MSc Program

Renewable Energy in Central and Eastern Europe

Osmotic Power -

A Promising Renewable Energy Source for Croatia?

An Analysis of the Potential for Pressure Retarded Osmosis in Croatia

A Master's Thesis Submitted for the Degree of

"Master of Science"

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Vienna, September 2010

Affidavit

I, **Werner Klein**, hereby declare

1. that I am the sole author of the present Master Thesis, "Osmotic Power – A Promising Renewable Energy Source for Croatia?",
   120 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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I Abstract

Osmotic Power is a completely renewable and emission-free energy source, and *Pressure Retarded Osmosis* (PRO) is one of the possible conversion technologies. The development to the current state of PRO has been led by Norway's Statkraft S.A. and a demonstration plant was opened in Tofte, Norway in November 2009.

The goal of this study is to examine the PRO technology in order to:

- Understand and describe the principles, processes components and preconditions,
- Determine the theoretical, technical and realisable potential and analyse the supporting and limiting factors for a PRO implementation in Croatia,
- Analyse and estimate the economic parameters for a business case scenario and possibly apply these to a potential site for a PRO pilot power plant.

With information available from public sources (internet, scientific articles), and after direct communication with Statkraft and other experts from relevant industries, probable investment and production costs are calculated for various scenarios. Finally, a promising site for a PRO pilot plant implementation in Croatia is selected, based on favourable environmental and infrastructure conditions. Based on a site visit, some ROI calculation parameters are adapted and the specific investment case analysed. The calculations' results are put in relation to suggested feed-in tariffs that would support the PRO dissemination within the Croatian subsidy framework for renewable energy.

The calculated costs of energy (LCoE) for PRO are found in the range between the costs of wind and photo voltaic, although key technology components like membranes are still in an early stage of development. In order to reach the expectations stated by Statkraft, these calculated costs will have to half until 2020. The main future challenge will be to increase the specific power of membranes and to decrease their specific costs. Enormous production capacities for membranes will be required to build PRO power plants with capacities relevant for utilities. The necessary growth of the production capacity can in fact create the steep learning curve that is required for the predicted cost decrease.

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atm	Atmosphere (pressure)
BAU	Business as Usual
BiH	Bosnia & Herzegovina
d	Day
EIA	Environmental Impact Assessment
FIT	Feed-in Tariff
FLH	Full Load Hours
FO	Forward Osmosis
K	Kelvin
kPa	Kilo Pascal
KPI	Key Performance Indicator
L	Litre
LCoE	Levelized Cost of Electricity
M	Molality (solution concentration in mol/Litre)
OG	Official Gazette
Pa	Pascal (pressure)
Π (Pi)	Osmotic Pressure
ppm	Parts Per Million
PRO	Pressure Retarded Osmosis
P&L	Profit & Loss
PV	Photo Voltaics
Q_{avg}	Average Flow (Discharge) [m^3/s]
Q_i	Installed Flow Capacity [m^3/s]
RED	Reverse Electro-Dialysis
RES	Renewable Energy Source
RES-E	Renewable Energy Source for Electricity
RO	Reverse Osmosis
ROI	Return of Investment
R&D	Research and Development
SWRO	Sea Water Reverse Osmosis
WACC	Weighted Average Cost of Capital

1. Introduction

1.1 Power Water – Water Power

"With the oceans covering over 70% of the earth's surface, they are the world's largest collector and retainer of the sun's vast energy – and the largest powerhouse in the world."[1]

Ultimately, most energy sources can be attributed to the sun's practically endless solar radiation reaching out to our planet: biomass that grows via photo synthesis, wind that balances air temperature, moisture and pressure differences, sunshine that heats solar thermal panels or directly converts to electricity in photo voltaic installations.

Simply said, with the heat of the sun the earth's water reservoirs release vapour, which condenses to clouds that distribute the rain and fill the rivers. Utilizing this principle, water has been the prevalent renewable energy source (RES) since 1895, when Nicola Tesla built Europe's first hydroelectric power station at the Croatian river Krka. For more than a century it has been the water's potential energy that was exploited in numerous hydro-power plants. The enormous power inherent in the natural, solar driven water cycle led to an annual energy production of ~340 TWh in Europe and 3,310 TWh worldwide[2].

