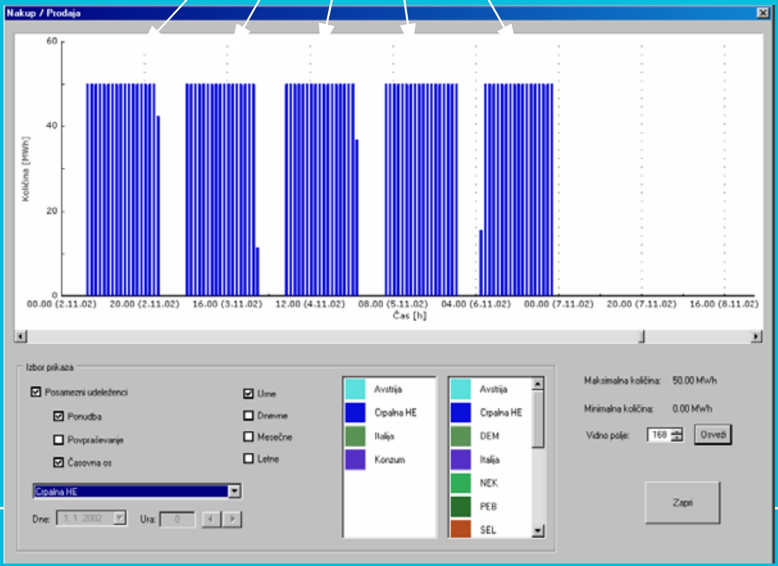
During work-day peak hours the energy is produced and sold to the market.

Bought hourly quantities:



☑ Posamezni udeleženci
☐ Ponudba
☑ Povpraševanje
☑ Časovna os
☑ Urne
☐ Dnevne
☐ Mesečne
☐ Letne
Crpalna HE
Dne: 1.1.2002
Ura: 0
Maksimalna količina: 50.00 MWh
Minimalna količina: 0.00 MWh
Vidno polje: 168

Sold hourly quantities:



☑ Posamezni udeleženci
☑ Ponudba
☐ Povpraševanje
☑ Časovna os
☑ Urne
☐ Dnevne
☐ Mesečne
☐ Letne
Crpalna HE
Dne: 1.1.2002
Ura: 0
Maksimalna količina: 50.00 MWh
Minimalna količina: 0.00 MWh
Vidno polje: 168

THANK YOU FOR YOUR ATTENTION

VBPC Summer School 2006, Fojnica, BiH

Faculty of Electrical Engineering
University of Belgrade

IMPACT OF RES ON POWER SYSTEM OPERATION

Prof. dr Nikola Rajaković

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

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

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.

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

OPF problem formulation

- General form of an optimization problem is to minimize the objective function:
- $F(x)$
- subject to the equality constraints:
- $g_i(x) = 0 \quad i = 1,2,\dots,l$
- and subject to the inequality constraints:
- $h_j(x) \geq 0 \quad j = l+1,\dots,m$
- 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, ...*

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

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

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

Newton iterative procedure

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

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

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

Newton type matrix equation

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

Short version

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

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

Equality constraints

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

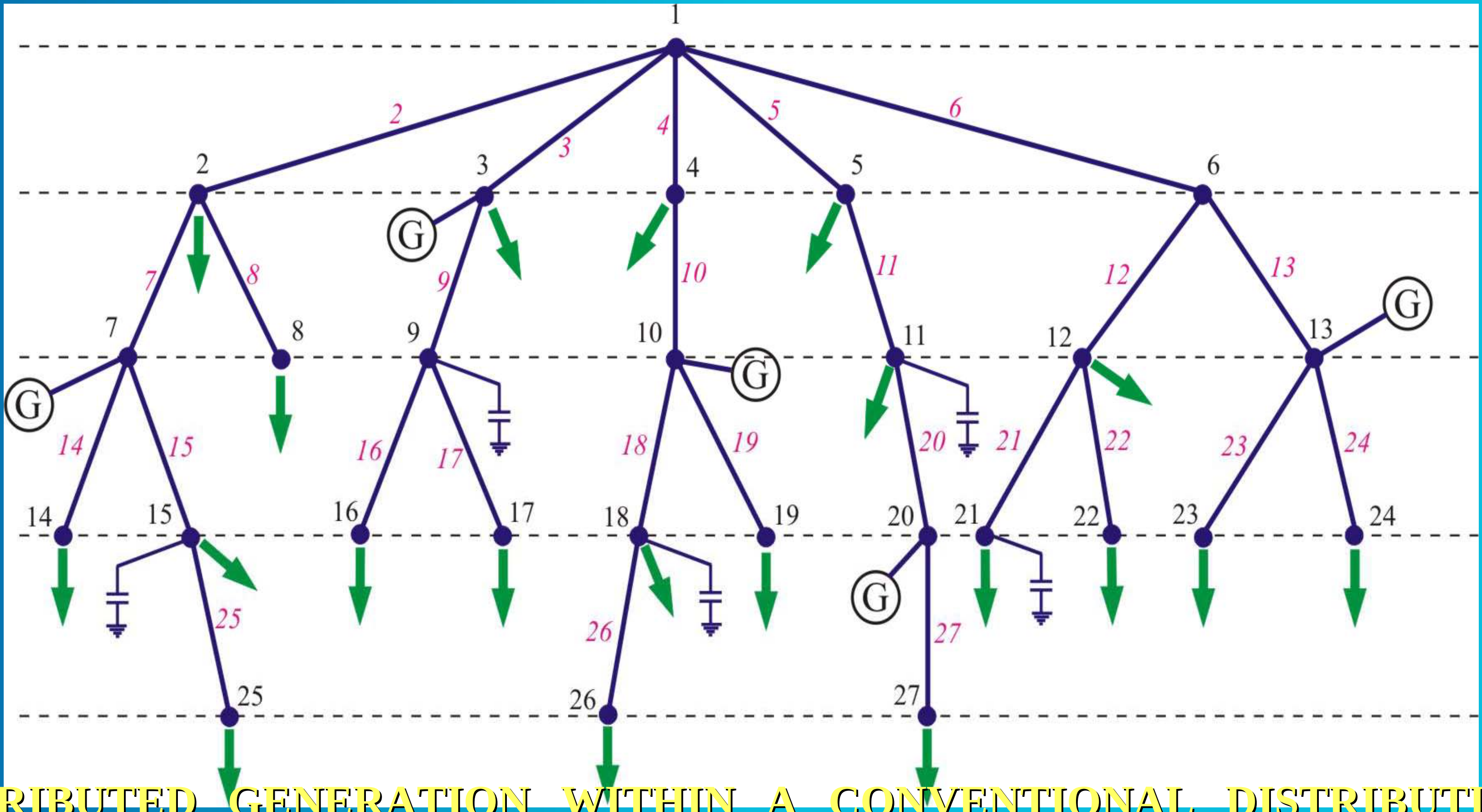
$$Q_k = U_k \sum_{m=1}^{N} U_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] - Q_{Gk} + Q_{Pk} = 0$$

Nonequality constraints

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

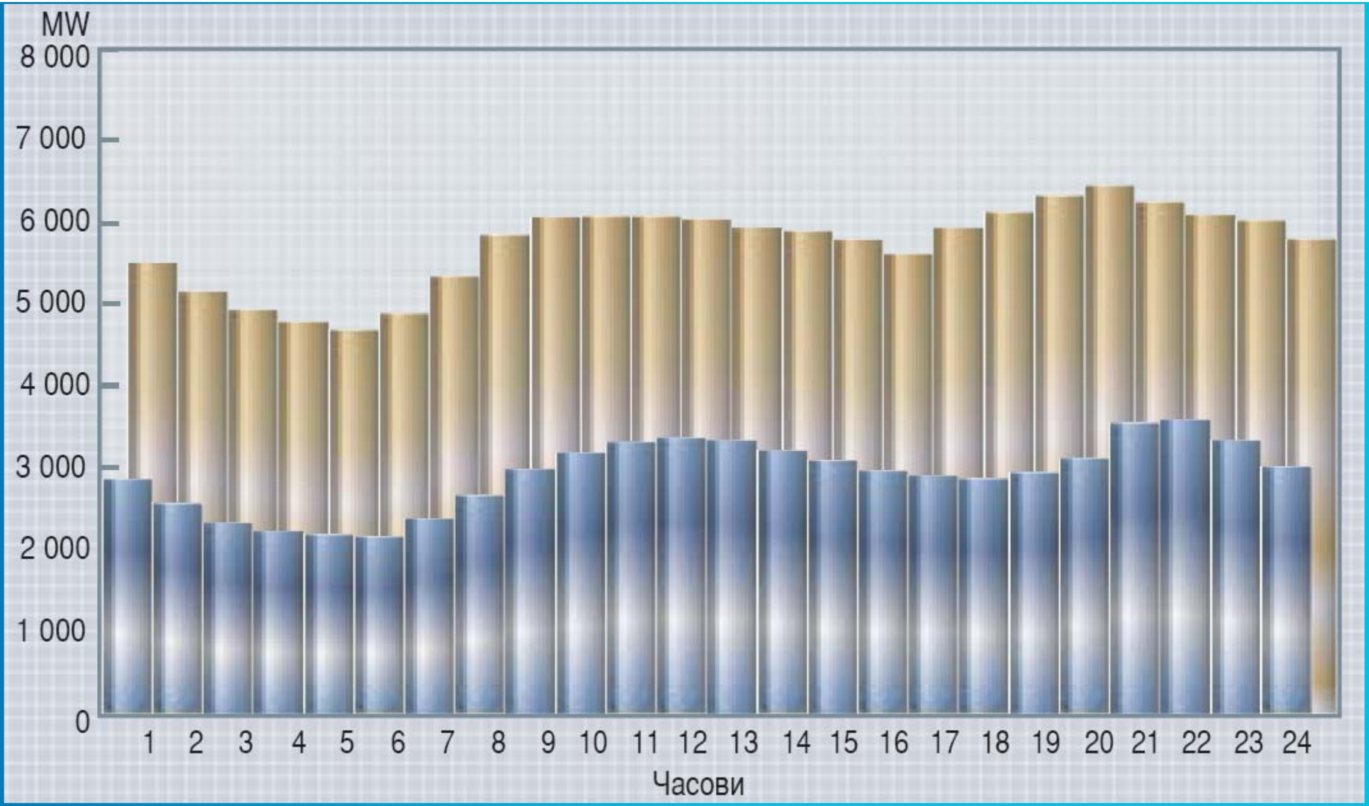
$$U_{i\min} - U_i \leq 0$$

ILLUSTRATIVE EXAMPLE



DISTRIBUTED GENERATION WITHIN A CONVENTIONAL DISTRIBUTION NETWORK

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.)

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

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

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,…)

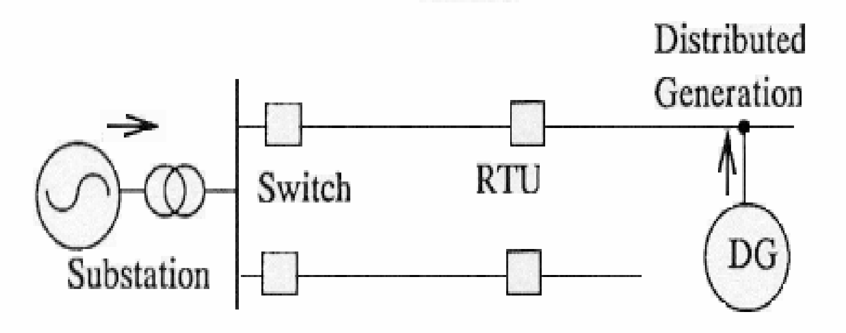
Load profiles and impact on operation of networks with DGs

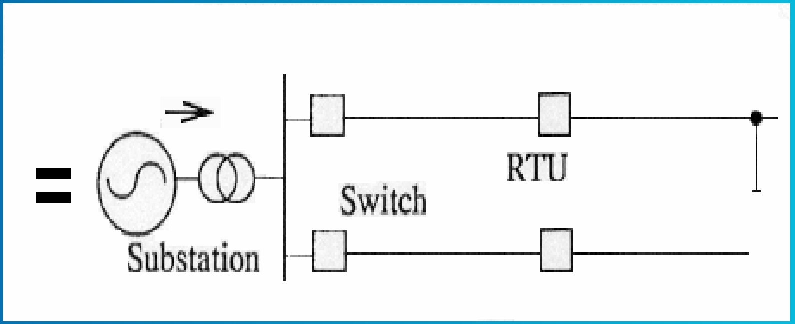
- Monitoring of load profiles
- Objective of effective operation

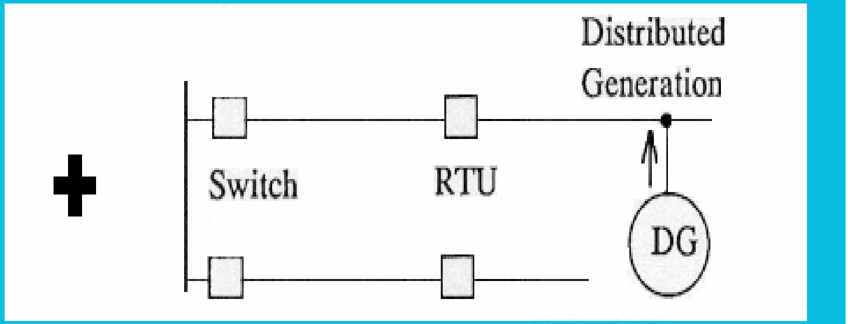
Economical operation in networks with DGs

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

Superposition concept







Reduction of loads

Reduction of node loads in accordance with the small generator power

Losses are neglected and loads are independent of voltage magnitudes

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

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

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*

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

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

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

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

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

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

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.

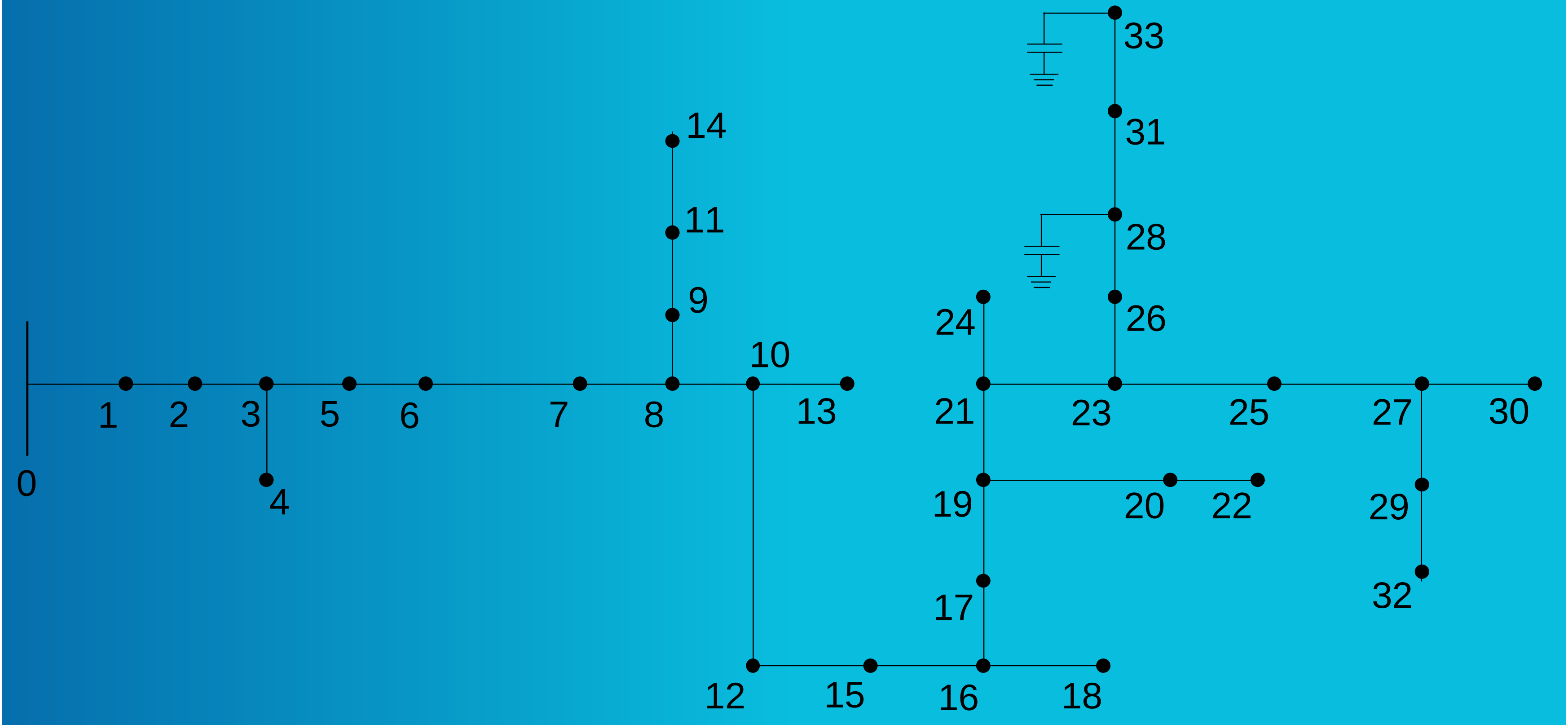
System performance – critical current reserve of the supply transformer

- 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

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

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

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

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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RENEWABLE ENERGY SOURCES IN WESTERN BALKANS

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,…)

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)

Connection schemes of the DGs to the DN

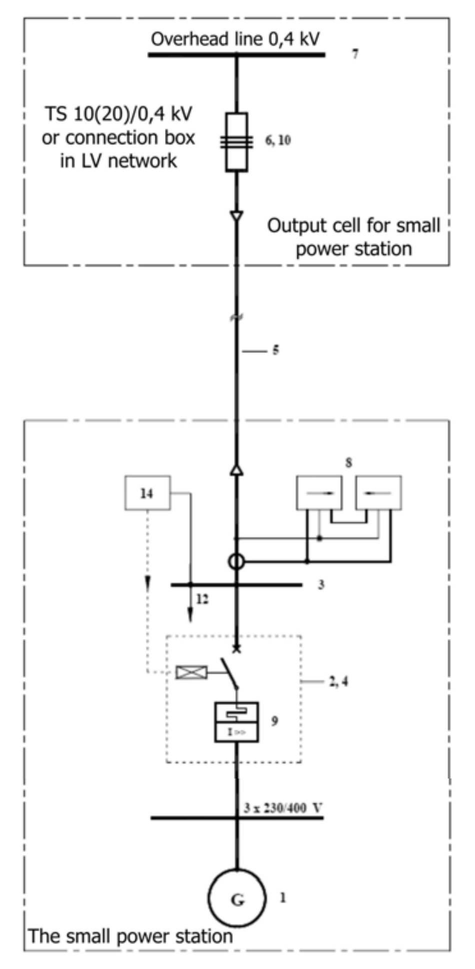


Fig. 1

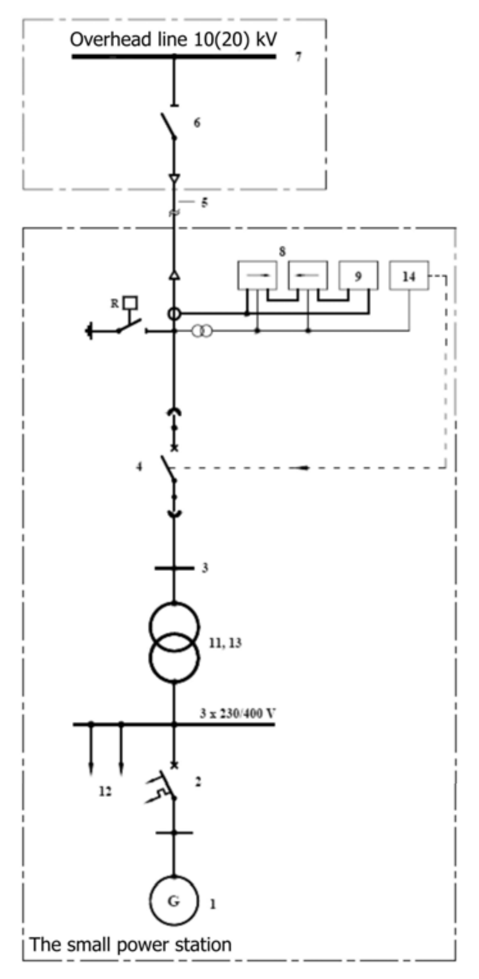


Fig. 2

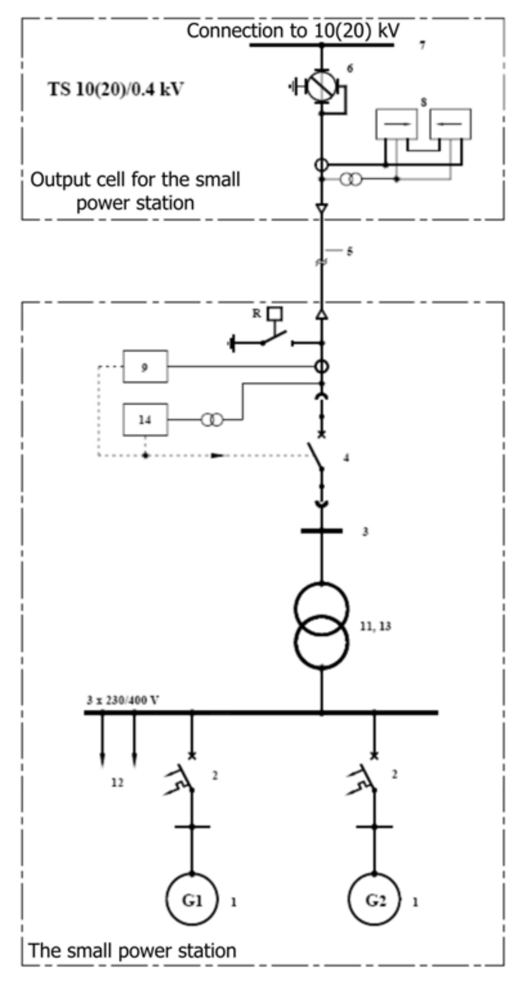

Connection to 10(20) kV
7
TS 10(20)/0.4 kV
6
8
Output cell for the small power station
5
R
9
14
4
3
11, 13
3 x 230/400 V
12
2
2
G1
1
G2
1
The small power station

Fig. 3

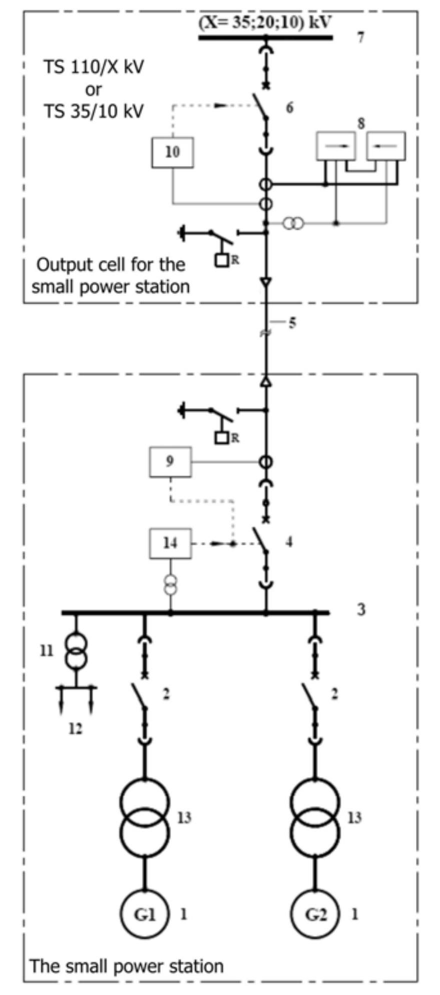

(X= 35;20;10) kV
7
TS 110/X kV
or
TS 35/10 kV
6
8
10
R
Output cell for the small power station
5
R
9
14
4
3
11
12
2
2
13
13
G1
1
G2
1
The small power station

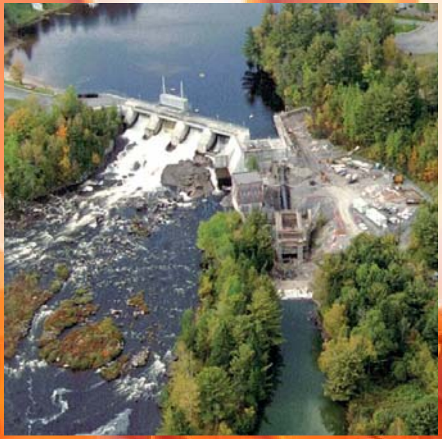
Fig. 4

Thank You for Your attention !!!