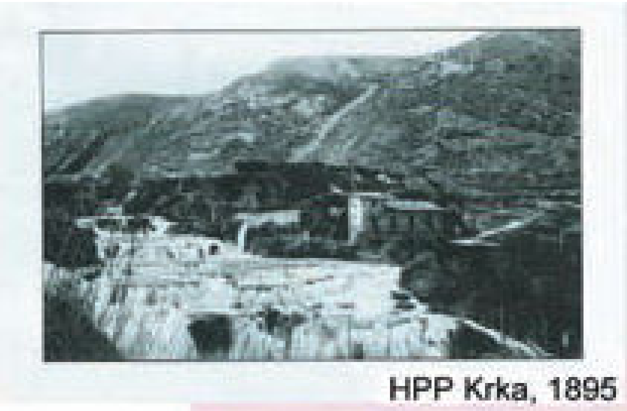

Figure 1: Hydropower plant Krka, 1895[3]

But energy inherent in water can also present itself in other forms than the potential kinetic energy. Various discoveries and inventions from the early 20th century have become topics of scientific research after the energy crisis in the1970s. Especially ocean power has emerged as a wide area of research, covering several RES-E niche technologies. Until today, many publications from the 1970s are cited when it comes to an estimation of the power potential of these technologies. E.g., data from a study by Wick and Schmitt published in 1977, showing the power density of various ocean phenomena, is still widely referenced in presentations and studies.

[1] Ocean Energy Council
[2] Eurostat (2007), p. 10
[3] Car (2006), p. 117

For example, an article from 2003 about “Recent Developments in Salinity Gradient Power” is referencing the same data source. With that, like many other studies, it picks up and underlines an early but strong conclusion: the power of salinity gradients is the biggest source of ocean energy.

Table 1: Estimations of ocean power [TW] and ocean energy density [meters of equivalent water head][4]

Resource	Power (TW)	Energy Density (m)
Ocean Currents	0.05	0.05
Ocean Waves	2.7	1.5
Tides	0.03	10
Thermal Gradient	2.0	210
Salinity Gradient	**2.6**	**240**

Source: Wick and Schmitt 1977, MTS Journal

For many reasons this power, which was first promoted in 1954 by R.E. Pattel[5], was completely untapped in an economic sense until recently. But the scientific community has continuously elaborated on procedures to exploit the salinity power.

1.2 The Salinity Power Project

From 2001 to 2004, an EU funded project (contract no ENK6-CT-2001-00504) was launched and performed under the co-ordination of Statkraft to evaluate the possibilities of commercial “Power production from the osmotic pressure difference between fresh water and sea water. ….The aim of the project was to evaluate the feasibility of commercial power production from the entropy change of mixing of fresh water and sea water. This was done through development and optimization of membranes and membrane modules, suitable for pressure retarded osmosis. The project made great progress in developing membranes especially designed for pressure retarded osmosis…. The partners in the Salinity Power project were Statkraft (Norway), SINTEF (Norway), Forchungszentrum GKSS (Germany), Helsinki University of Technology (Finland) and ICTPOL Instituto de Ciência e Tecnologia de Polímeros (Portugal).[6]”

4 Jones and Finley (2003), p. 2284
5 Pattel (1954), p. 660
6 EU Project brochure (2004), p. 1

1.3 The World's First Osmotic Power Prototype

On November 24, 2009, Norway's energy heavyweight Statkraft opened the world's first osmotic prototype plant[7]. The official opening was conducted by Her Royal Highness Crown Princess Mette-Marit of Norway and was embedded in a well-organized PR event that made the development known to the wider renewable energy community.

The plant's opening marked an important milestone in the development of the technology, as it will allow testing and proving the scaling up of the technology and the processes and the optimizing of the procedures and integration into the environment.

Figure 2: Statkraft demonstration plant in Tofte-Norway

Statkraft has published the main steps of research and development as well as the future outlook on its web site[8], together with a good overview of the technology:

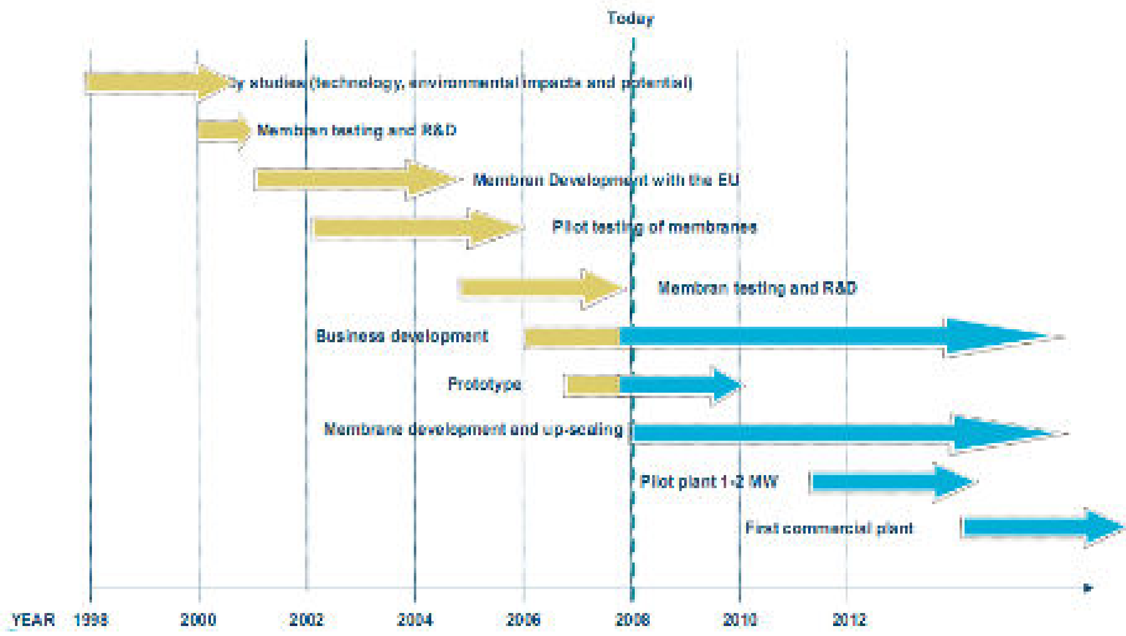

Figure 3: History and future of osmotic power[9]

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[7] Statkraft Press
[8] Statkraft Osmotic
[9] Skilhagen (2009)

2. Objectives

With further development of the technology components based on and deployed in the prototype plant, osmotic power is expected to reach technical and economical marketability, justifying projects development at sites with good potential. As soon as osmotic power becomes commercially deployable, the industry focus will shift from fundamental R&D to project development and will require research on the available potential per country and a pre-selection of priority sites. At the same time, public awareness about the technology must be raised in those countries with the biggest potential for fast exploitation.

Accordingly, this study

- Supplies sufficient background information on the technology parameters and Croatia specific implementation surrounds for stakeholders,
- Determines the theoretical, technical and realisable potential for the PRO technology in Croatia,
- Estimates the economic and environmental conditions for a realistic business case, or
- Alternatively, substantiates the argument if there is no potential to pursue the PRO technology.

The reasons for selecting Croatia as target country to investigate the PRO potential are as follows:

- Obvious geographic situation (rivers flowing into ocean with good salinity grade),
- Relevance to the Master's Program "Renewable Energy in Central & Eastern Europe",
- Defined targets and policies for RES-E applications available,
- Market realities supporting RES-E development.

3. The Osmotic Power Technology

3.1 Chemical Potential Energy

Potential energy is energy stored within a physical system as a result of the position or configuration of the different parts of that system[10]. It has the potential to be converted into other forms of energy, such as kinetic energy, and to provide power in the process.

Chemical potential energy is one form of potential energy and is related to the structural arrangement of atoms or molecules, and their bonds. A chemical bond can be thought of as an attracting force between atoms, because of which atoms and molecules contain chemical potential energy. Any time two atoms enter a strong bond or two molecules enter a weak bond, chemical energy is converted into other forms of energy, usually in the form of heat and light. (Therefore, strong bonds have low chemical energy and weak bonds have high chemical energy.)

Chemical reactions, attracted by possible stronger bonds, convert chemical potential energy into heat (and light) energy, as shown below for 2 hydrogen atoms forming a strong bond.

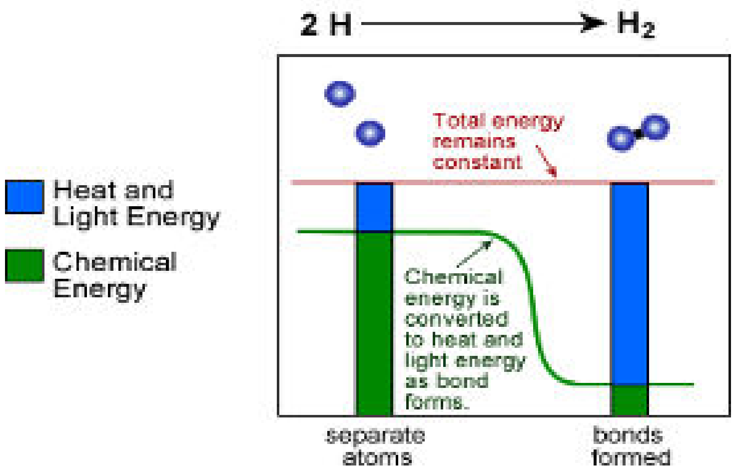

Figure 4: conversion of chemical potential energy into heat and light[11]

Another example of such a chemical reaction, driven by the formation of stronger chemical bonds and setting free energy, is the dissolving of salt (the solute) in water (the solvent) forming a solution. This reaction always happens when fresh water mixes with sea water.