In the name of him who gave us wisdom and heart to help each others

L HYDRO PLANTS

MER SCHOOL – VIRTUAL BALKAN
ER CENTER – RENEWABLE ENERGY
RCES



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

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.

By: Suad S. Halilčević

Department of Systems and Network Theory
University of Tuzla
Faculty of Electrical Engineering

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.

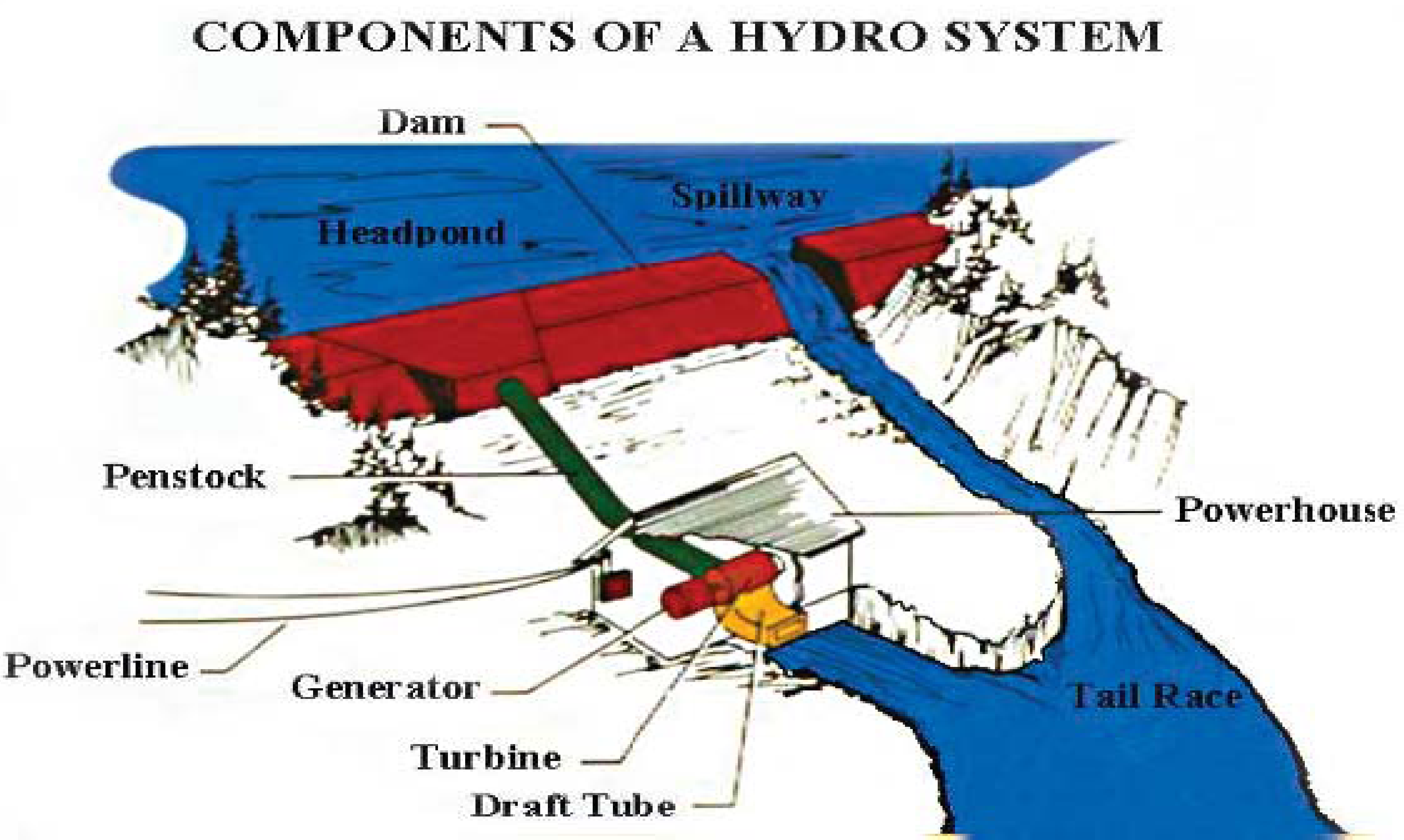
Description of Small Hydro Power Plants

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



COMPONENTS OF A HYDRO SYSTEM

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:

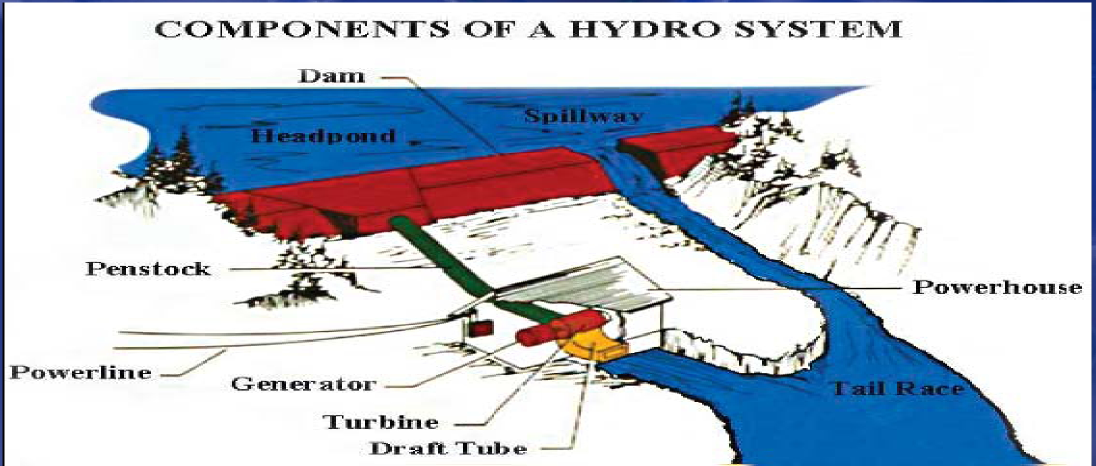
- concrete,
- wood,
- masonry, or
- a combination of these materials.

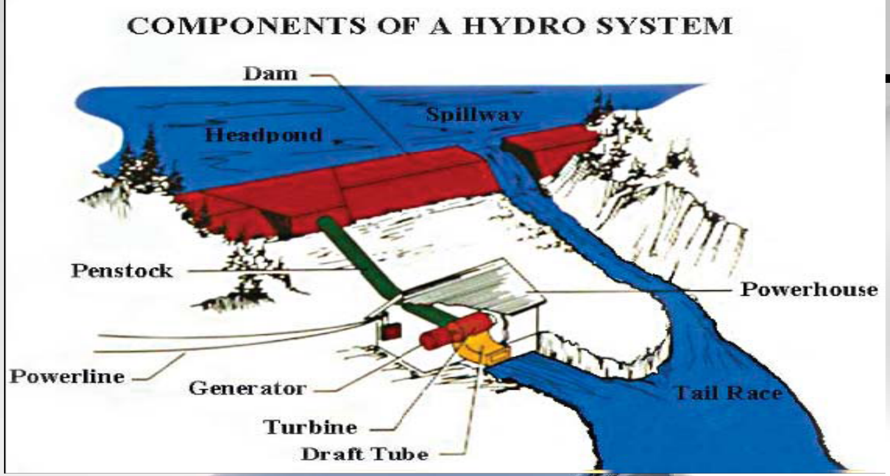
Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable.

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.

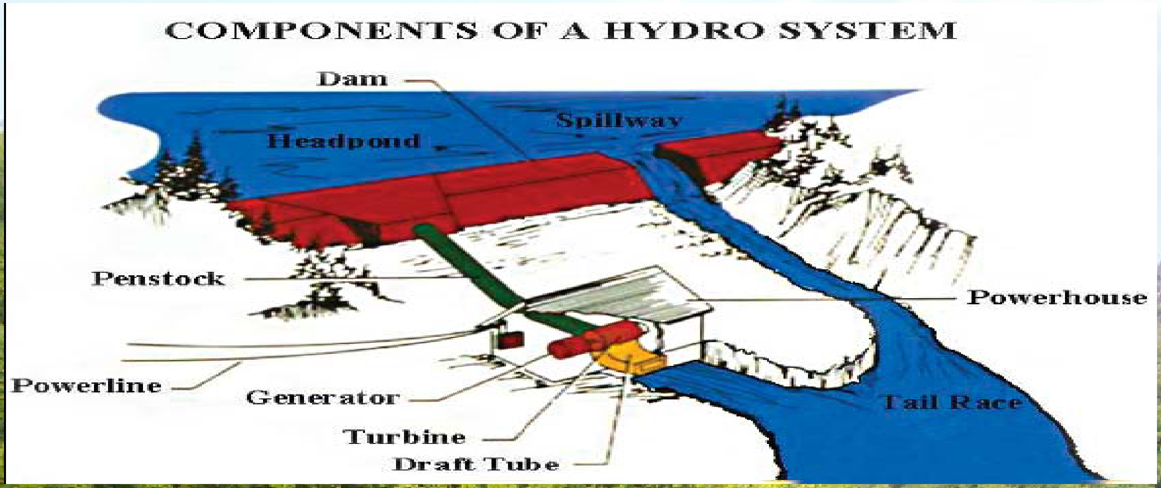




A canal, tunnel and/or penstock, which carries the water to the powerhouse in developments where the powerhouse is located at a distance downstream from the intake.

Canals are generally excavated and follow the contours of the existing terra[illegible]

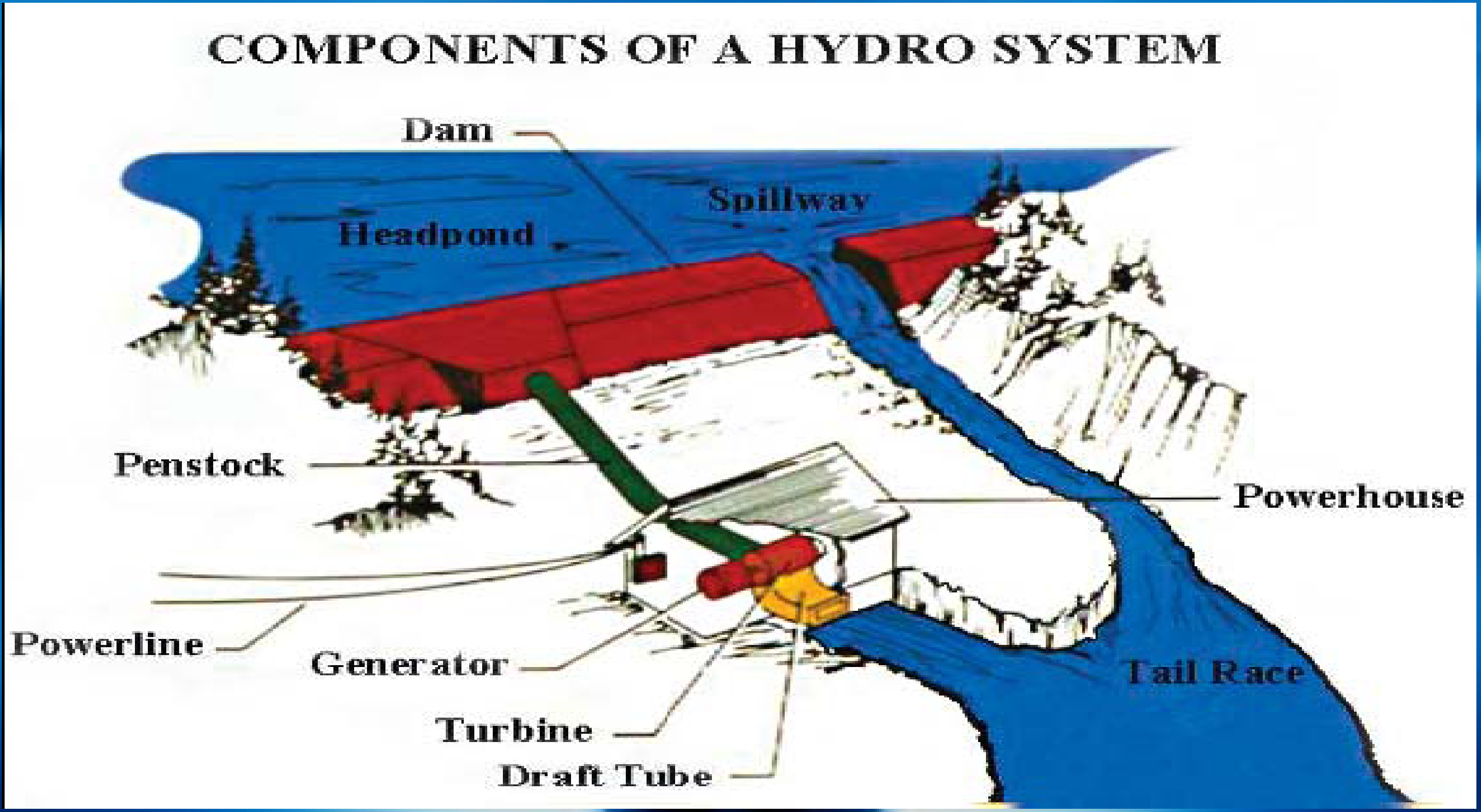
Tunnels are underground and excavated
by drilling and blasting.
Penstocks, which convey water under pressure, can be made of steel, iron, fibreglass, plastics, concrete or wood.



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.

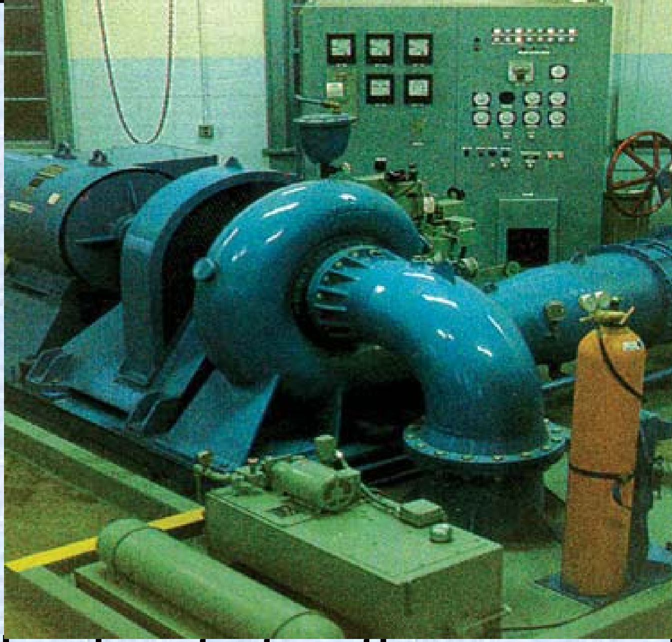
These components are generally made of steel or iron.

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



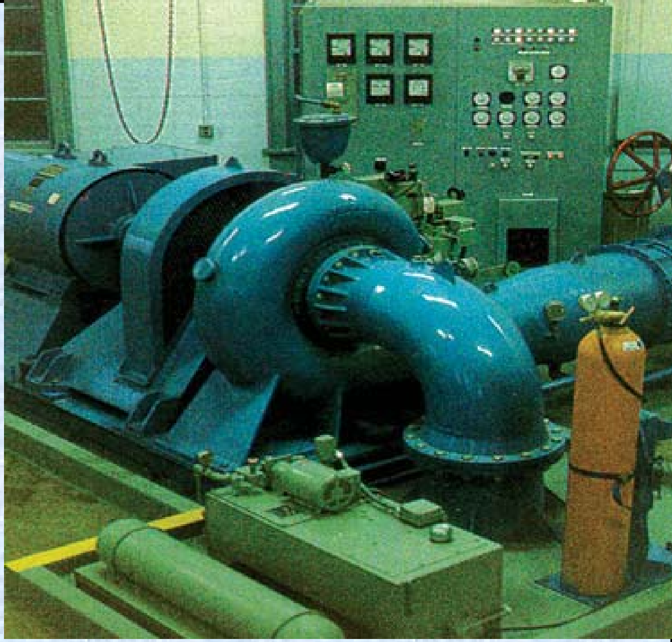
The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment.

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



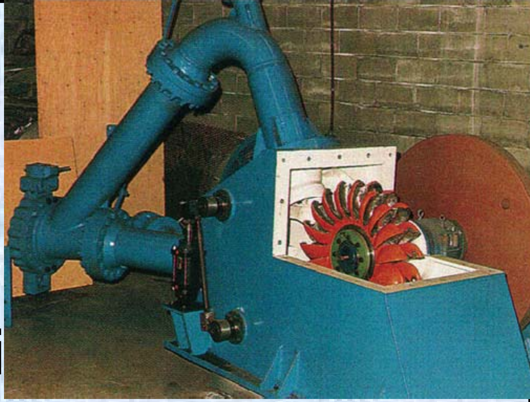
Francis turbine

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.

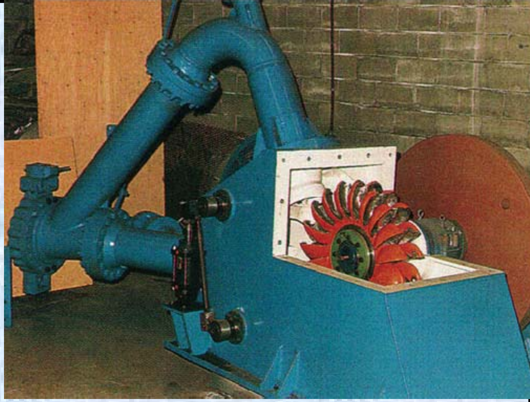
Turbines



Turbines used for low to medium head applicati
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.

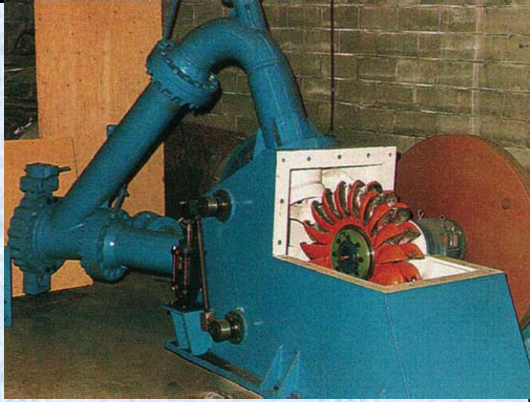
Turbines



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

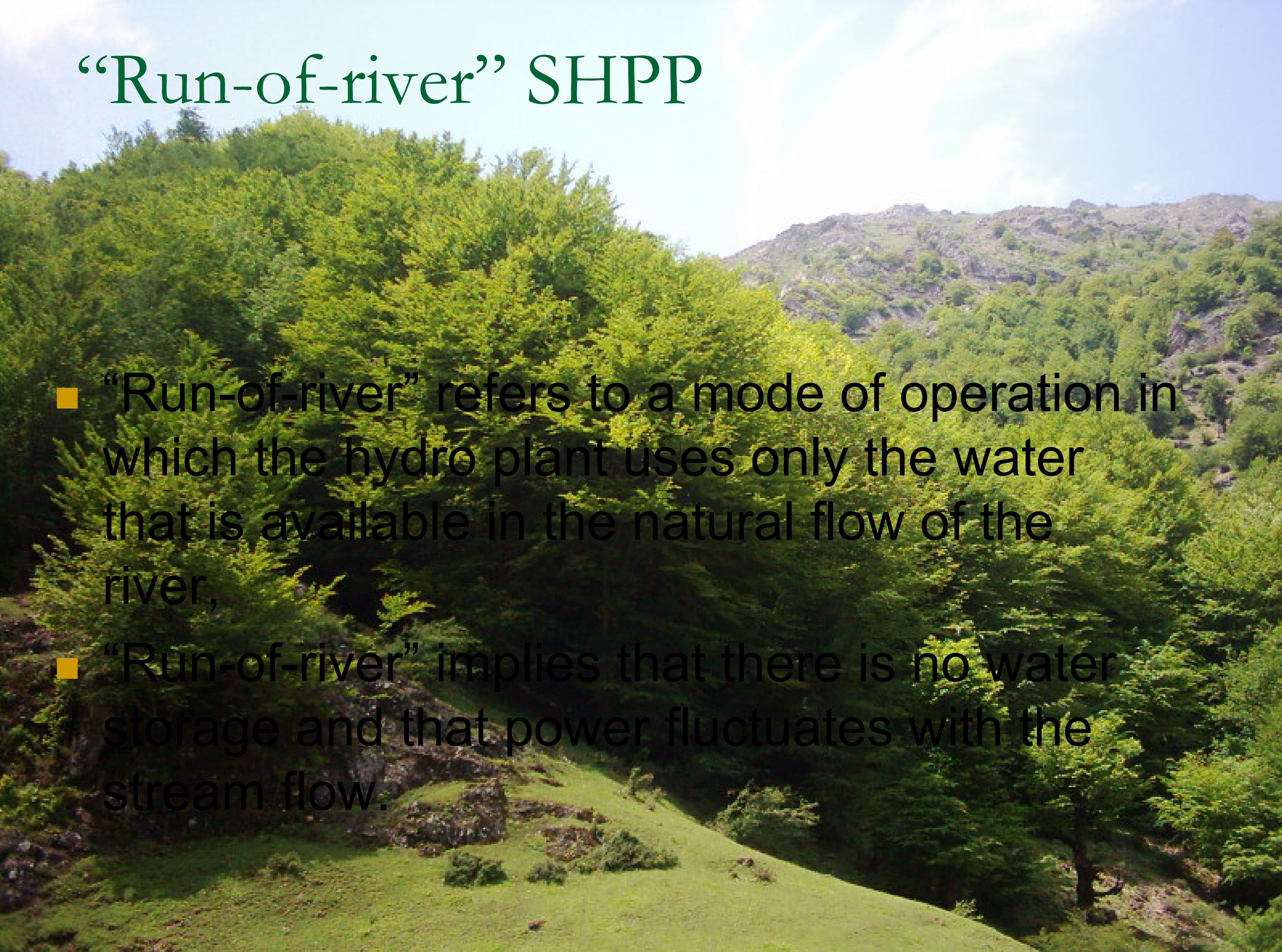
Small hydro projects can generally be categorised as:

1. “run-of-river developments”, and/or
2. “water storage (reservoir) developments”.

Run-of-river developments

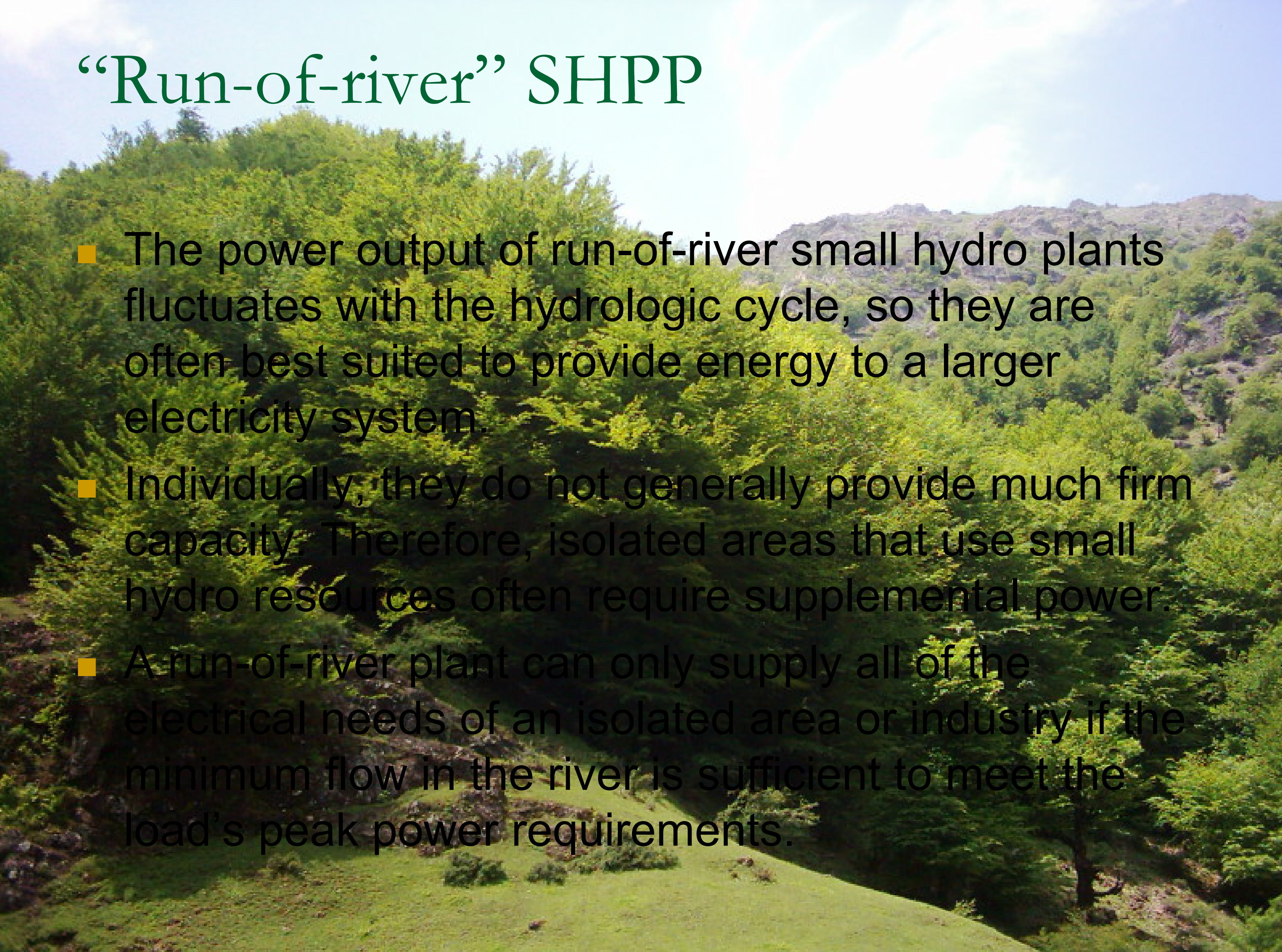
Run-of-River Small Hydro Project in a Remote Community.

“Run-of-river” SHPP

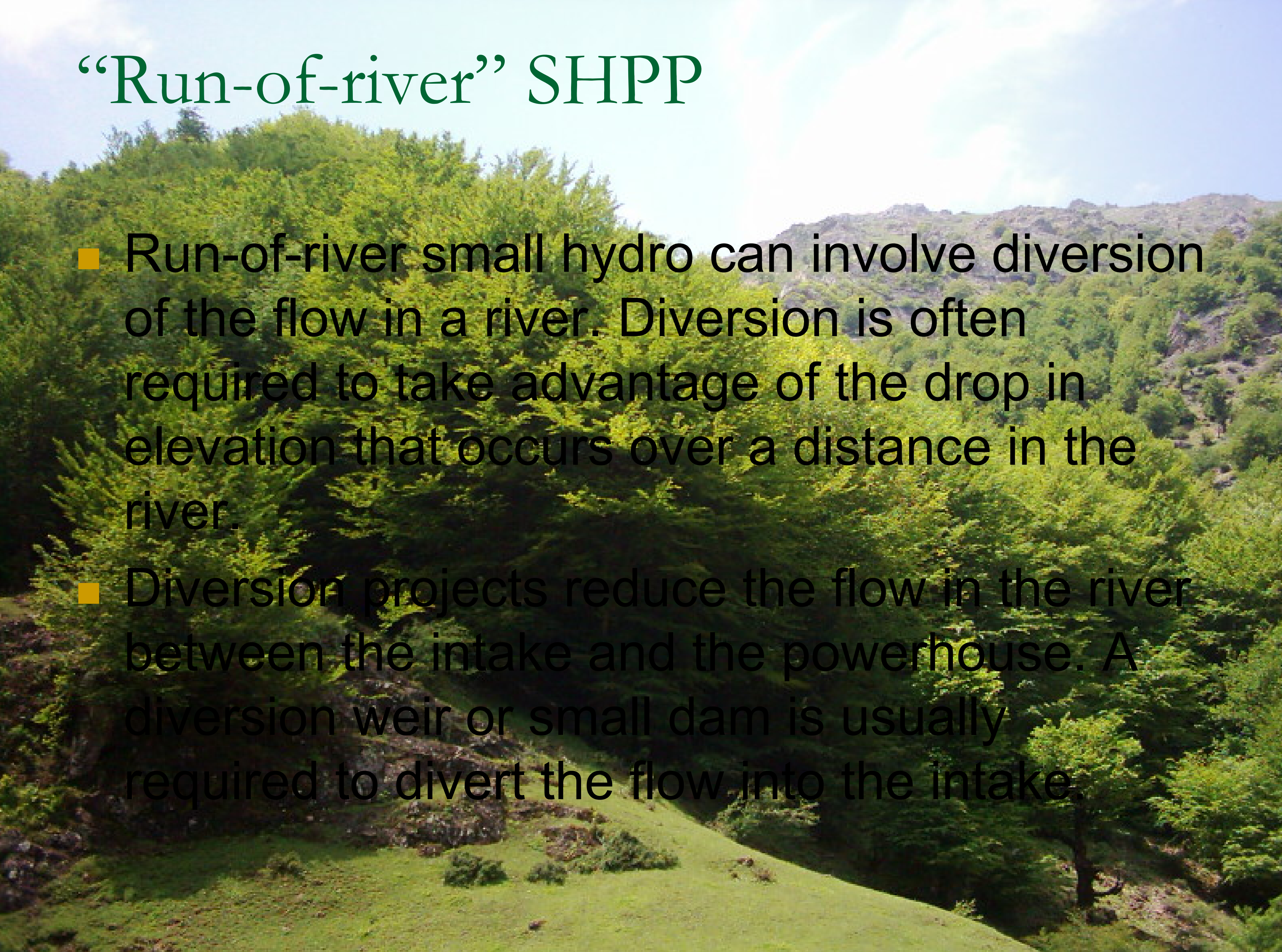


- “Run-of-river” refers to a mode of operation in which the hydro plant uses only the water that is available in the natural flow of the river,
- “Run-of-river” implies that there is no water storage and that power fluctuates with the stream flow.

“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.

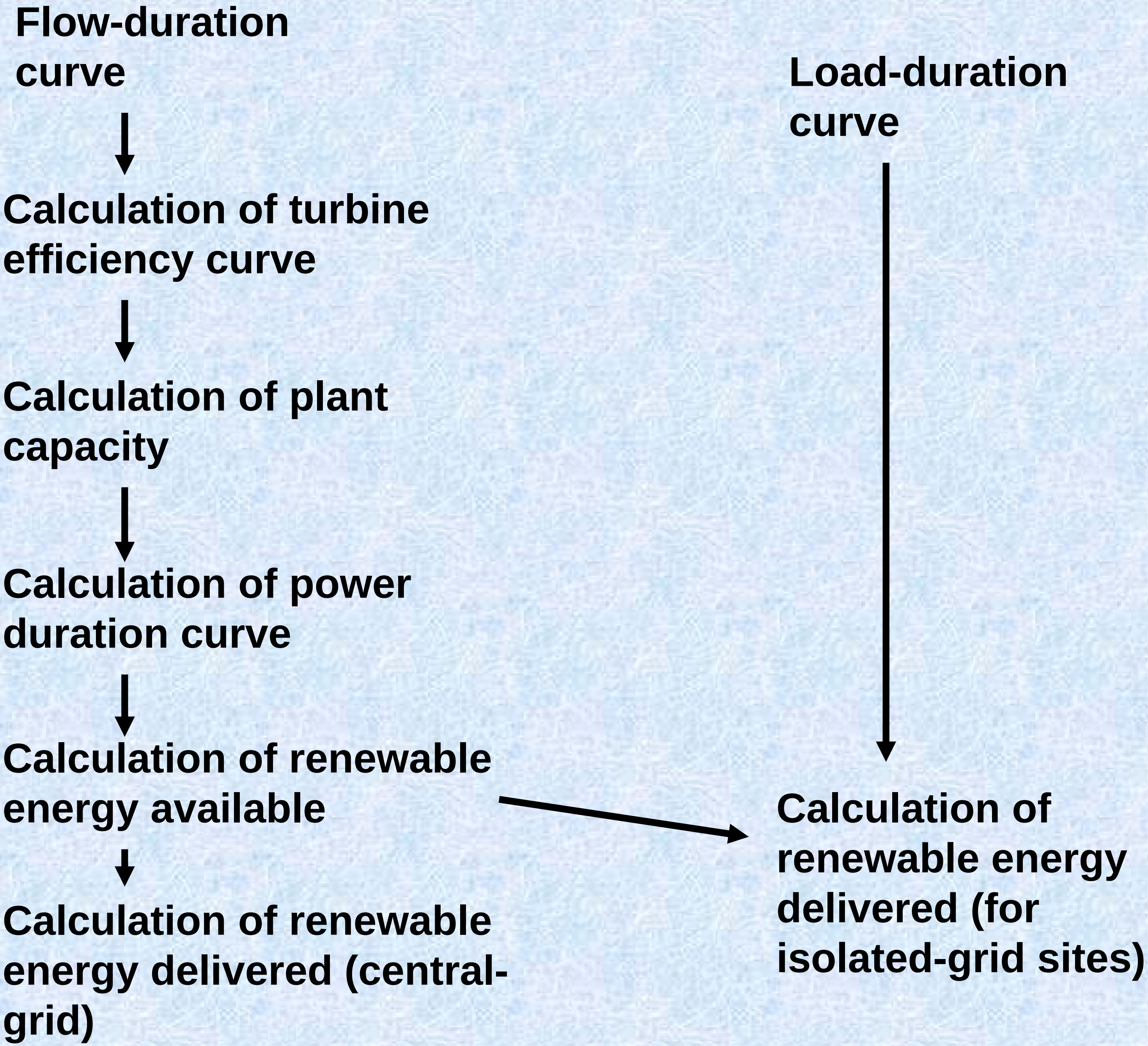
SHPP PROJECT MODEL

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.

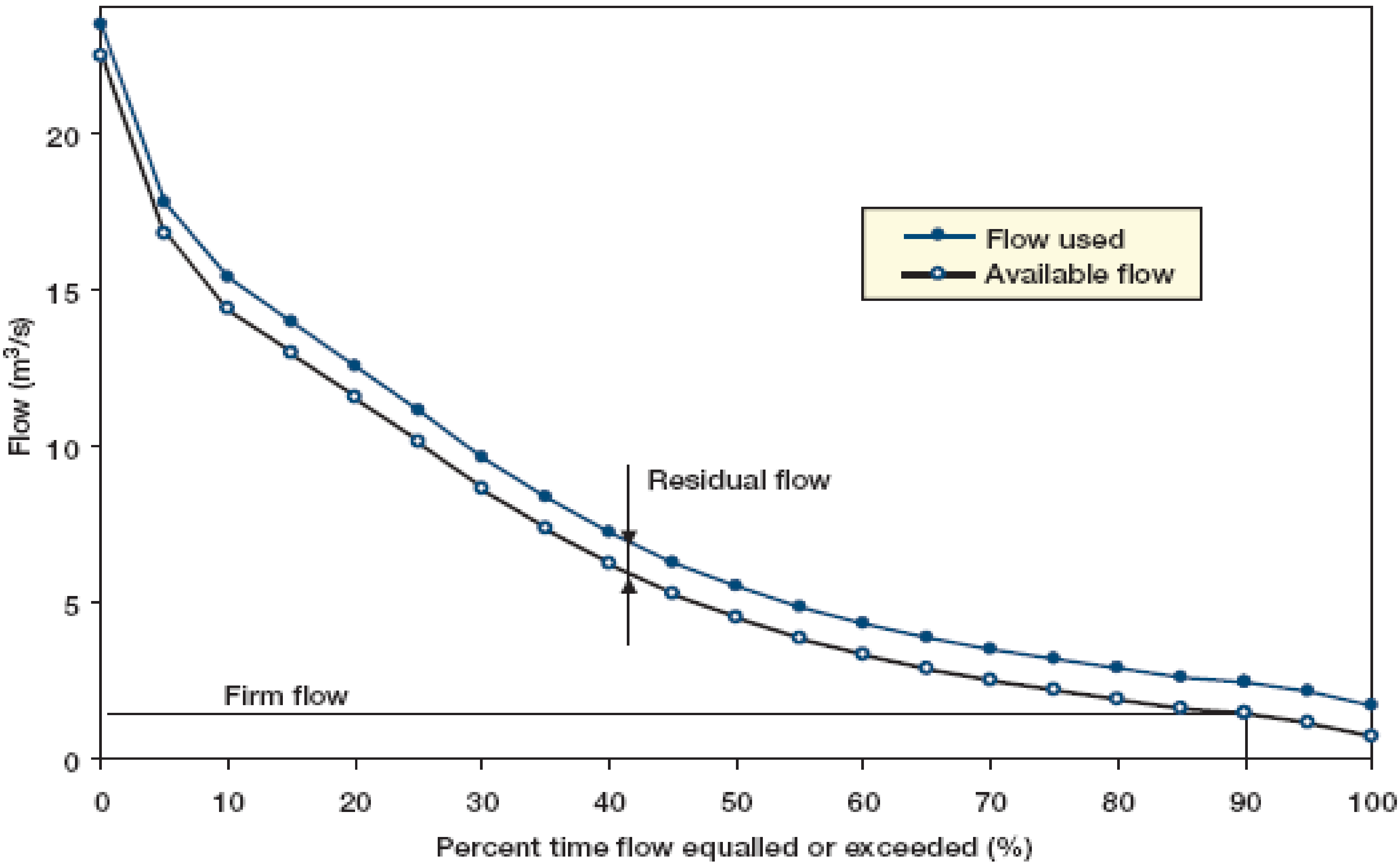
A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow.