[10] Potential Energy
[11] Damelin (2007)

The reverse is true for breaking chemical bonds: the breaking of a bond requires the absorption of heat and/or light energy which is converted into chemical energy when the bond is broken.[12]

Again, a typical example for such a reverse dissolving is solar radiation, supplying heat to evaporate water from the oceans' solution, resulting in the storage of solar energy transformed into chemical energy in the form of a higher concentration of the solute (salt) in the solution (ocean).

3.2 Osmotic Pressure

3.2.1 Definition

Osmotic pressure occurs when two solutions of different concentrations, or a pure solvent and a solution, are separated by a semi-permeable membrane. Molecules such as solvent molecules that can pass through the membrane will migrate from the side of lower concentration (high water potential) to the side of higher concentration (low water potential) in a process known as osmosis. The physical pressure required to stop osmosis is called the osmotic pressure[13].
Jacub Van't Hoff won the first Nobel Prize for chemistry (1901) for the introduction of an accurate calculation of osmotic pressure. In his definition, osmotic pressure is: "when a solution, e.g., of sugar in water, is separated from the pure solvent - in this case water - by a membrane which allows water but not sugar to pass through it, then water forces its way through the membrane into the solution. This process naturally results in greater pressure on that side of the membrane to which the water is penetrating, i.e., to the solution side. This pressure is osmotic pressure."[14]

3.2.2 Calculation of Osmotic Pressure[15]

In dilute solutions, osmotic pressure (Π … large Pi)) is directly proportional to the molality [mol/litre] of the solution and its temperature in Kelvin. Osmotic pressure is expressed by the Van't Hoff equation:

$\Pi = M * R * T$

Π = osmotic pressure in kPa or atm

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[12] Damelin (2007)
[13] Botany
[14] Van't Hoff (1901), p. 1
[15] Osmotic Pressure

M = molality = concentration of a solution in mol/Liter

T = temperature [K]

R = ideal gas constant [J / (K/mol)]

R = gas constant (dependent on the units of pressure, temperature and volume)

$R = 8.314\ J\ K^{-1}\ mol^{-1}$ if pressure is in kilopascals (1 kPa = 0,01 bar)

$R = 0.0821\ L\ atm\ K^{-1}\ mol^{-1}$ if pressure is in atmospheres (1 atm = 1,0133 bar)

3.2.3 Occurrence and Application of the Osmotic Effect

Natural

Many natural processes that are essential for fauna and flora are based on the osmotic effect. For instance, plants depend on osmosis to transport water from their roots to their leaves: the further toward the edge or the top of the plant, the greater the solute concentration, which creates a difference in osmotic pressure.

In our bodies, the process of osmosis plays an important role in the movement of fluid, e.g., to transport water back from the kidneys, or transmit oxygen into our cells[16].

Technical

The main technical exploitation of osmotic pressure is by stopping the dissolving or exchange of two solutions (e.g., pure water and salt water) due to separation by a special filter, i.e., a semi-permeable membrane.

A semi-permeable membrane is an organic filter with extremely small holes. Nano-filtration membranes with hole diameters of only a few micro meters are necessary to allow small molecules, such as water molecules, to pass through on one direction and prevent larger molecules such as salt or pollutants from passing in the opposite direction.

3.2.4 Osmotic Processes through Membranes

Osmosis is the flux of water through semi permeable membrane from a solution with higher chemical potential of water (solvent, lower osmotic pressure) to a solution of lower water chemical potential (solution, higher osmotic pressure). The osmotic pressure differential ($\Delta\Pi$) is the pressure which would need to be applied as a hydraulic pressure (ΔP) to the more concentrated solution, in order to prevent transport of water across the membrane.

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[16] Osmosis

Forward Osmosis (FO) uses the pressure differential across the membrane as the driver for transport of water through the membrane. The FO process results in concentration of a feed stream and dilution of a highly concentrated stream, referred to as the *draw solution* (DS).

In *Reverse Osmosis* (RO), water flux is in the opposite direction of FO, and here an external hydraulic pressure $\Delta P > \Delta \Pi$ is applied to revert the flux of the water through the membrane.

Pressure Retarded Osmosis (PRO) can be viewed as an intermediate process between FO and RO: hydraulic pressure is applied to the draw solution (similar to RO) but the net water flux is still in the direction of the concentrated draw solution (similar to FO).[17]

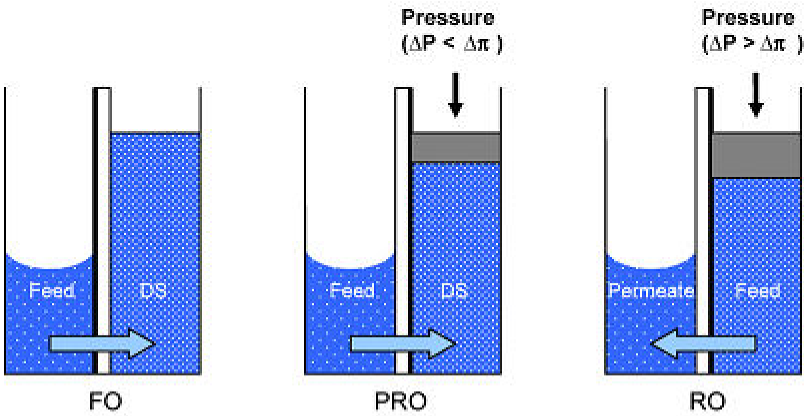

Figure 5: Schema of Forward Osmosis (FO), Reverse Osmosis (RO) and Pressure Retarded Osmosis (PRO)[18]