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:

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

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

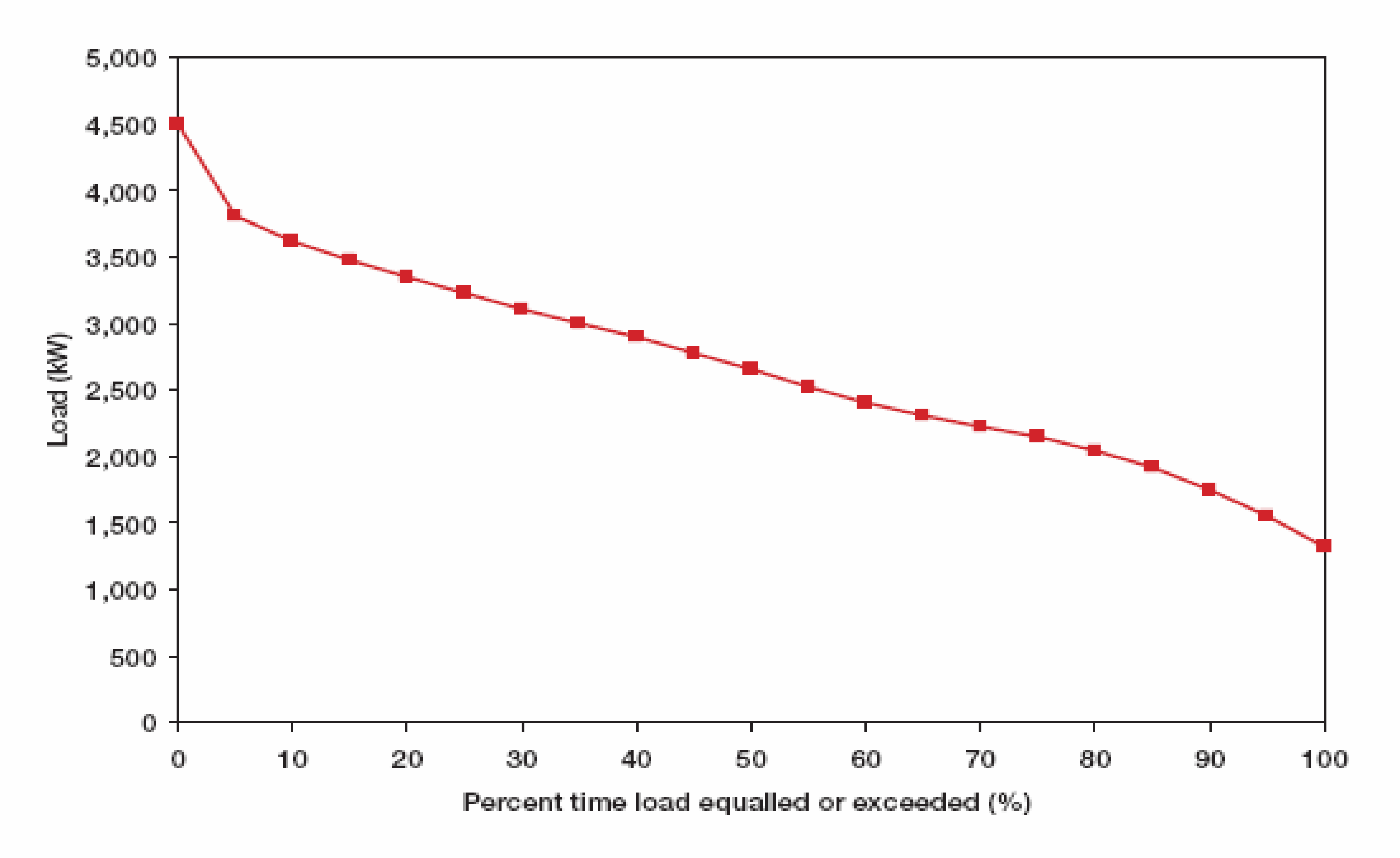
Load

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,
- 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

SHPP Project Model

Energy Production

Turbine efficiency curve

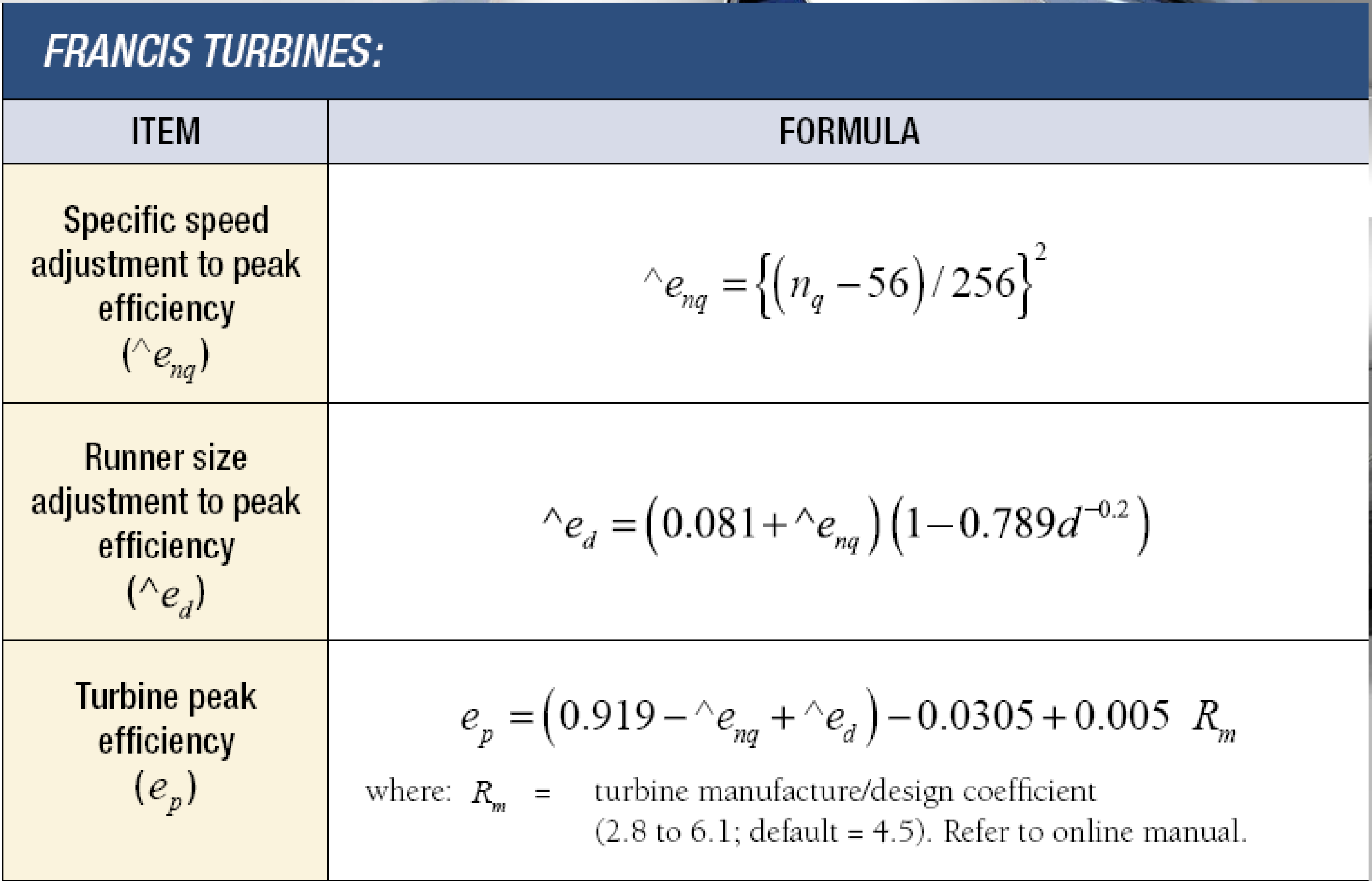
FRANCIS, KAPLAN AND PROPELLOR TURBINES (REACTION TURBINES):

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 $({}^\wedge e_{nq})$	${}^\wedge e_{nq} = \{(n_q - 56)/256\}^2$
Runner size adjustment to peak efficiency $({}^\wedge e_d)$	${}^\wedge e_d = (0.081 + {}^\wedge e_{nq})(1 - 0.789 d^{-0.2})$
Turbine peak efficiency (e_p)	$e_p = (0.919 - {}^\wedge e_{nq} + {}^\wedge e_d) - 0.0305 + 0.005\ R_m$ where: R_m = turbine manufacture/design coefficient (2.8 to 6.1; default = 4.5). Refer to online manual.

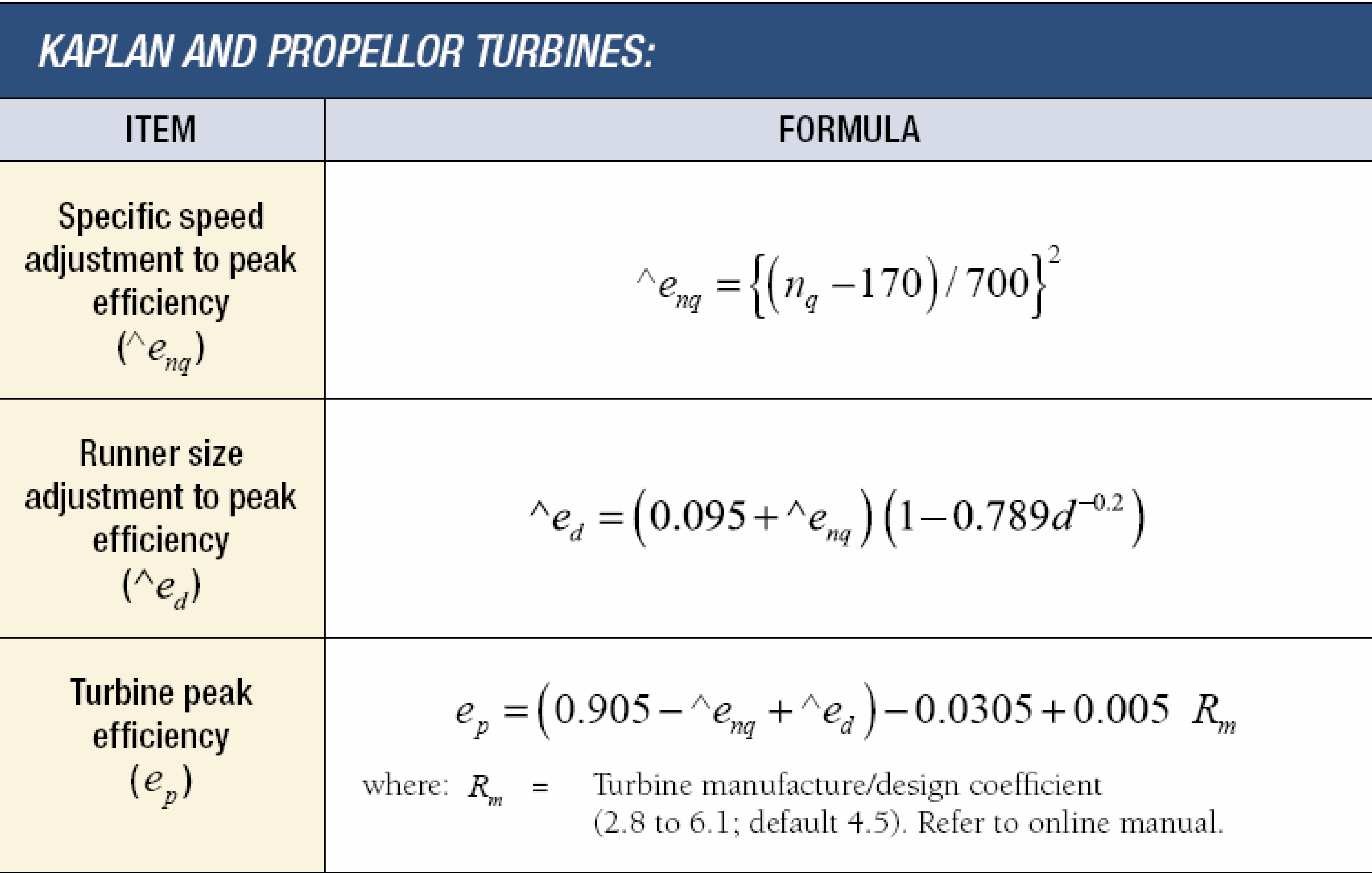
SHPP Project Model

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)	$e_q = e_p - \left[\left(\frac{Q - Q_p}{Q_d - Q_p}\right)^2 (e_p - e_r)\right]$

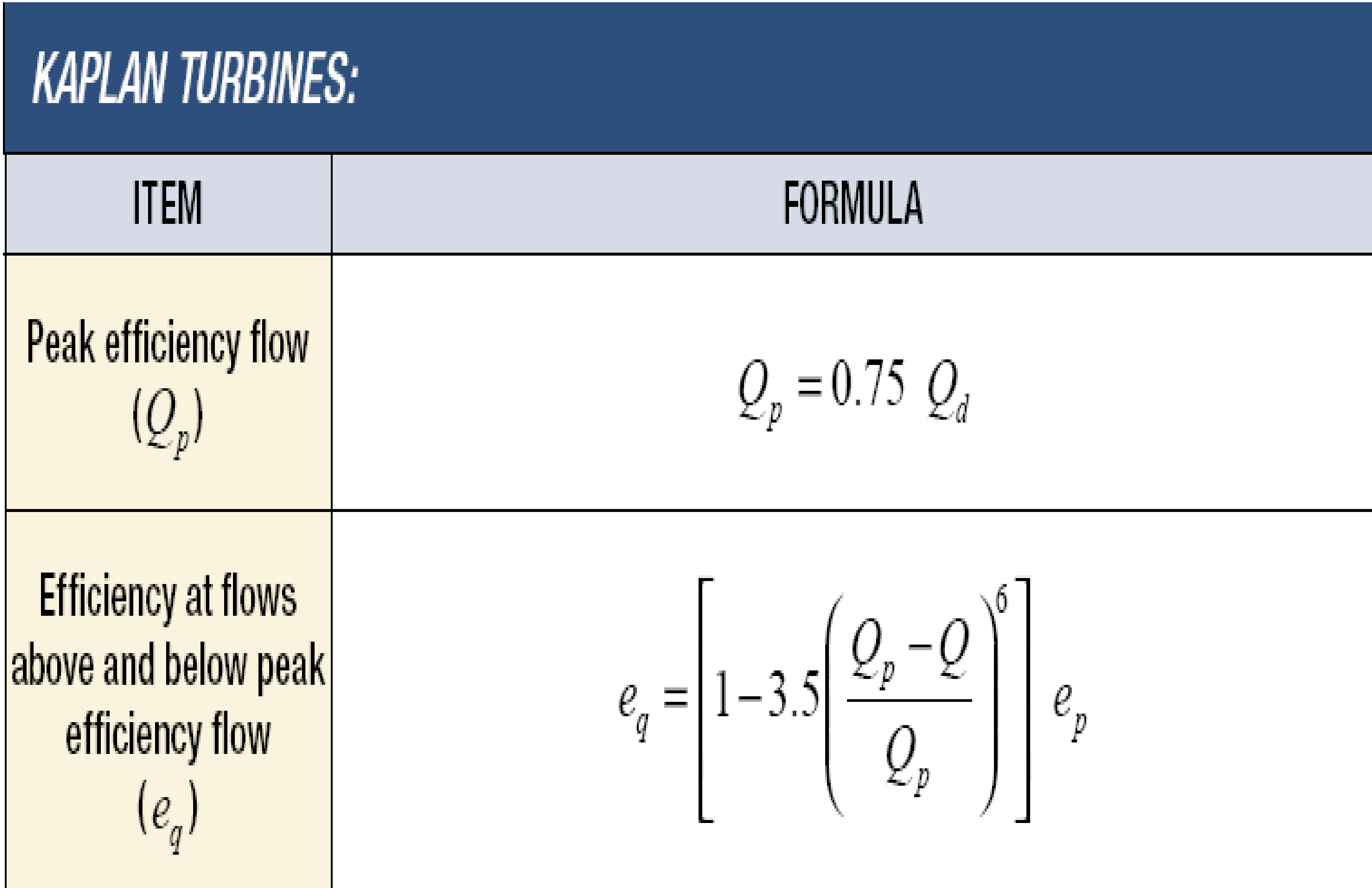
SHPP Project Model
Energy Production
Turbine efficiency curve



KAPLAN AND PROPELLOR TURBINES:

ITEM	FORMULA
Specific speed adjustment to peak efficiency $(^\wedge e_{nq})$	$^\wedge e_{nq} = \left\{\left(n_q - 170\right)/700\right\}^2$
Runner size adjustment to peak efficiency $(^\wedge e_d)$	$^\wedge e_d = \left(0.095 + {}^\wedge e_{nq}\right)\left(1 - 0.789 d^{-0.2}\right)$
Turbine peak efficiency (e_p)	$e_p = \left(0.905 - {}^\wedge e_{nq} + {}^\wedge e_d\right) - 0.0305 + 0.005\ R_m$ 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



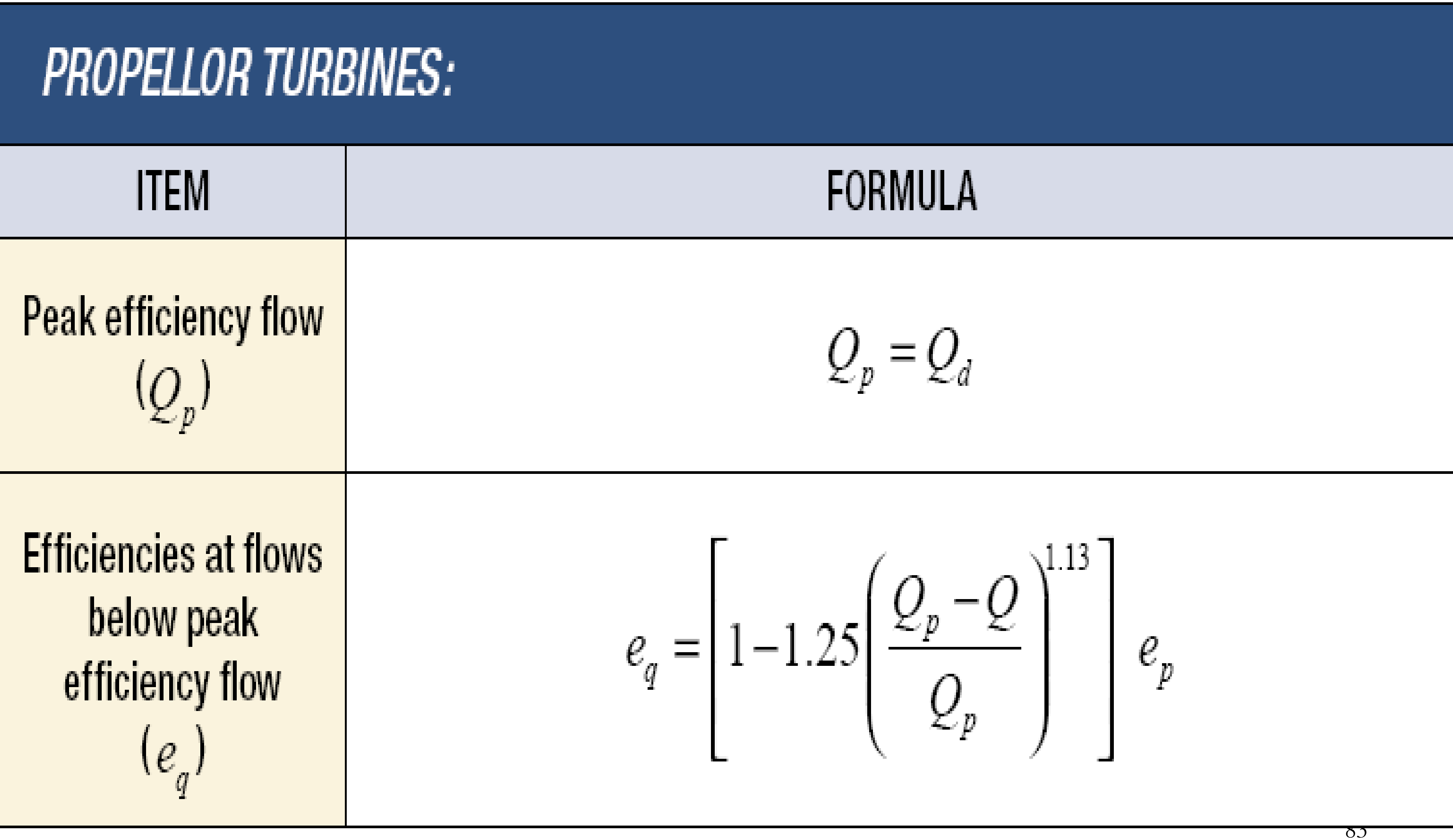
KAPLAN TURBINES:

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

SHPP Project Model

Energy Production

Turbine efficiency curve



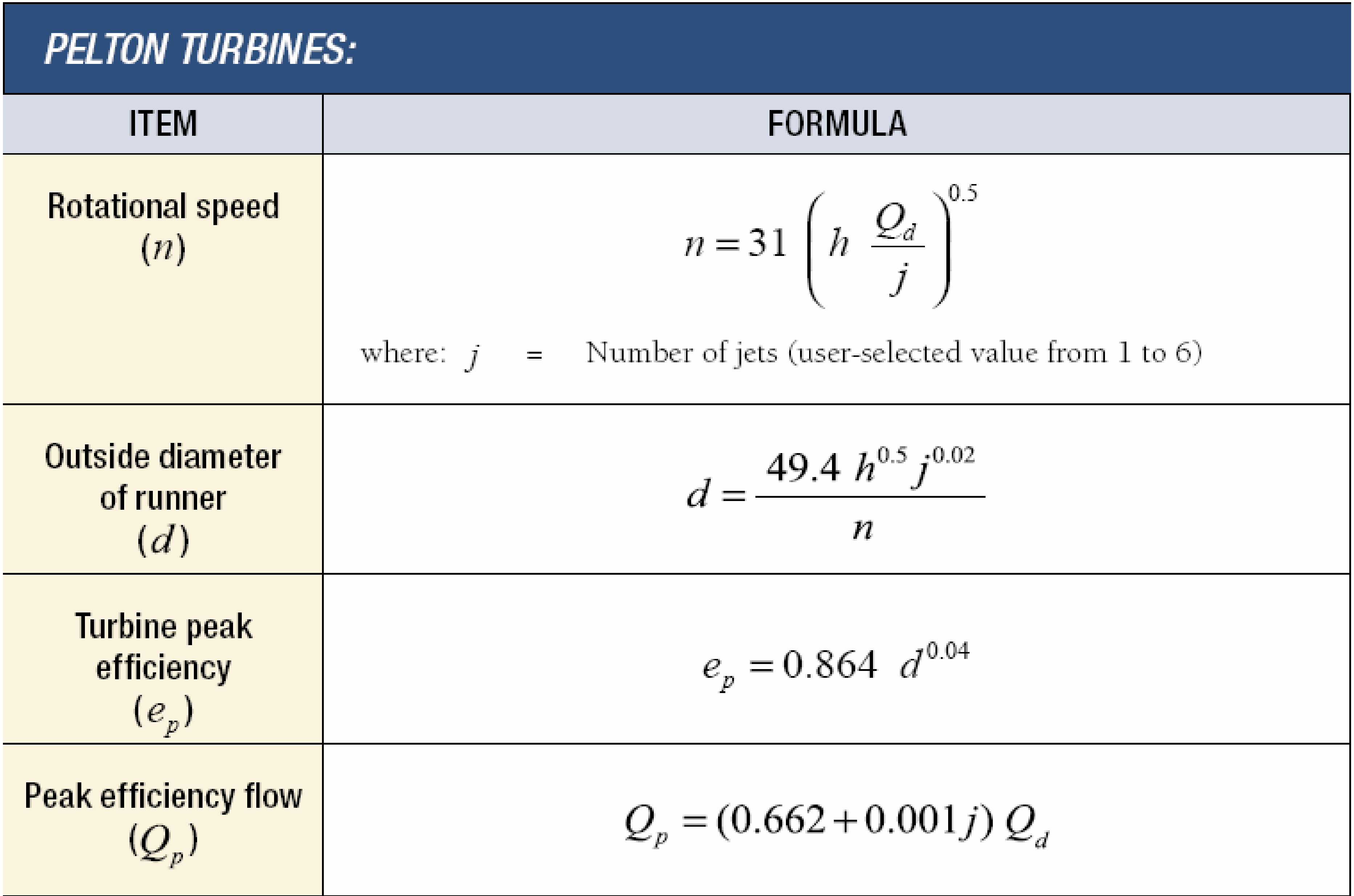
PROPELLOR TURBINES:

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

SHPP Project Model

Energy Production

Turbine efficiency curve



PELTON TURBINES:

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

SHPP Project Model

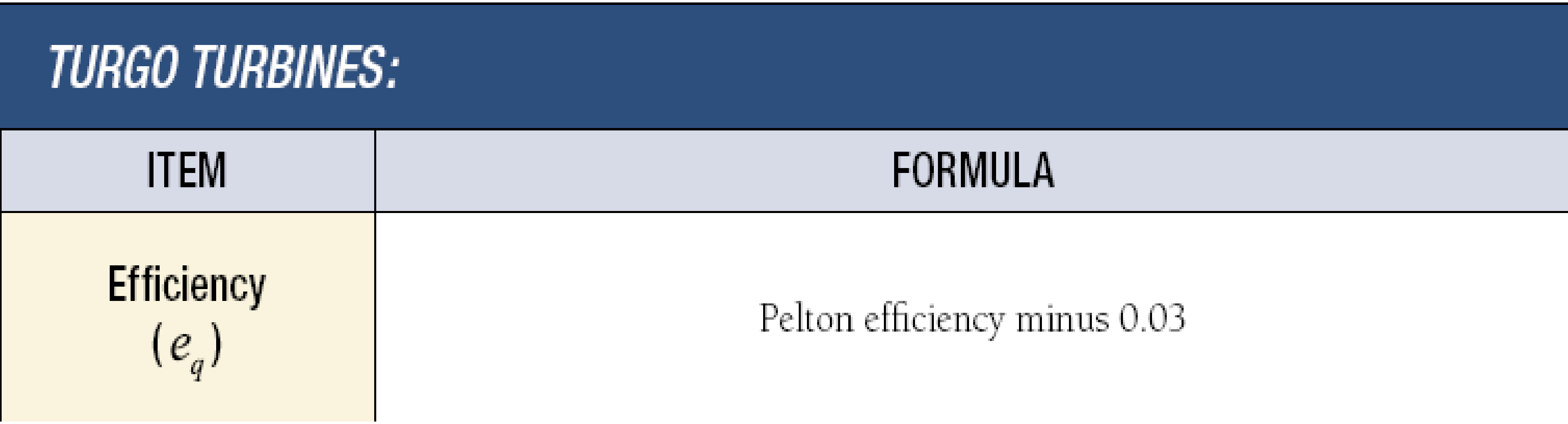
Energy Production

Turbine efficiency curve – Pelton turbines

Efficiency at flows above and below peak efficiency flow (e_q)

$$e_q = \left[1 - \left\{ (1.31 + 0.025\,j) \left| \left(\frac{Q_p - Q}{Q_p} \right) \right|^{(5.6+0.4\,j)} \right\} \right] e_p$$

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)	$e_q = 0.79 - 0.15\left(\frac{Q_d - Q}{Q_p}\right) - 1.37\left(\frac{Q_d - Q}{Q_p}\right)^{14}$

SHPP Project Model
Energy Production
Turbine efficiency curve

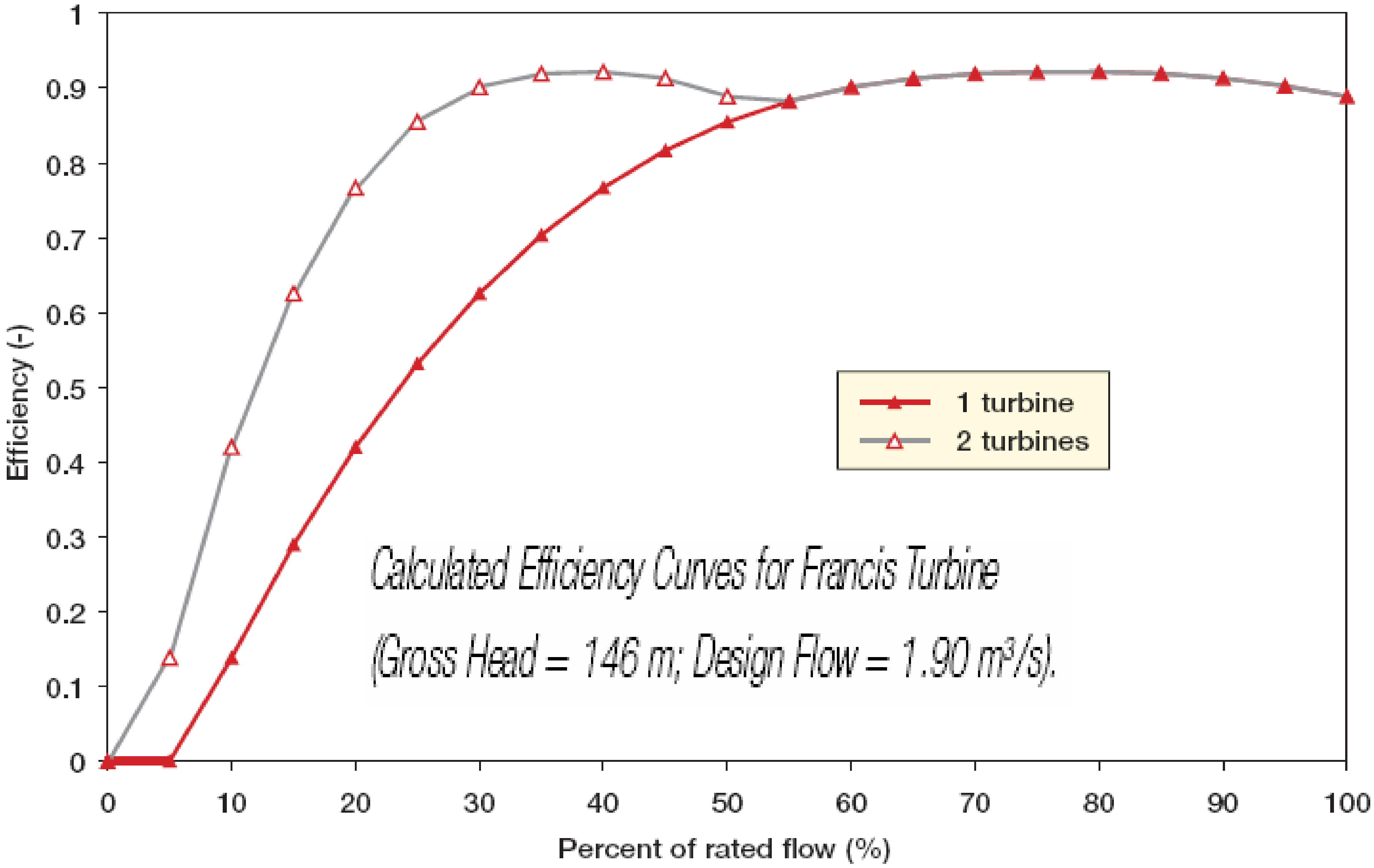
The turbine efficiency equations and the number of turbines are used to calculate plant turbine efficiency from 0% to 100% of design flow (maximum plant flow) at 5% intervals.

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

SHPP Project Model

Energy Production

Turbine efficiency curve



Calculated Efficiency Curves for Francis Turbine

(Gross Head = 146 m; Design Flow = 1.90 m^3/s).

SHPP Project Model

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:

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

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;

Energy Production

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.

SHPP Project Model

Energy Production

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:

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

Energy Production

Power available as a function of flow

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

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 $Q > Q_{des}$).

SHPP Project Model

Energy Production

Plant capacity

when $Q \le Qdes$

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.

Energy Production

Power-duration curve

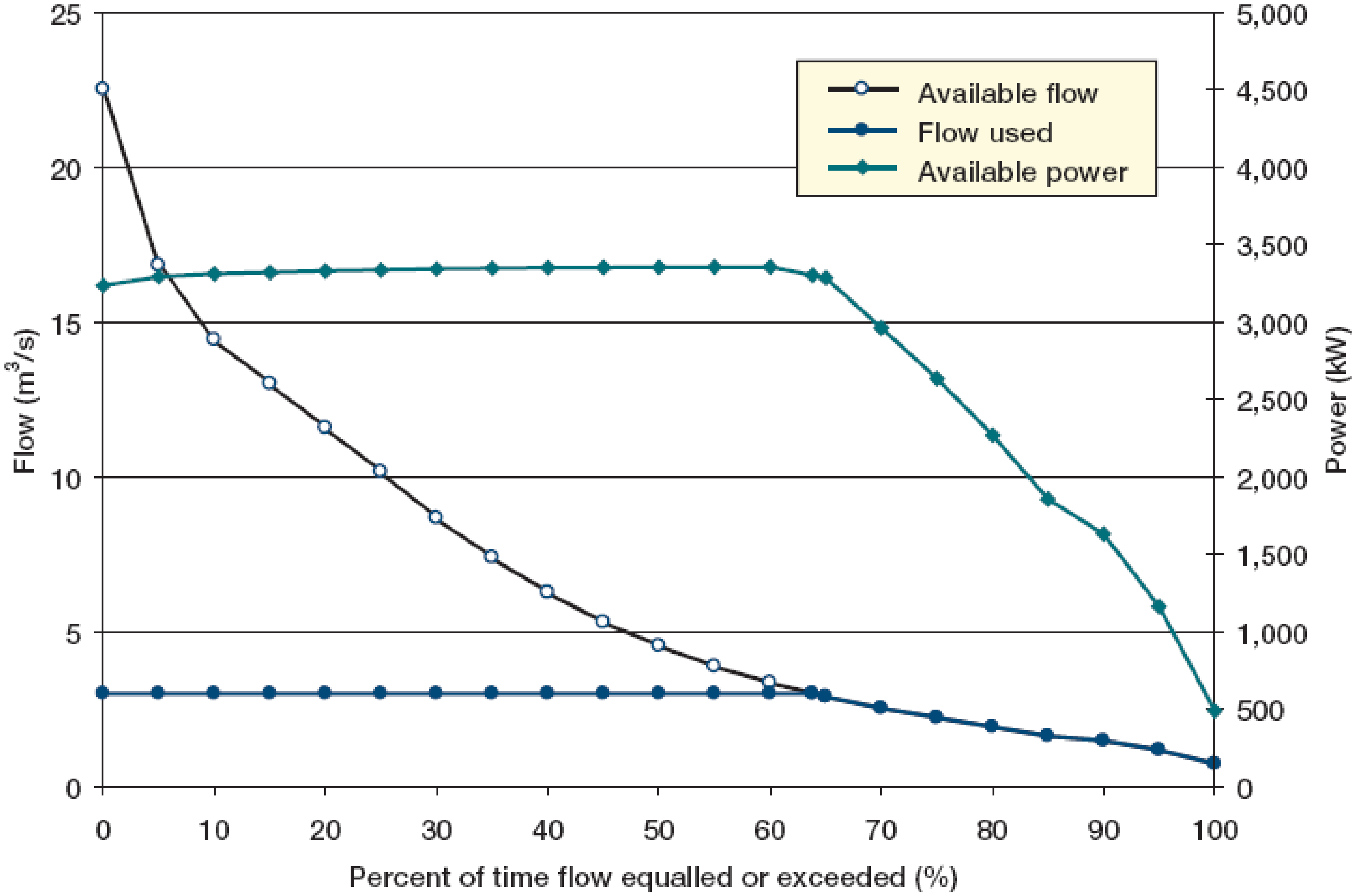
Calculation of power available as a function of flow using equation (*) for all 21 values of the available flow Q_0' Q_5' , ... , Q_{100}' , used to define the flow duration curve,

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.

SHPP Project Model

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.

SHPP Project Model

Energy Production

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).

Energy Production- Renewable energy available

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:

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

SHPP Project Model

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

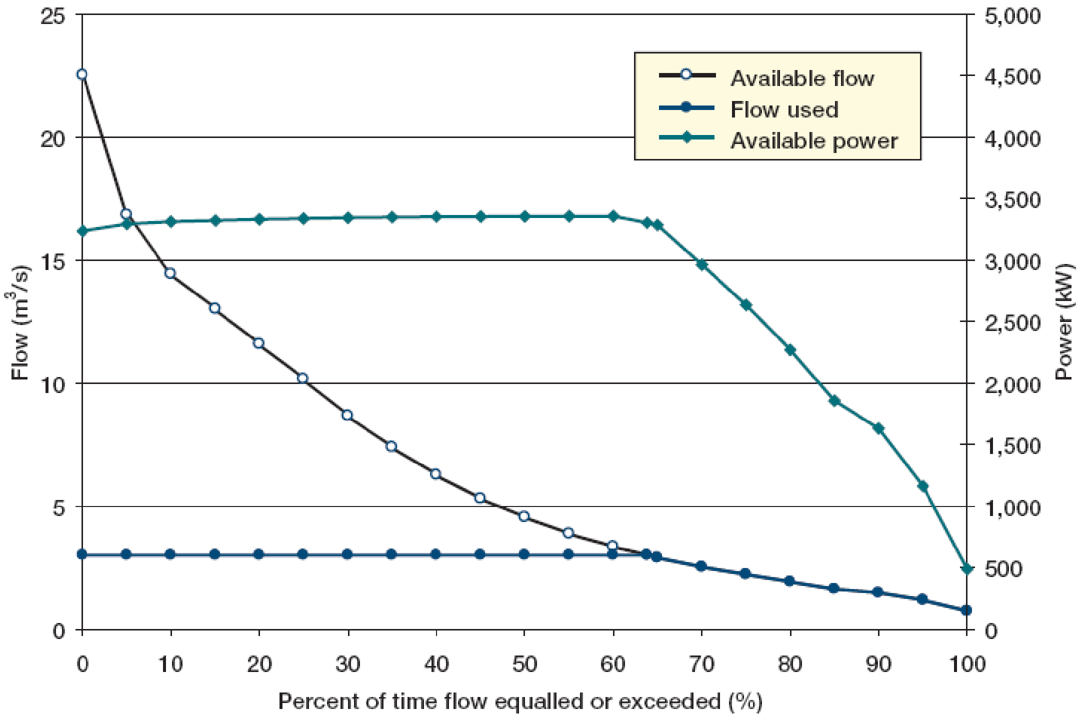
The procedure is illustrated by an example:

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



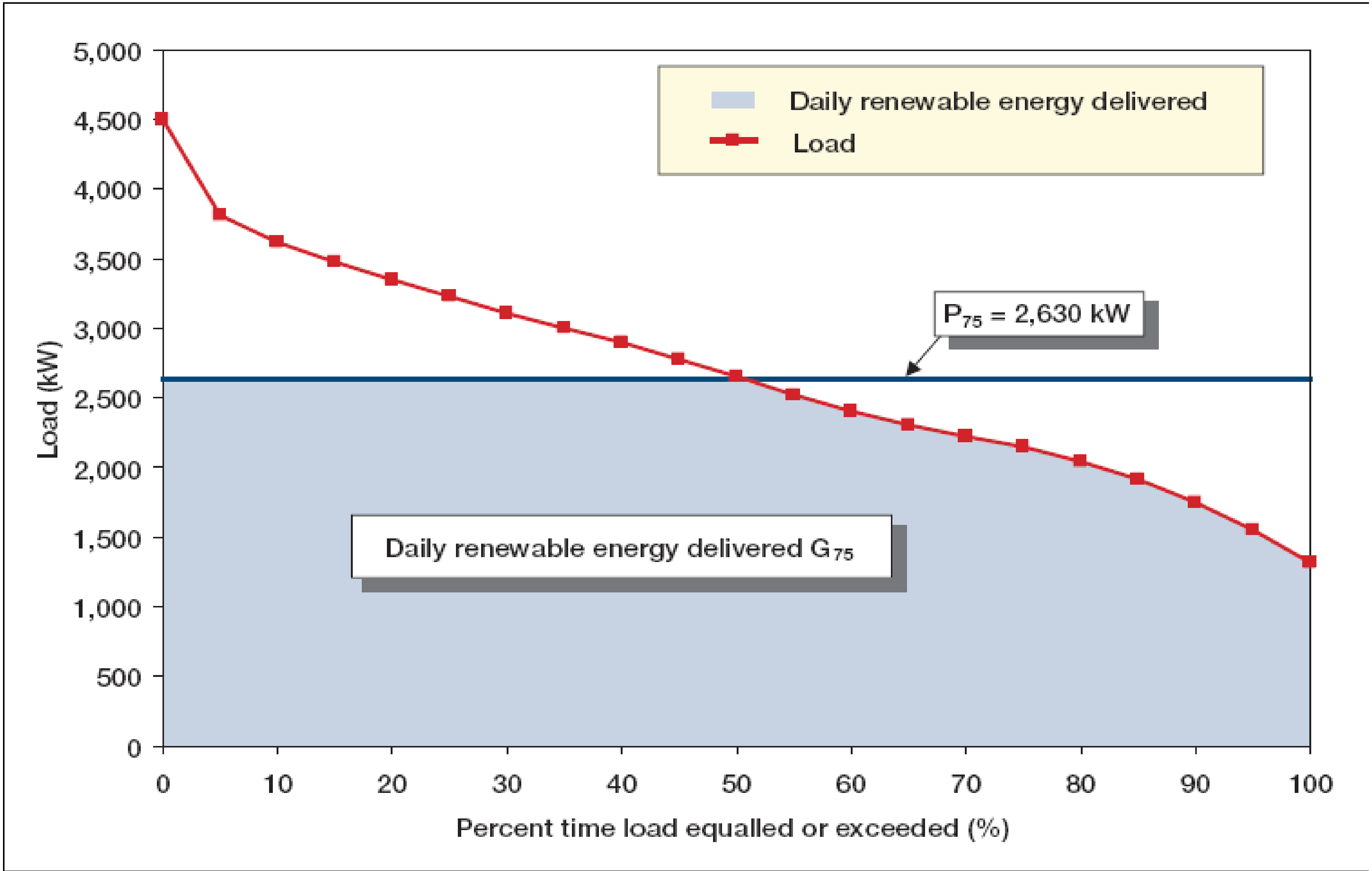
Power-Duration Curve

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

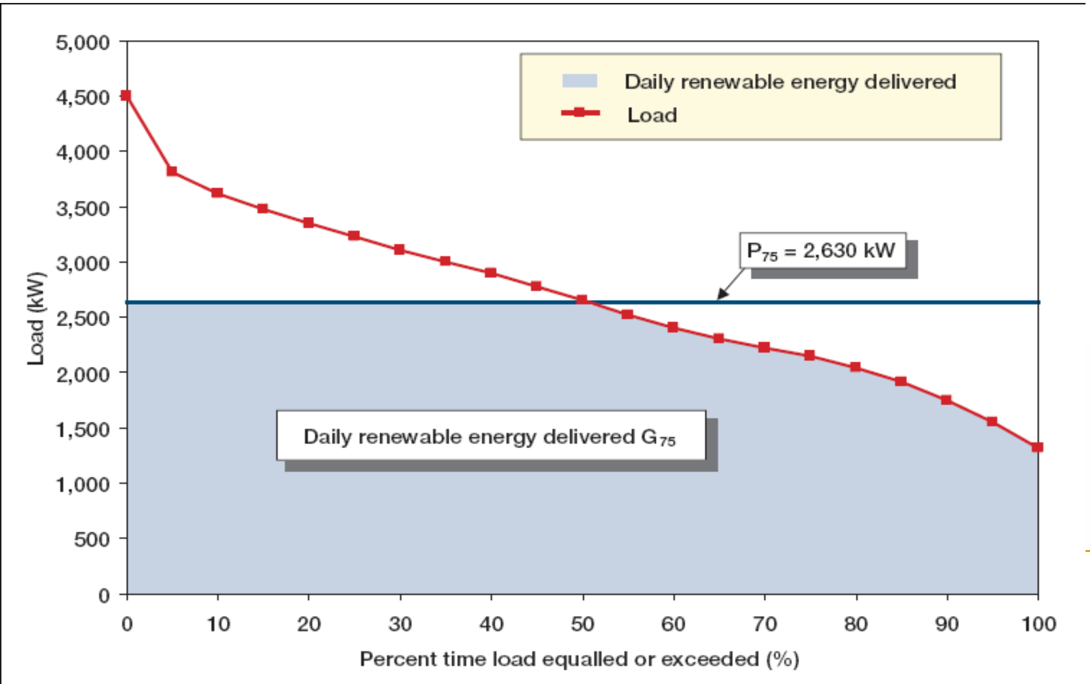


SHPP Project Model

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:

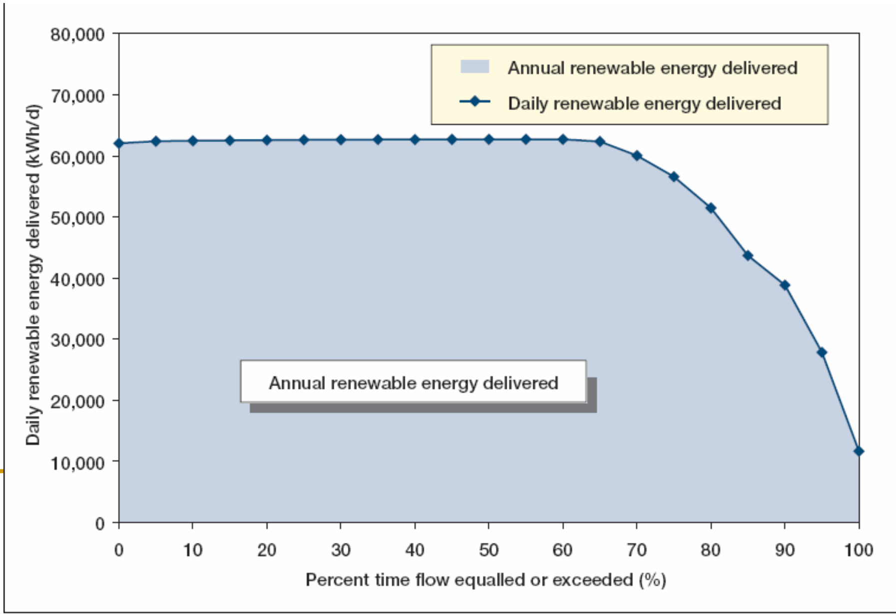
$$G_{75} = 56.6 \text{ MWh/d}$$

Energy Production- Renewable energy available

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

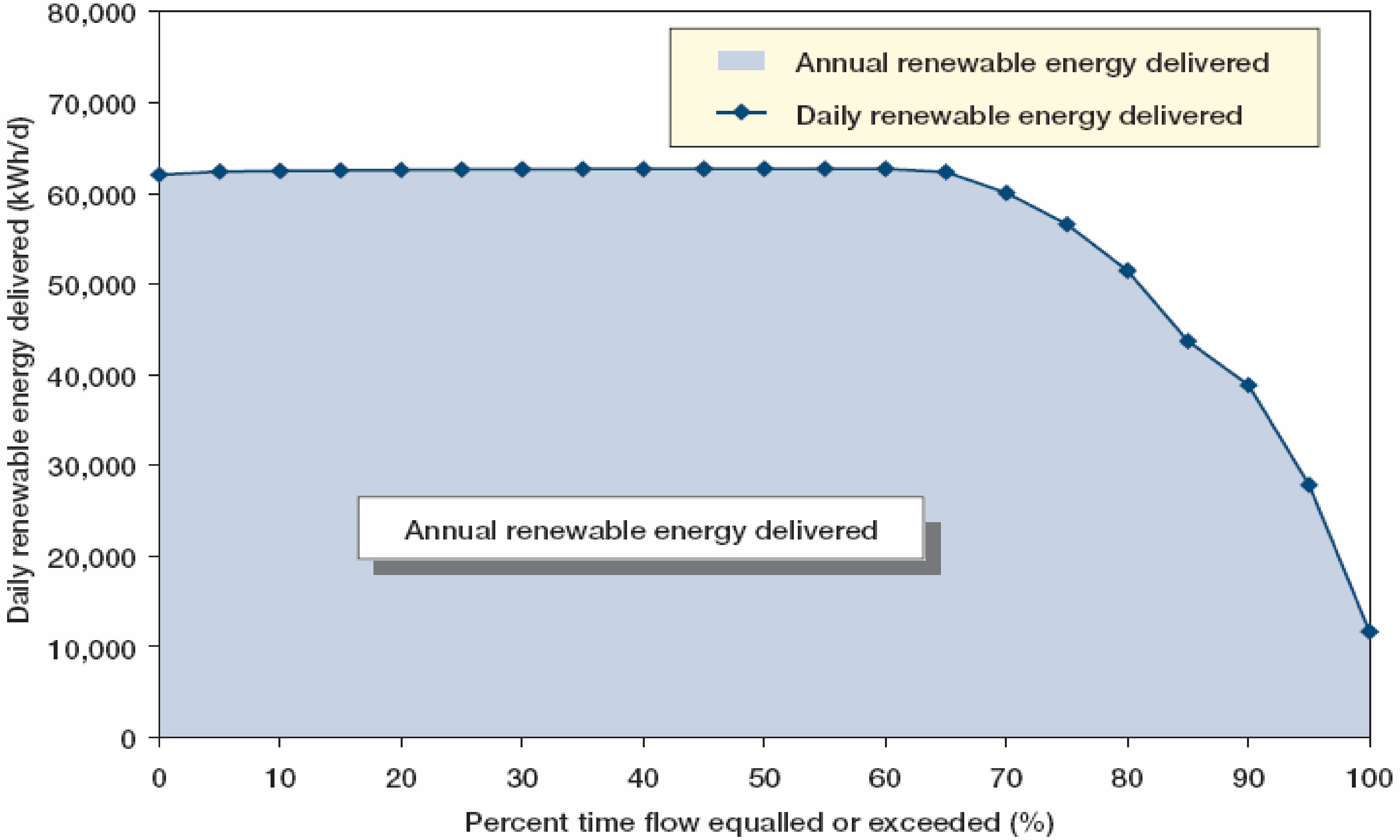
The procedure is repeated for all values P_0 P_5 ,…, P_{100} to obtain twenty one values of the daily renewable energy delivered G_0 G_5 ,…, G_{100} , as a function of percent time the flow is exceeded as shown in down Figure.

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:

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

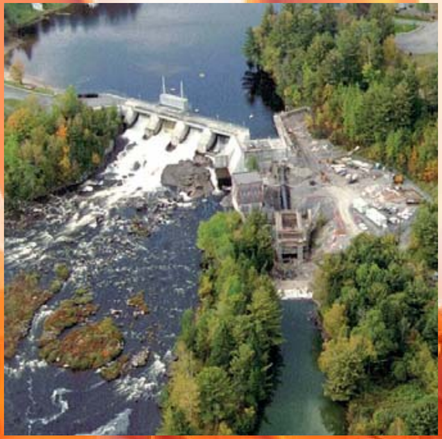
SHPP Project Model

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

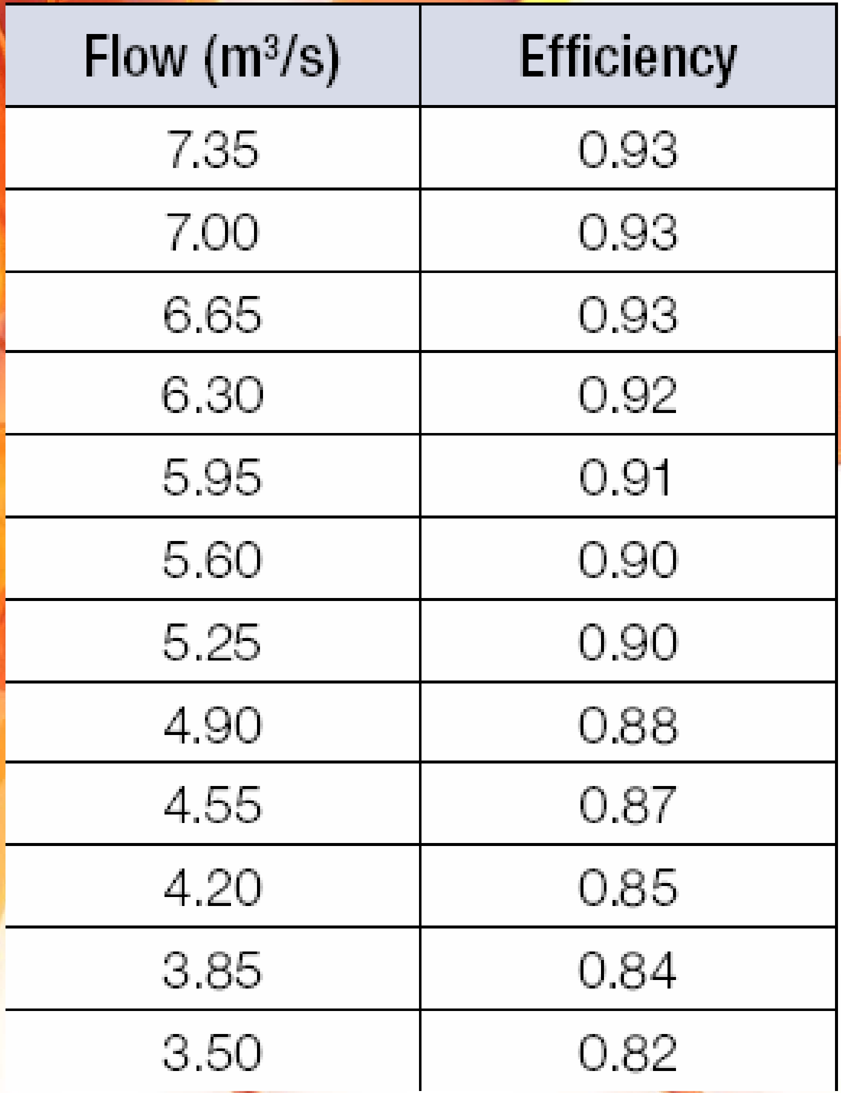
Maximum rated power:
7,115 kW at 105.6 m net head

RPM:
514

Diameter:
1,100 mm

Number of blades:
13

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



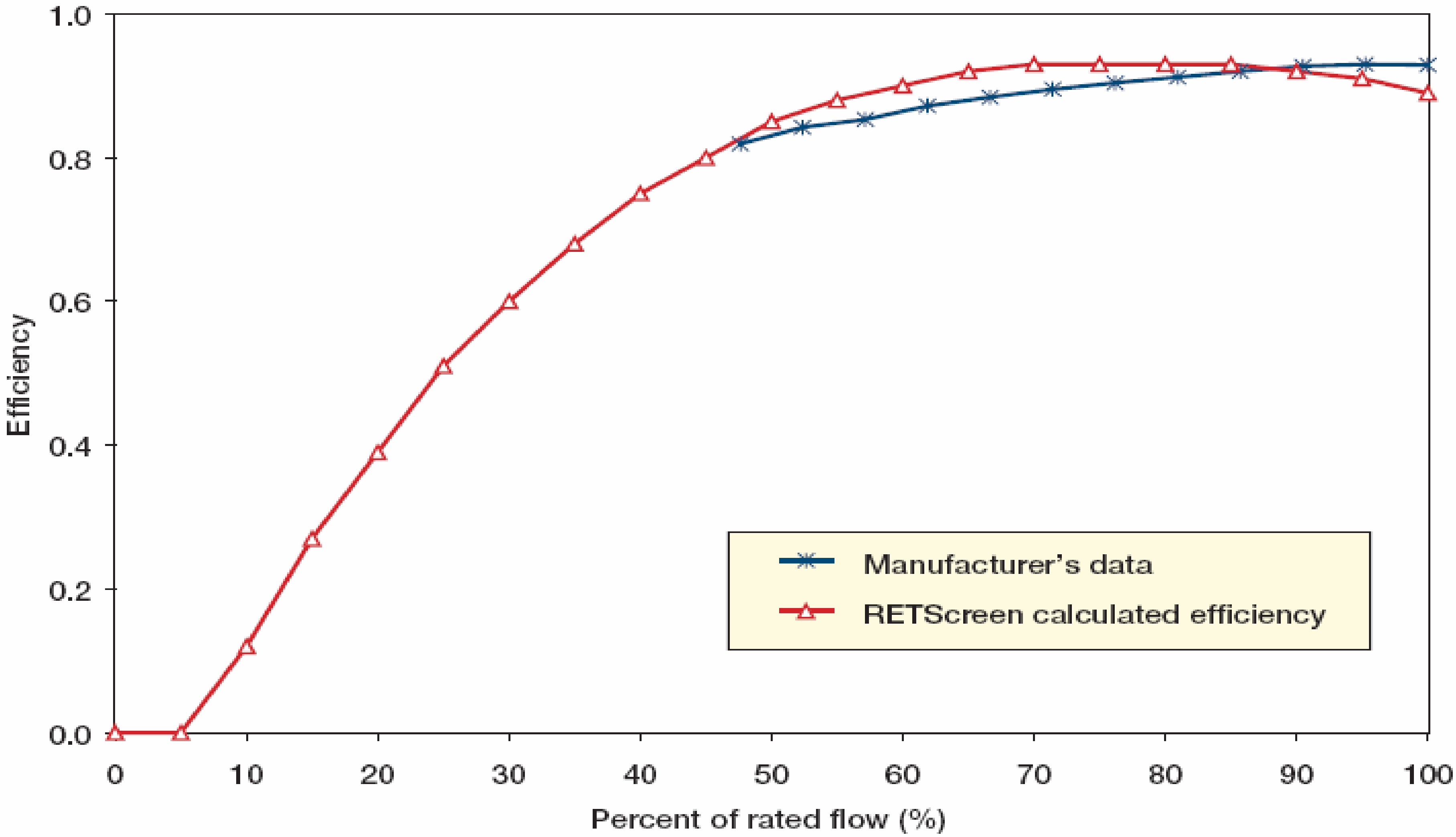
Flow (m^3/s)	Efficiency
7.35	0.93
7.00	0.93
6.65	0.93
6.30	0.92
5.95	0.91
5.60	0.90
5.25	0.90
4.90	0.88
4.55	0.87
4.20	0.85
3.85	0.84
3.50	0.82

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

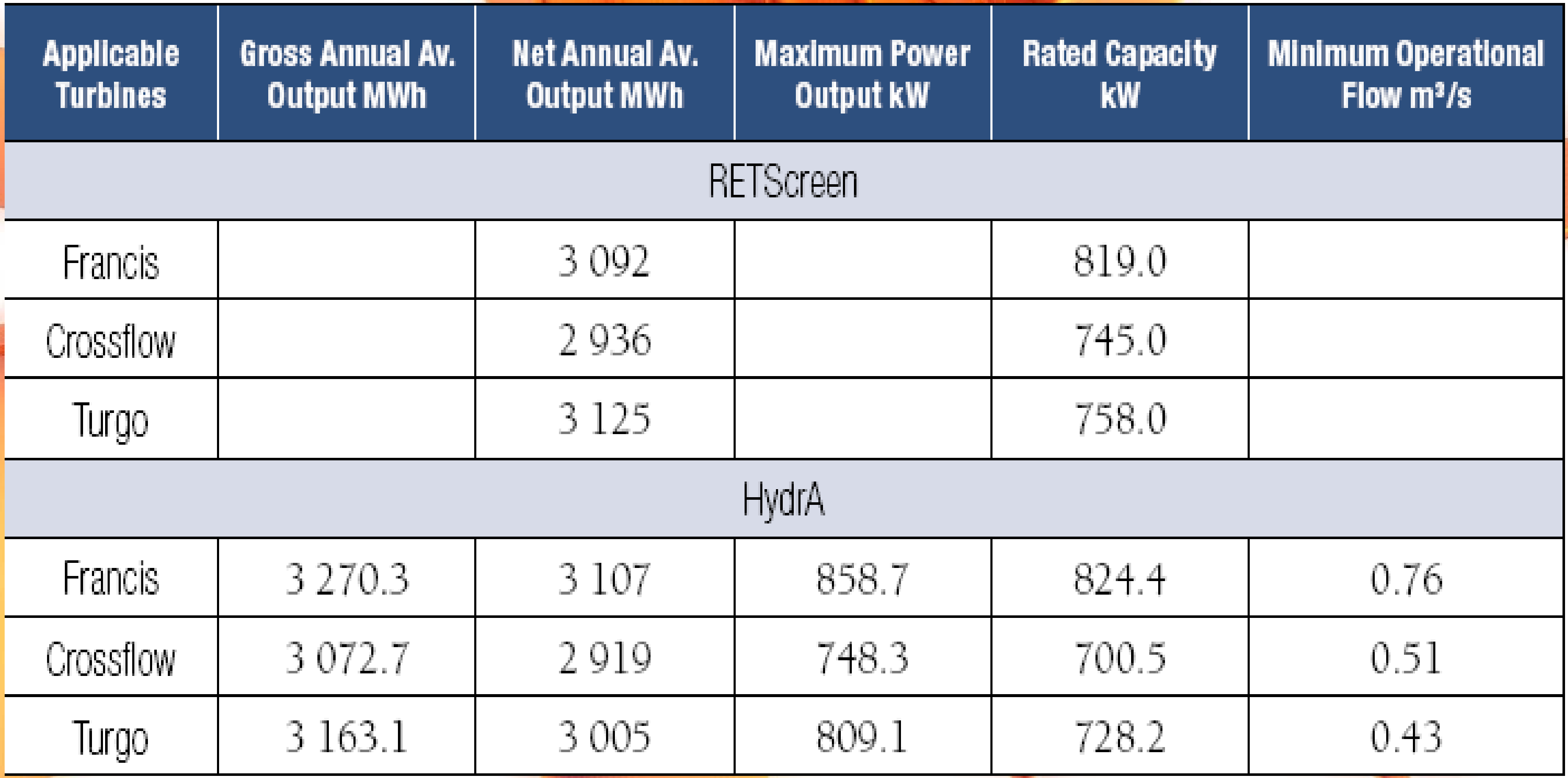
Net hydraulic head: 58.5 m

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 m^3/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

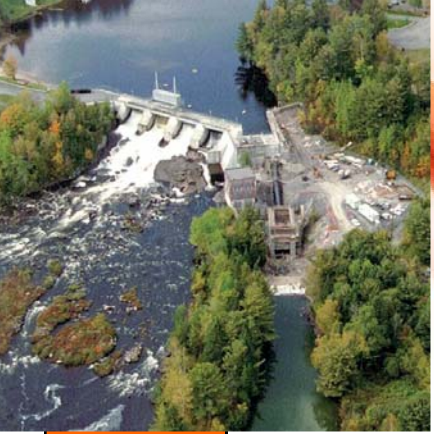
The key parameters of the SHPP project are summarised below:

Project name:
Fojnica

Owner/developer:
B&H

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

Date commissioned:
December 2007



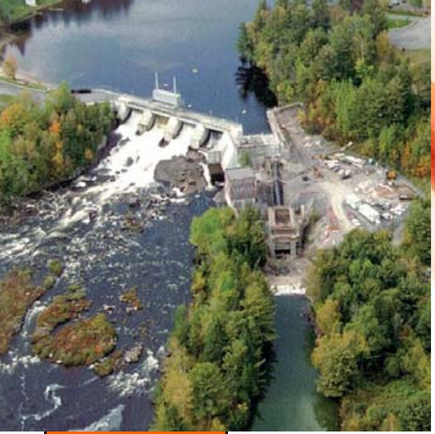
The key parameters of the SHPP project are summarised below:

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 flow:

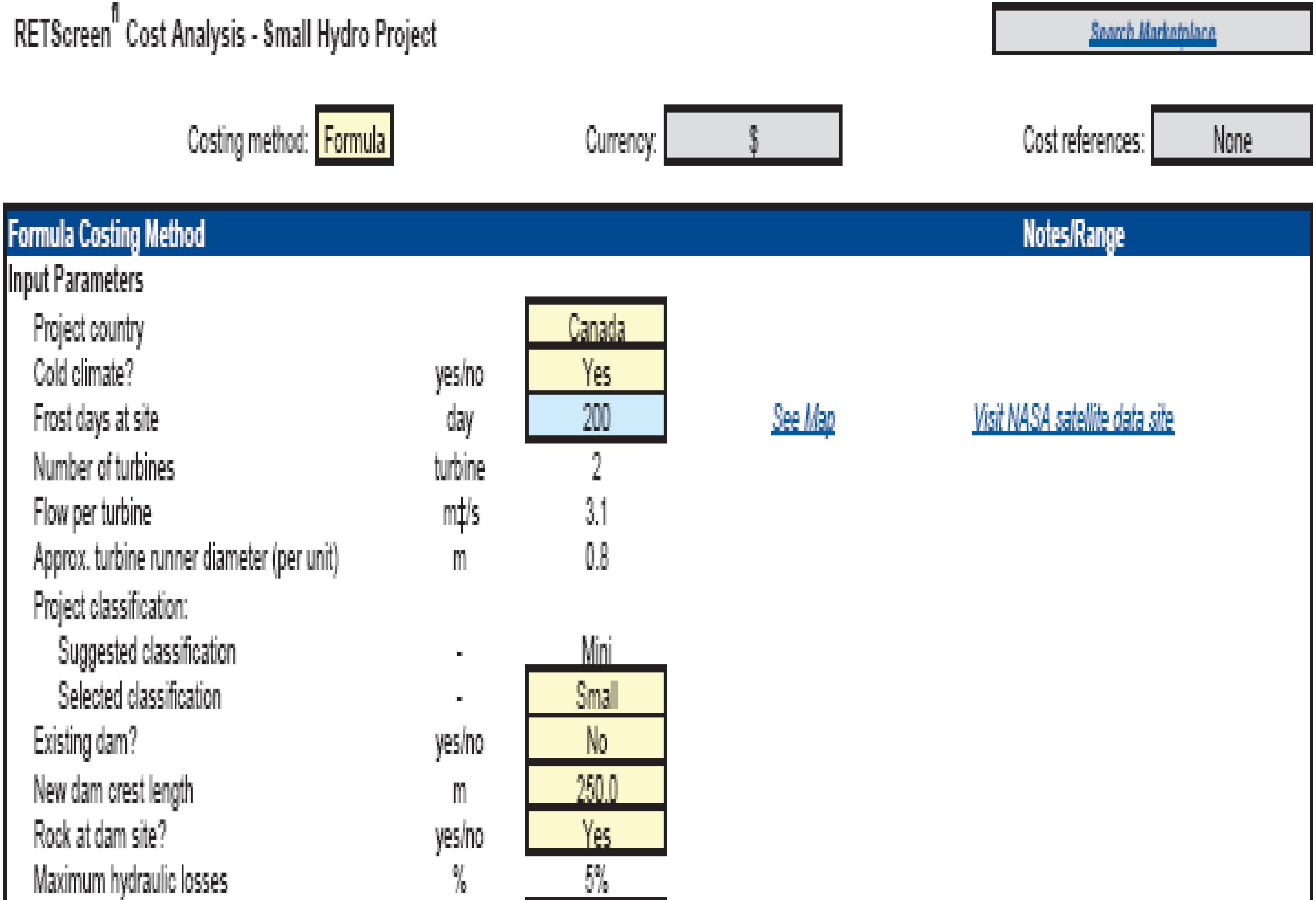
6.1 m3/s

Turbine/generator:

win Francis turbines connected to a single generator.