3.2.5 Reverse Osmosis and Desalination

Osmosis is a reversible thermodynamic process and, as shown above, the direction of water flow through the membrane can be reversed at any moment by control of the external pressure on the solution. To produce drinking water from sea water, by reverse osmosis, the pressure p of the salty water must be higher than the osmotic pressure, so that clean water will cross the semi-permeable membrane and accumulate on the other side. As a result, reverse osmosis is an energy intensive process[19].

Currently, the main application of reverse osmosis (RO) is the purification from low scale drinking water to desalination of sea water in large scale plants. The growing demand for fresh water in many areas of the world has spurred interest in the

[17] Childress et.al. (2009) p. 43
[18] Childress et.al. (2009) p. 44
[19] Lachish (1998)

process of desalting sea water or brackish water (less salty than sea water, but not fresh). According to the American Membrane Technology Association (AMTA), the worldwide desalination capacity is over 11 billion gallons (~4 10^9 litres) per day from over 12.000 plants (membrane and thermal)[20].

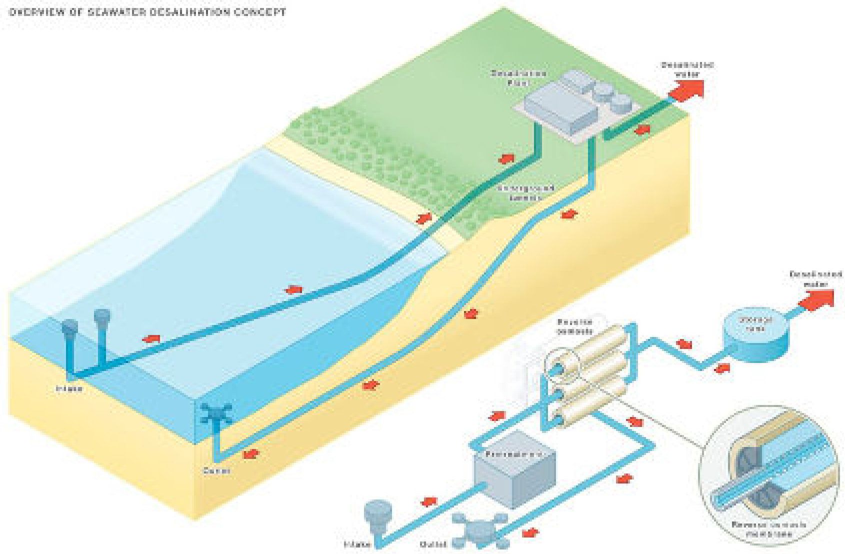

Figure 6: Desalination with Reverse Osmosis – plant schema[21]

In the last decade, membrane based desalting technology utilizing the reverse osmosis (RO) technology has improved about 50% from a price / performance ratio perspective. This is primarily due to the specific module costs, e.g., of membranes and pressure exchangers. Both are major components of a RO desalination plant as well as for power generation plants based on the PRO technology.

3.3 Concepts of Salinity Power Generation

3.3.1 Reverse Electro-Dialysis (RED)

This process utilizes direct electrochemical conversion in dialytic cells which use the potential between solutions of different salt concentrations. The solutions are separated by electrically charged membranes. In a RED system, a number of cation and anion exchange membranes are stacked in an alternating pattern between a cathode and an anode. The compartments between the membranes are alternately filled with a concentrated salt solution and a diluted salt solution. The salinity gradient results in an electric potential difference (e.g., 80mV for sea water and river

[20] AMTA (2006) p. 1
[21] Melbourne (2007)

water) of each membrane, the so-called membrane potential. The potential difference between the outer compartments of the membrane stack is the sum of the potential differences over each membrane. The chemical potential difference causes the transport of ions through the membranes from the concentrated solution to the diluted solution. This electrical current and the potential difference over the electrodes can be used to generate electrical power, when an external load or energy consumer is connected to the circuit.[22]

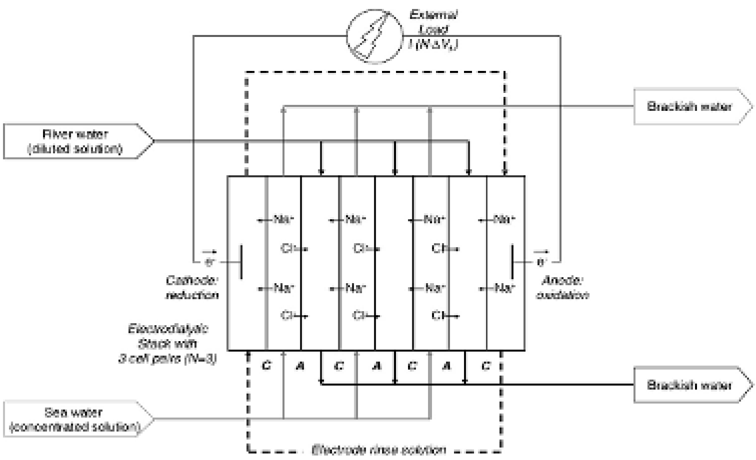

Figure 7: Schema of a reverse electro-dialysis process[23]

3.3.2 Pressure Retarded Osmosis (PRO)

In a pressure-retarded osmosis system, two solutions of different salinity grade are brought into contact by a semi-permeable membrane. This membrane allows the solvent (i.e., water) to permeate and retains the solute (i.e., dissolved salts) from crossing in the opposite direction. The chemical potential difference between the solutions causes transport of water from the diluted salt solution to the more concentrated salt solution. If hydrostatic pressure is applied to the concentrated solution, the water transport will be partly retarded. The transport of water from the low-pressure diluted solution to the high-pressure concentrated solution results in a pressurization of the volume of transported water. This pressurized volume of transported water can be used to generate electrical power in a turbine.[24]

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[22] Post et.al. (2007), p. 219
[23] Post et.al. (2007), p. 220
[24] Post et.al. (2007), p. 219

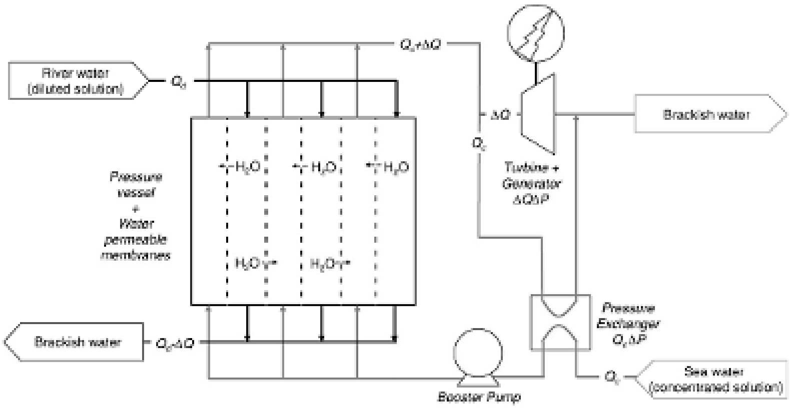

Figure 8: Schema of a pressure retarded osmosis process[25]

3.3.3 Comparison of Technologies (PRO, RED)

Both technologies, PRO and RED, are in early development stages. A study performed by a group of Dutch scientists (Post et.al.) published in 2007 evaluated the technologies in the light of their theoretical and experimental performance as found in literature and elaborated in models for both technologies. The prevalent performance indicators in relation to membrane performance are power density in $W/m^2_{membarne}$ and energy recovery in %. Their results indicate a clear advantage of RED in low concentrated solutions (e.g., sea water) and an advantage of PRO in highly concentrated, brine solutions (see Figure 9). Additional parameters for validation remained unanswered, such as cost/performance, bio-fouling of membranes, internal process losses, etc.

A subsequent study by Norwegian scientists Thorsen and Holt[26] in 2009 analyzes in detail the PRO membrane technology based on a new theoretical model and lab based experiments simulating the realistic operating conditions of a membrane module. The results from the analysis lead to conclusions that are more optimistic than the ones made by Post et al. (2007). In the new study, PRO appears to be significantly more efficient with respect to the specific power achievable.

The purpose of this chapter is to emphasize that there is constant research going on in order to force membrane development and to supply proof of this concept for field implementation.