Other project features:

Required Input parameters



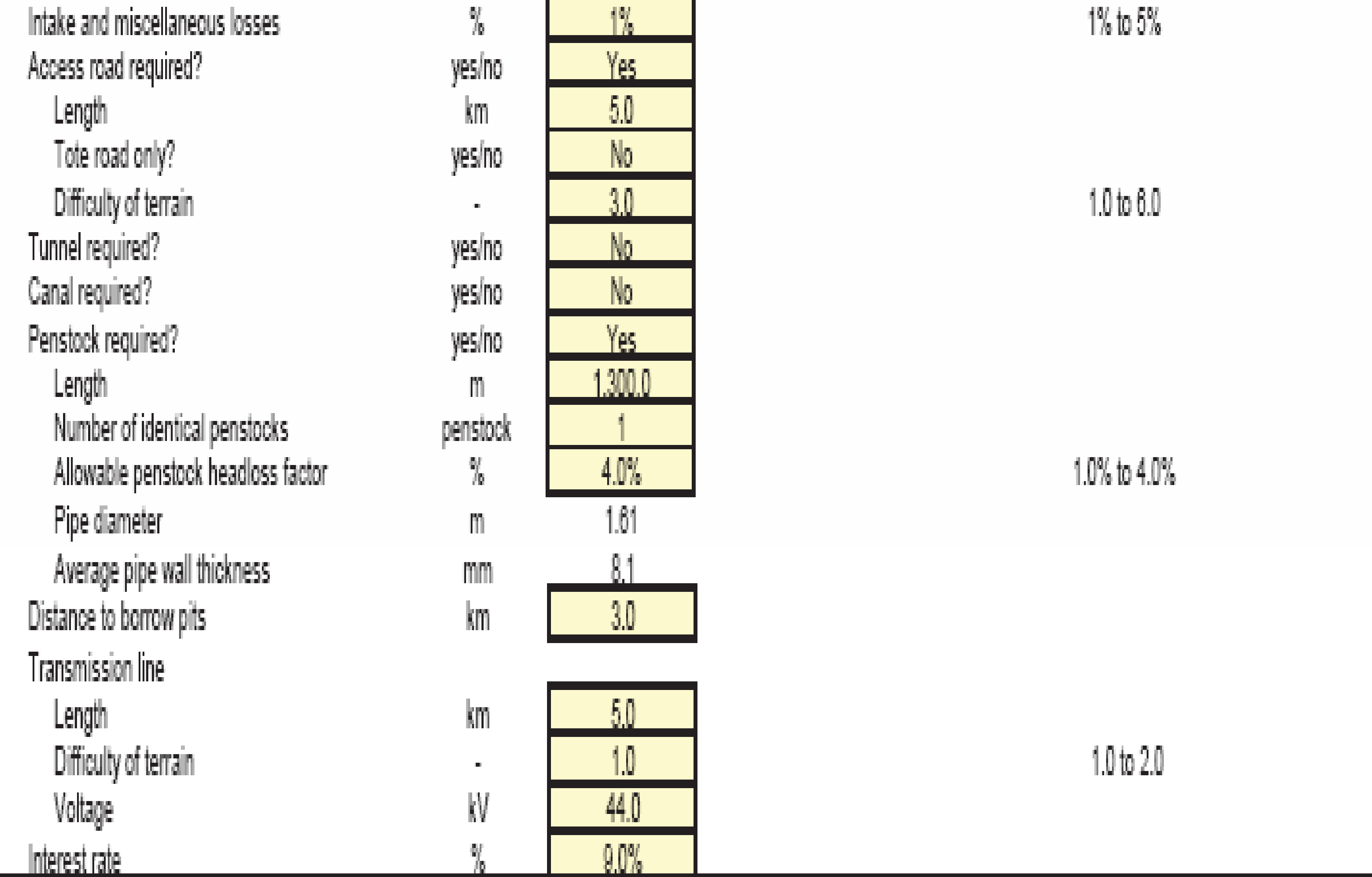
RETScreen^{fl} Cost Analysis - Small Hydro Project

Costing method: Formula

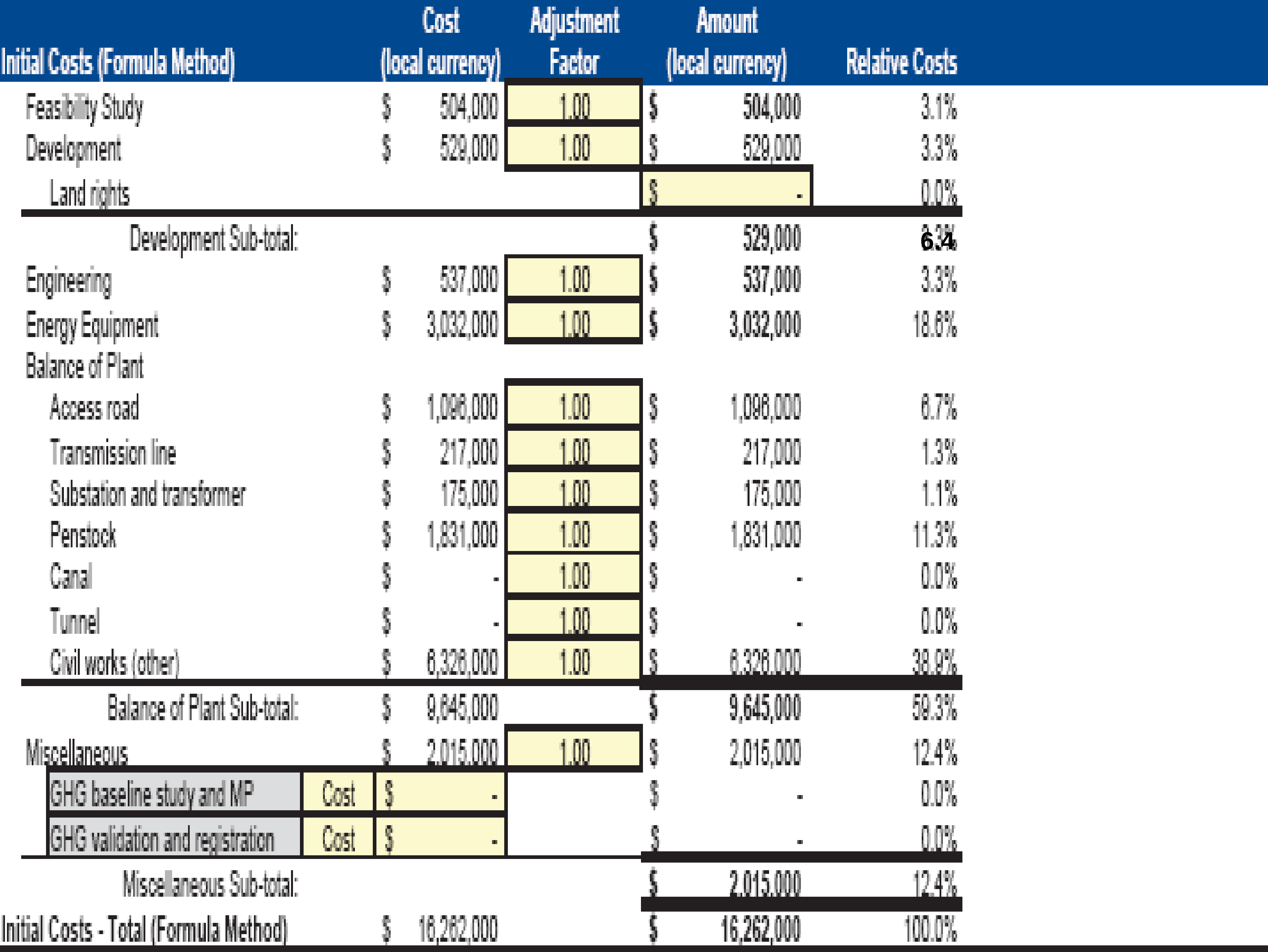
Currency: $

Cost references: None

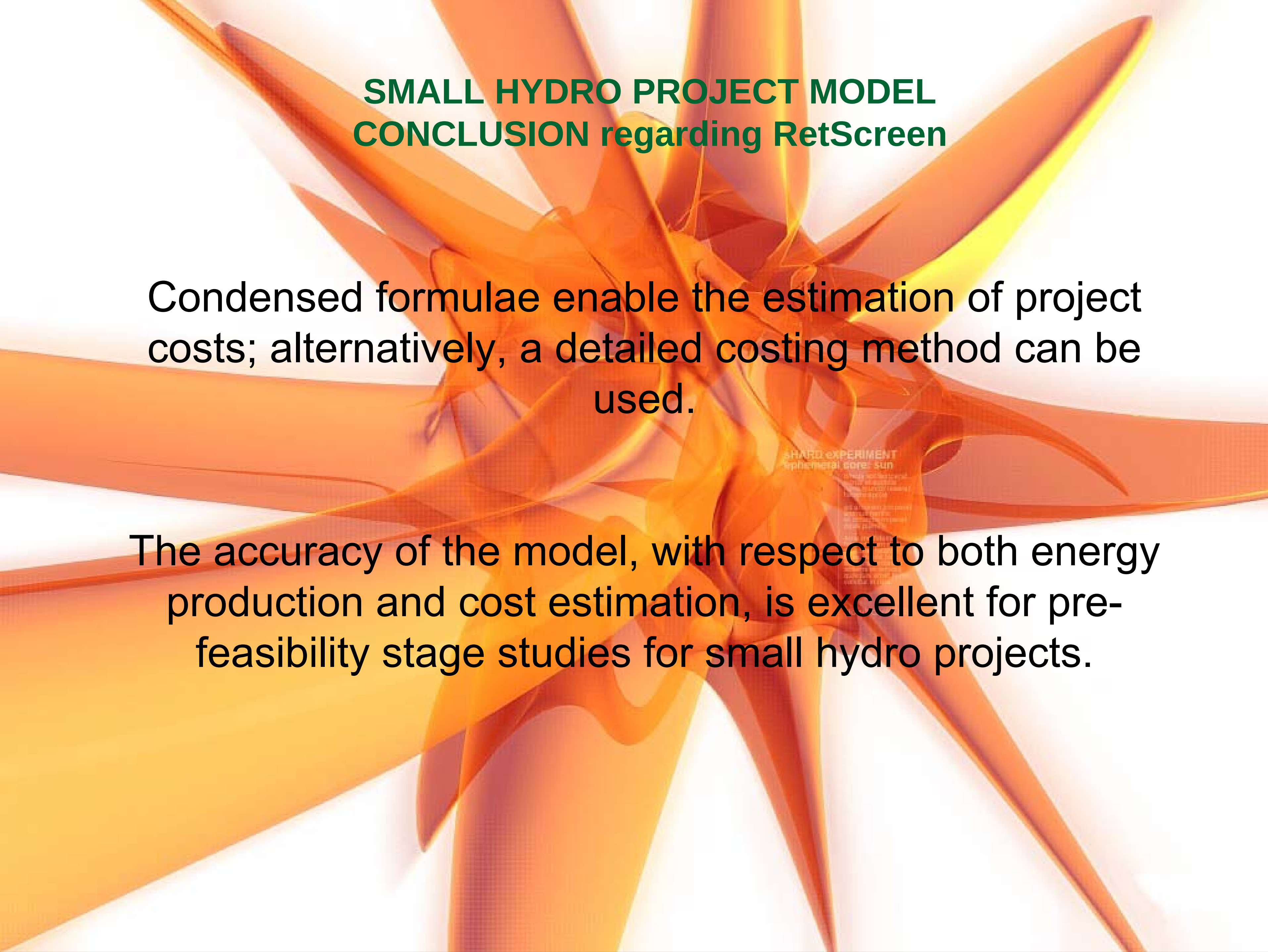
Formula Costing Method				Notes/Range
Input Parameters				
Project country		Canada		
Cold climate?	yes/no	Yes		
Frost days at site	day	200	See Map	Visit NASA satellite data site
Number of turbines	turbine	2		
Flow per turbine	m‡/s	3.1		
Approx. turbine runner diameter (per unit)	m	0.8		
Project classification:				
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%	



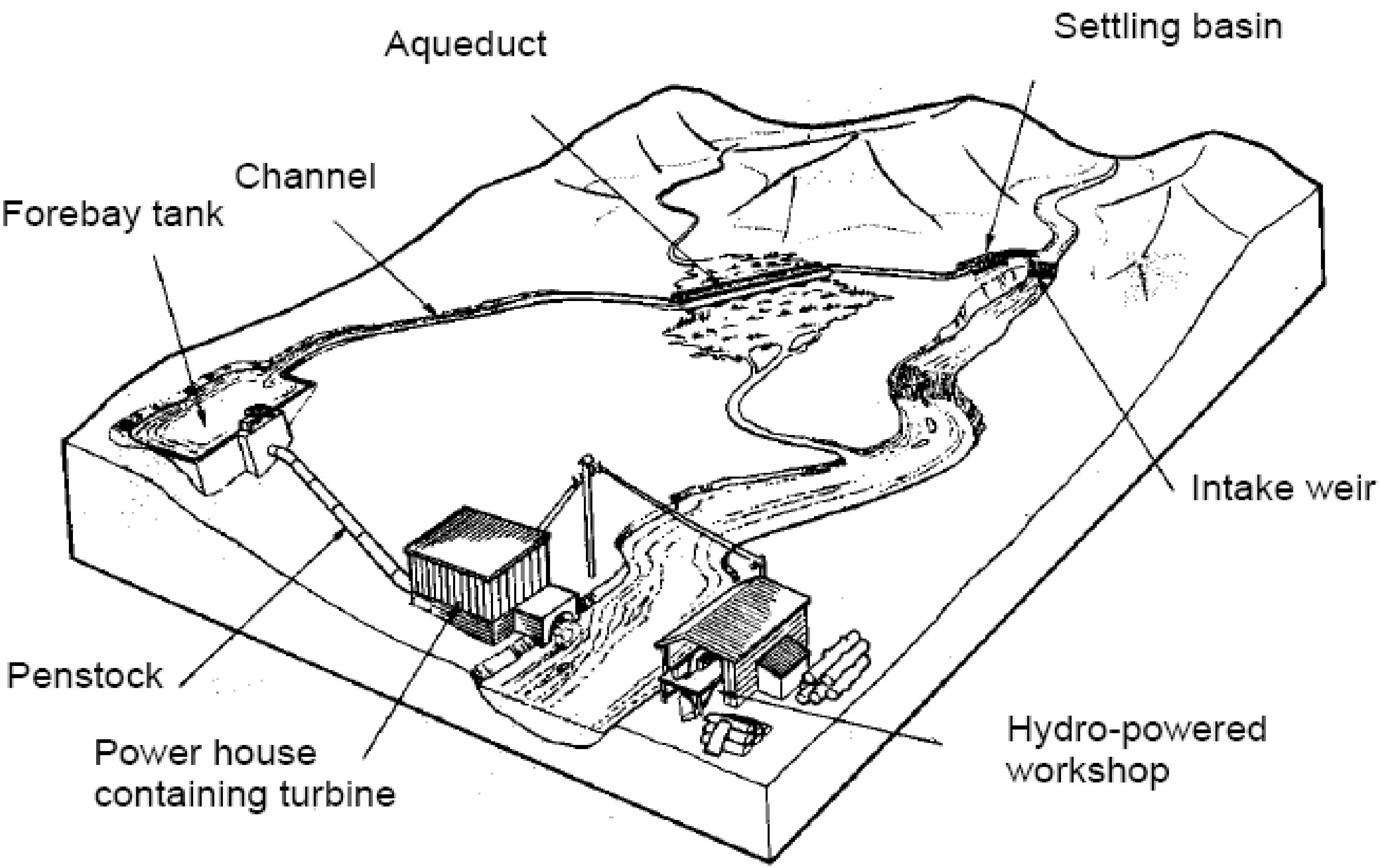
Initial Costs (Formula Method)	Cost (local currency)	Adjustment Factor	Amount (local currency)	Relative Costs
Feasibility Study	$ 504,000	1.00	$ 504,000	3.1%
Development	$ 529,000	1.00	$ 529,000	3.3%
Land rights			$ -	0.0%
Development Sub-total:			$ 529,000	3.3% **6.4**
Engineering	$ 537,000	1.00	$ 537,000	3.3%
Energy Equipment	$ 3,032,000	1.00	$ 3,032,000	18.6%
Balance of Plant				
Access road	$ 1,098,000	1.00	$ 1,098,000	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%



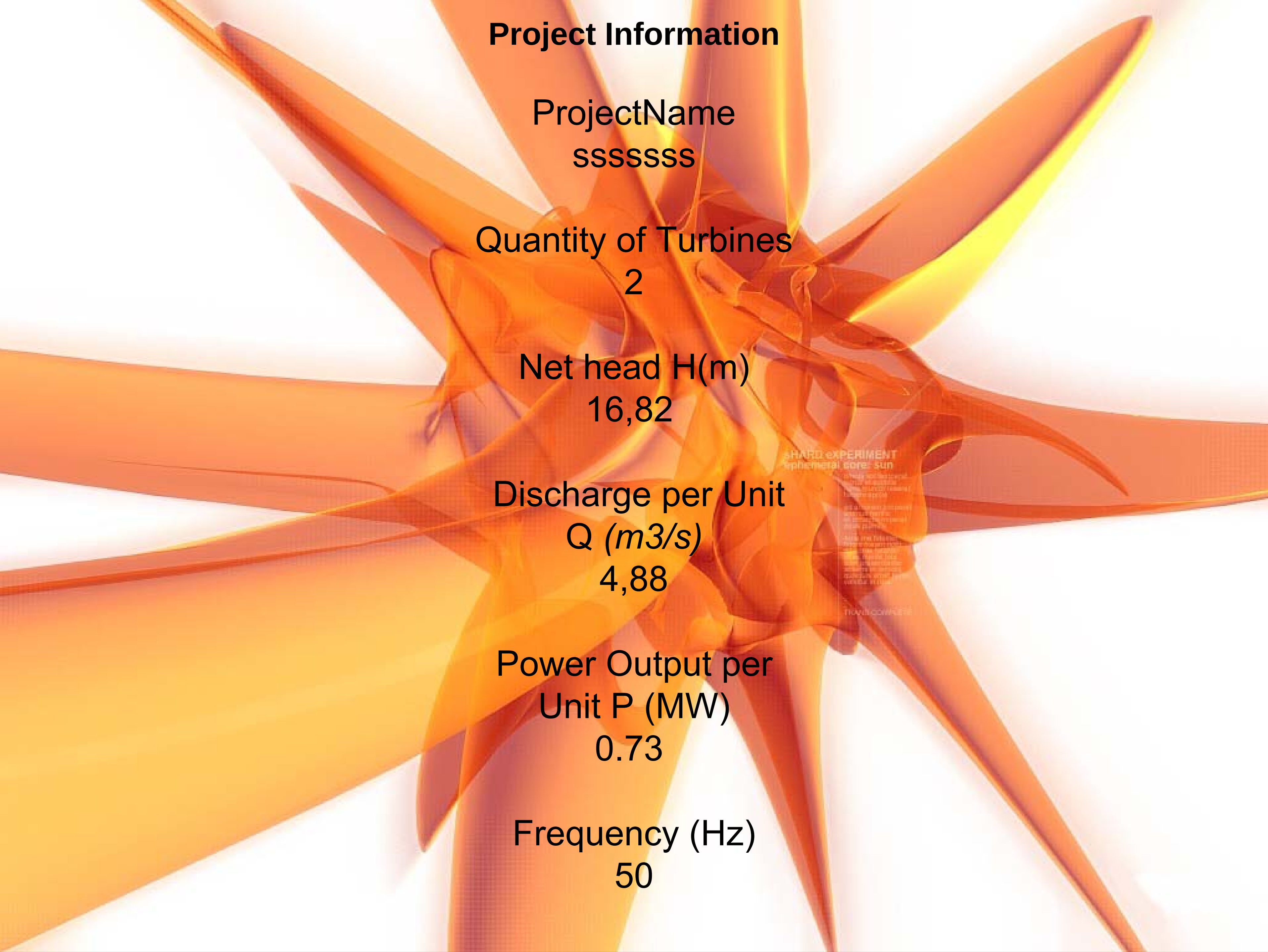
SMALL HYDRO PROJECT MODEL CONCLUSION regarding RetScreen

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

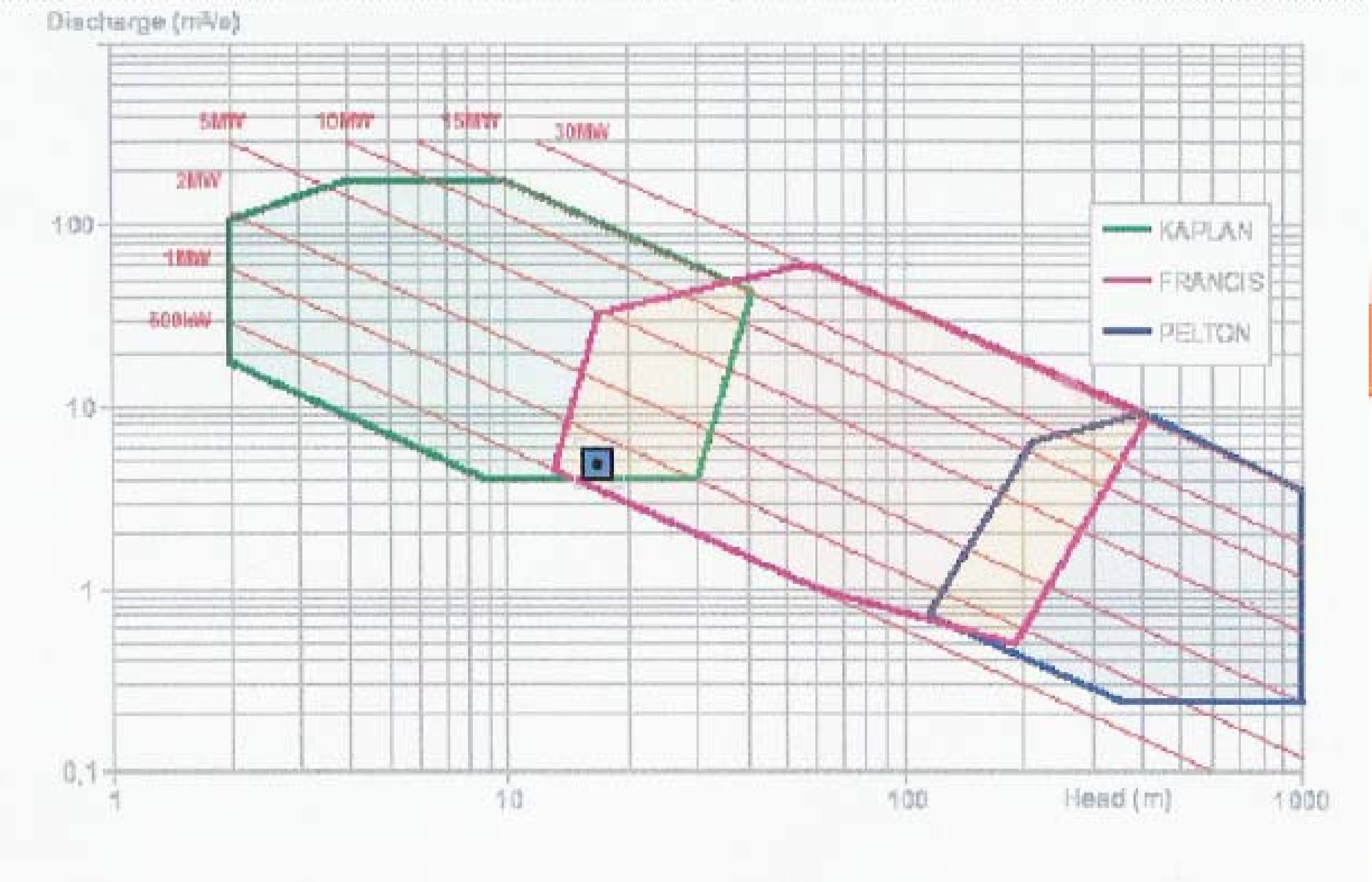
Net head H(m)
16,82

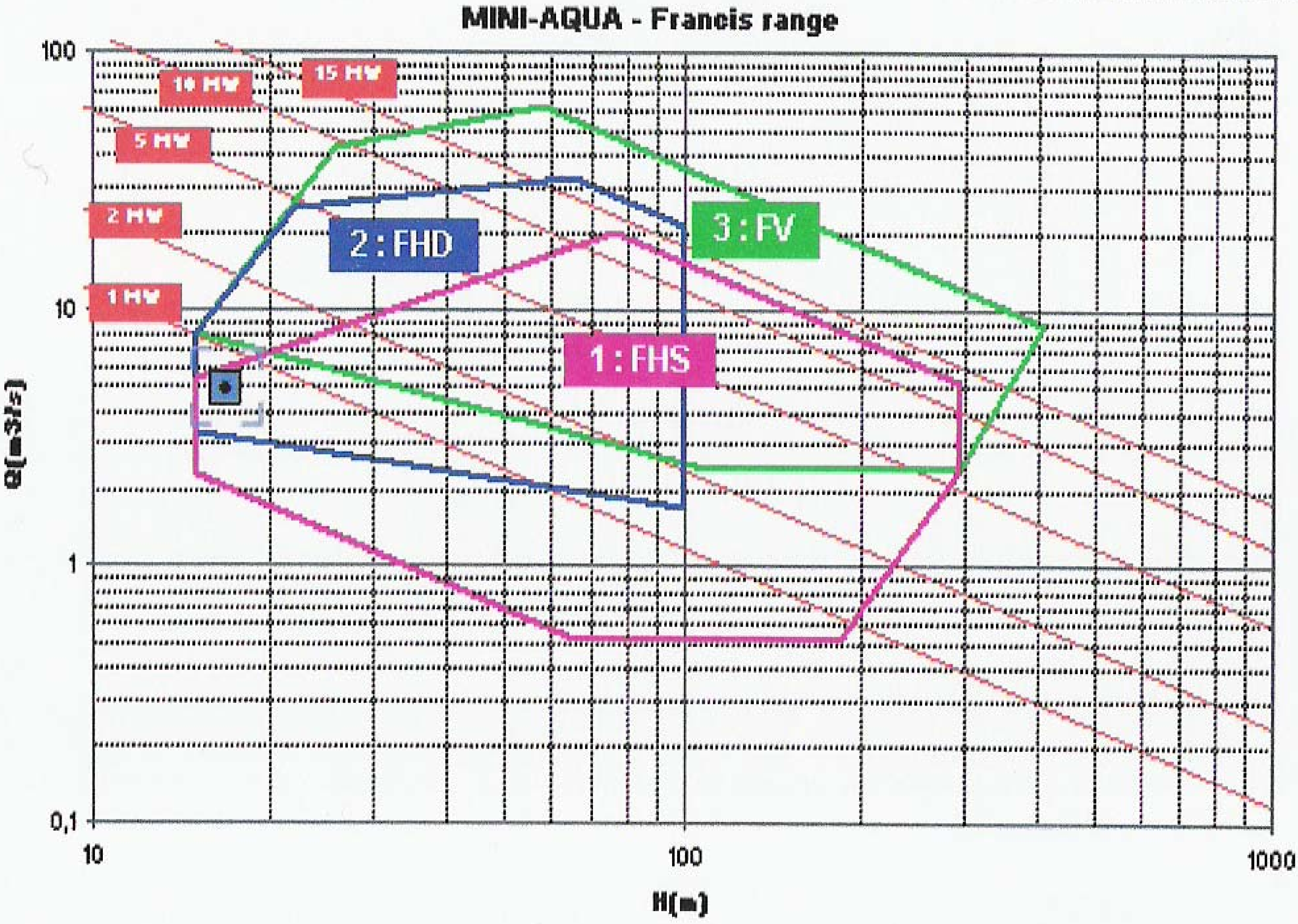
Discharge per Unit
Q *(m3/s)*
4,88

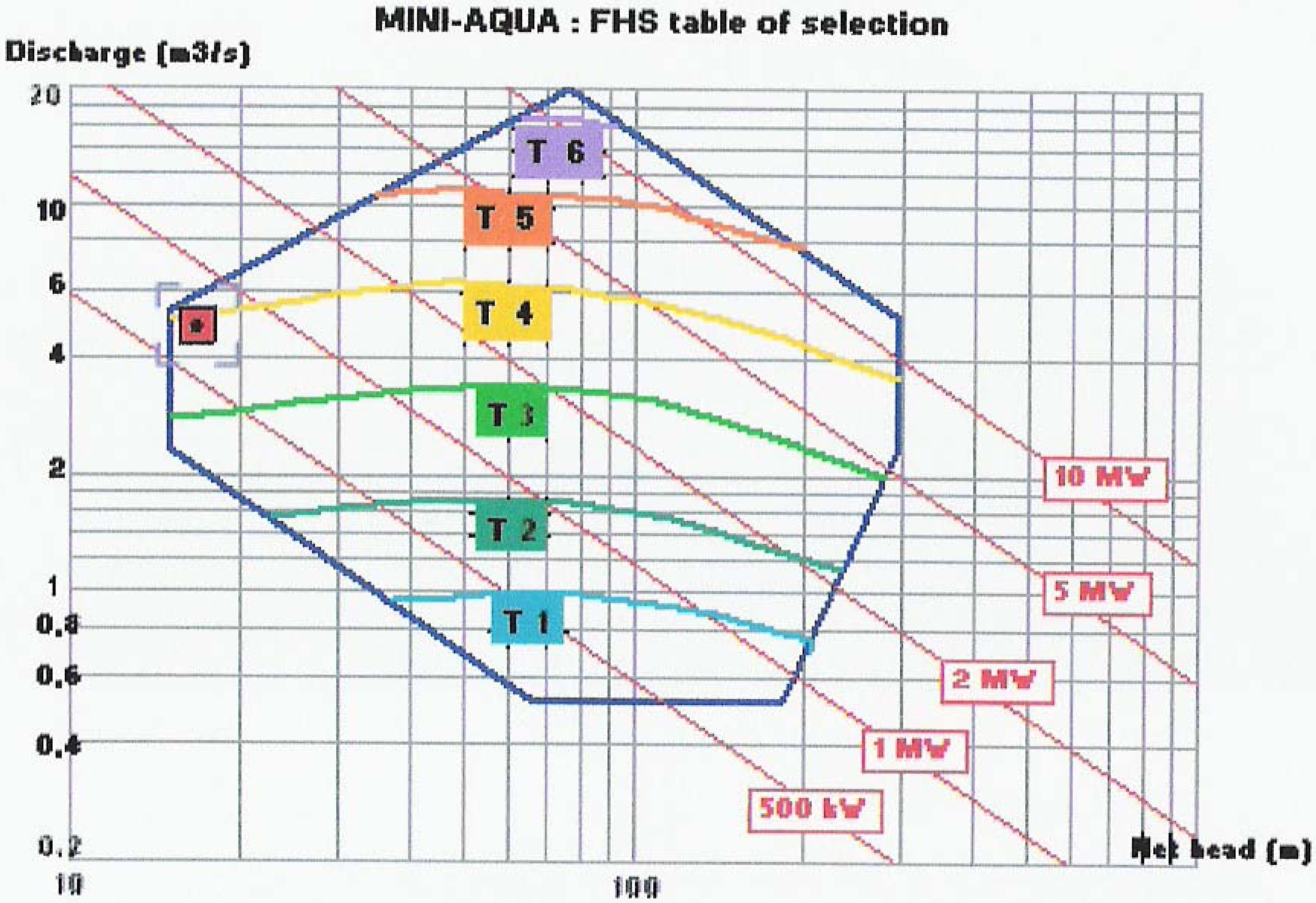
Power Output per
Unit P (MW)
0.73

Frequency (Hz)
50

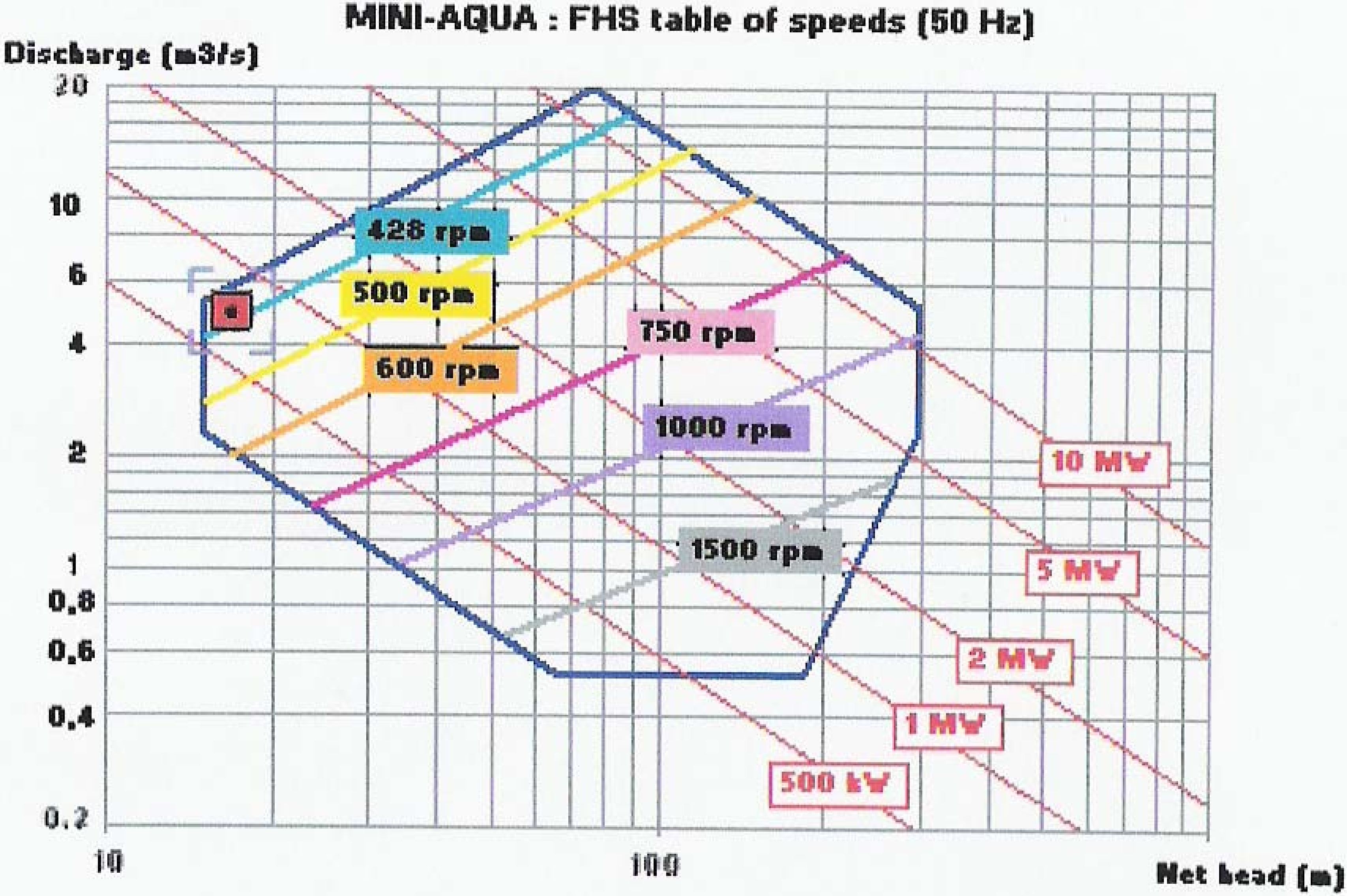
ProjectDefinition- MiniAqua Configurator



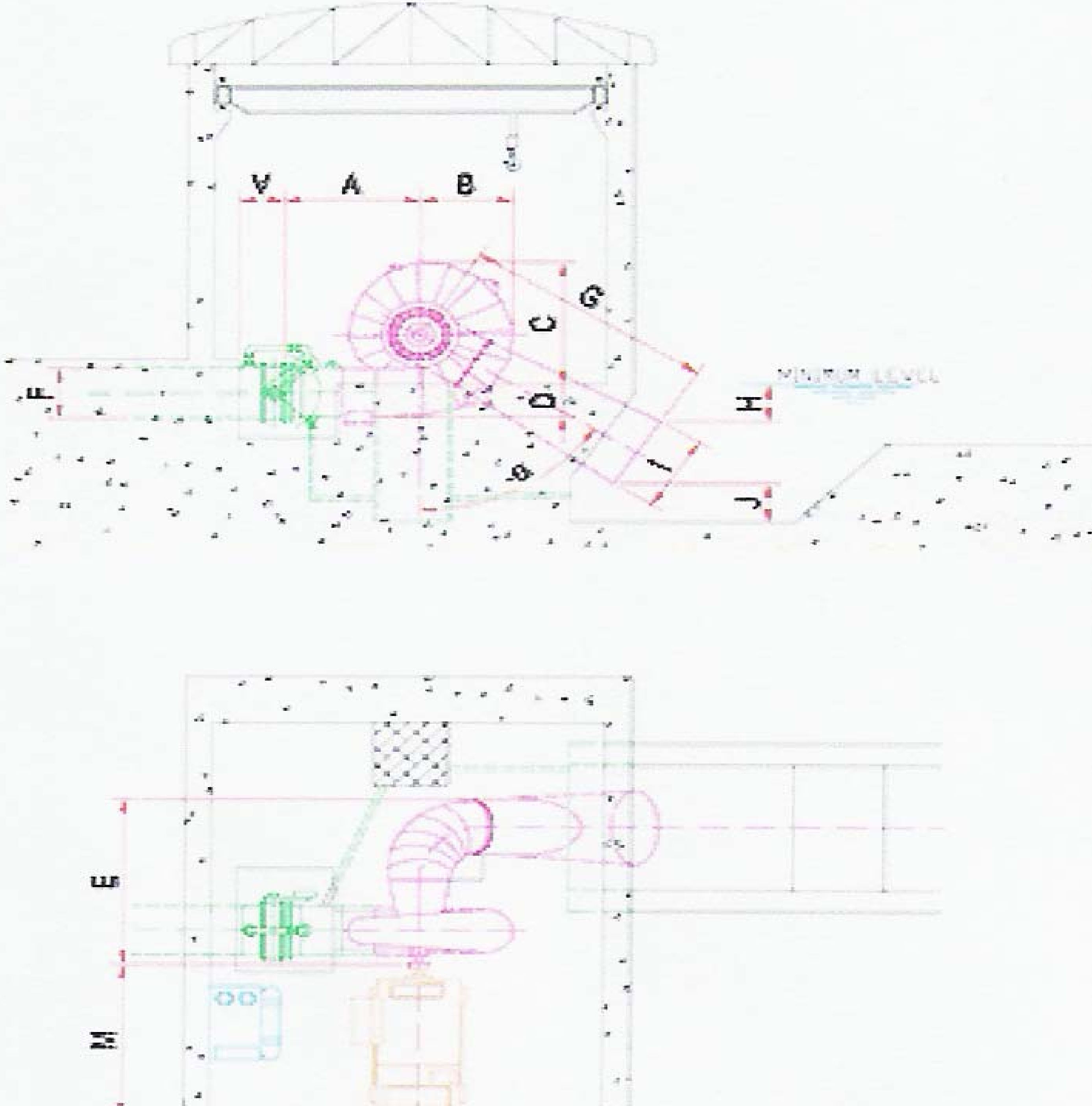

MINI-AQUA - Francis range
10 MW
15 MW
5 MW
2 MW
1 MW
2 : FHD
3 : FV
1 : FHS
Q(m3/s)
100
10
1
0,1
10
100
1000
H(m)

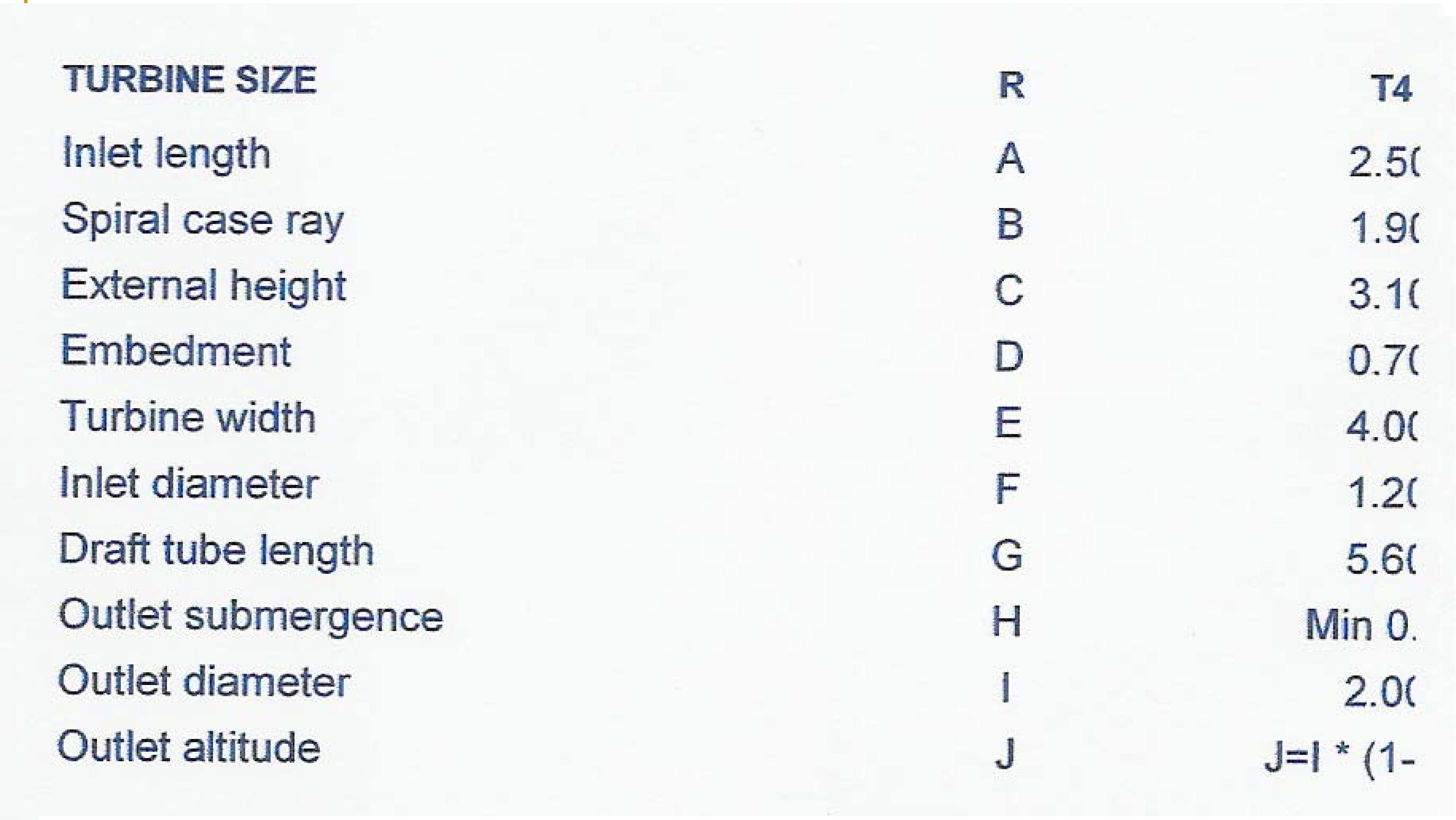

MINI-AQUA : FHS table of selection
Discharge (m3/s)
20
10
6
4
2
1
0,8
0,6
0,4
0,2
T 6
T 5
T 4
T 3
T 2
T 1
10 MW
5 MW
2 MW
1 MW
500 kW
Net head (m)
10
100

DIAMETER = T4



SPEED = 428 rpm


V
A
B
G
C
D
F
H
MINIMUM LEVEL
ø
I
J
E
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**