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[25] Post et.al. (2007), p. 220
[26] Thorsen and Holt (2009)

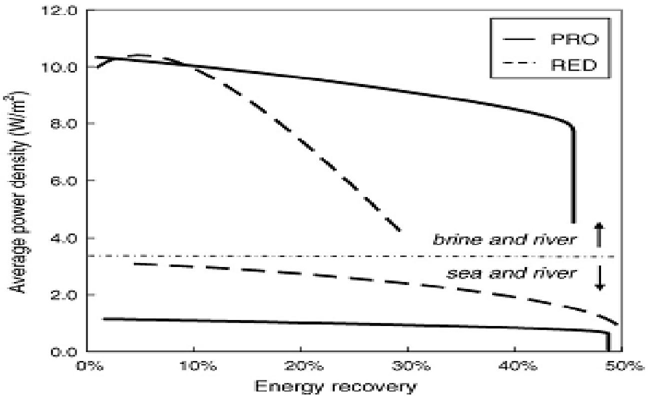

Figure 9: Average power density and energy recovery, calculated by Post et.al. (2007) for PRO and RED for mixing sea water with river water and for mixing brine with river water[27]

Figure 9, published in the cited study of Post et.al (2007), states a maximum membrane power density of ~1 W/m² for the PRO technology (with sea water conditions). In contrast to this, Figure 10 by Thorsten and Holt (2009) testifies a maximum specific membrane power of 5 W/m². Currently, this is perceived as the maximum specific power (W/m²) achievable in a PRO application.

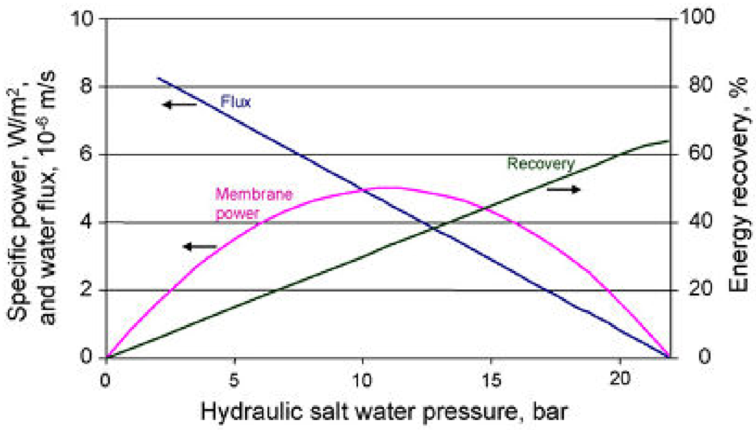

Figure 10: Membrane power, flux and energy recovery, calculated by Thorsen and Holt (2009) for PRO under specified conditions[28]

3.3.4 Non-Membrane Based Processes

For a complete overview, the following technologies for harvesting the salinity grade differences, which are mentioned in literature, are listed:

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[27] Post et.al. (2007), p. 228
[28] Thorsen and Holt (2009), p. 108

3.3.4.1 Vapour Pressure Differences

Another approach is to build a device that can use the difference in vapour pressure between fresh water and salt water. Fresh water is evaporated under a vacuum and condensed in sea water. The resulting vapour flow drives a turbine. There are many limitations to this system, but there are advantages as well, especially since no membranes are required in order to use the vapour pressure differences.[29]

3.3.4.2 Hydrocratic Generator

A Hydrocratic Generator captures the free energy of mixing between two bodies of water having different salinity concentrations. The technology does not require the use of any type of membrane. Experiments using a modified upwelling device, where fresh water was introduced into a vertical tube in the water, showed that the total hydraulic energy output of the system significantly exceeds the input from buoyancy (upwelling) and hydraulic head. The excess energy is attributable to the release of osmotic potential energy upon remixing of the fresh water and the salt water in the upwelling tube.[30]

[29] Jones and Finley (2003), p. 2285
[30] Jones and Finley (2003), p. 2286

4. Pressure Retarded Osmosis (PRO) Process for Power Generation

4.1 PRO Basics and Process

To better understand the preconditions and dependencies of a PRO power generation plant, the functionality and processes are described here in more detail.

4.1.1 Osmosis Power Potential

As described above, osmotic pressure occurs when the mixture of two solutions with different concentrations is partly intercepted by a semi-permeable membrane. In dilute solutions, the osmotic pressure (Π) is directly proportional to the molality of the solution and its temperature in Kelvin. Depending on the composition of the chemical substances in the solution a specific molality leads to a specific osmotic pressure. Therefore, the composition of the water used for the process is of some relevance for the resulting power production.

4.1.1.1 Composition and salinity of sea water

Salinity is the sum of the dissolved salts as listed in Table 2, is expressed in ppm (parts per million) = mg/L = 0.001g/kg, or in percentage. Nowadays salinity is expressed as a unit-less term, equivalent to the ppm number. The average sea water salinity is around 35 (3,5% or 35 ppm). The ions listed in below table make up approximately 99% of the sea salinity:

Table 2: Sea salinity elements[31]

chemical ion	valence	concentration ppm, mg/kg	part of salinity %	molecular weight	mmol/kg
Chloride Cl	-1	19345	55.03	35.453	546
Sodium Na	+1	10752	30.59	22.990	468
Sulfate SO4	-2	2701	7.68	96.062	28.1
Magnesium Mg	+2	1295	3.68	24.305	53.3
Calcium Ca	+2	416	1.18	40.078	10.4
Potassium K	+1	390	1.11	39.098	9.97
Bicarbonate HCO3	-1	145	0.41	61.016	2.34
Bromide Br	-1	66	0.19	79.904	0.83
Borate BO3	-3	27	0.08	58.808	0.46
Strontium Sr	+2	13	0.04	87.620	0.091
Fluoride F	-1	1	0.003	18.998	0.068

[31] Seafriends

Specific compositions lead to a specific osmotic pressure that can be easily calculated by online calculators, e.g., at the Lenntech homepage[32] as shown in Table 3 and Table 4. The composition of the salts in the sea water is rather stable across the world; what varies is the salinity (expresses the salt concentration in the solution), resulting from the different surface evaporation and inflow.

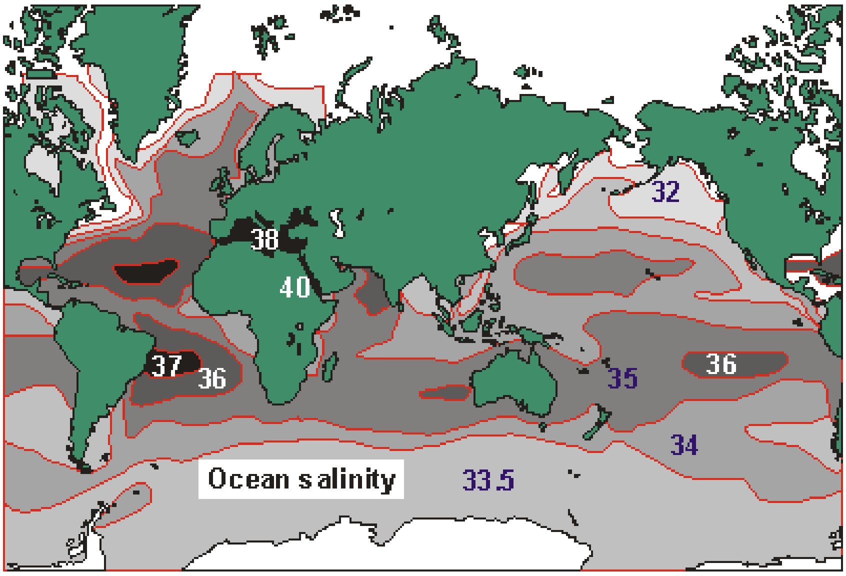


Figure 11: Average salinity of the world's oceans

According to Figure 11, for the Adriatic Sea a salinity of 38 can be assumed for the open sea. This salinity of a specific site will be affected by the inflow of rivers and dependent on the temperature differences of sea- and inflowing waters and the geographical surrounding, which may support or prevent a quick mixture and hence concentration of salinity.

4.1.1.2 Osmotic pressure and the Adriatic sea water

Using the Lenntech online calculator[33] and manipulating the standard sea water values to increase the salinity from average sea water (35) to ~38, the osmotic pressure at average sea temperature of 11°C results in ~26.5 bar. This pressure relates to a water height of ~270 m_{H2O}[34].

[32] Lenntech Osmosis Calculator
[33] Lenntech Osmosis Calculator
[34] Unit Converter

Table 3: Lenntech calculator input table for water composition and average 11°C temperature

Element	Concentration	unit	example	
Ammonium ($NH4^+$)	0	mg/L	0.05	-
Potassium (K^+)	390	mg/L	3.3	390
Sodium (Na^+)	11720	mg/L	36	10900
Magnesium (Mg^{2+})	1310	mg/L	6	1310
Calcium (Ca^{2+})	410	mg/L	84	410
Strontium (Sr^{2+})	13	mg/L	0.7	13
Barium (Ba^{2+})	0.05	mg/L	0.07	0.05
Carbonate (CO_3^{2-})	0	mg/L	-	-
bicarbonate (HCO_3^-)	152	mg/L	265	152
Nitrate (NO_3^-)	0.6	mg/L	4.3	0.6
Chloride (Cl^-)	21000	mg/L	45	19700
Fluoride (F^-)	1.4	mg/L	0.14	1.4
Sulfate (SO_4^{2-})	3000	mg/L	24	2740
Silica (SiO_2)	5	mg/L	9	5
Boron (B)	5	mg/L	-	5
			Brakish Water	Seawater
TDS	not used	mg/L		
Temperature	11	degree C		

Table 4: Lenntech calculator output - osmotic pressure

TDS	38007	mg/L
Total molality (mol/kg)	1210.7	
Total molar mass (g/mol)	727.92	
Osmotic pressure (bar)	26.553	
Indication about operational pressure	60.540	

These numbers represent the average of theoretically achievable pressure in the Adriatic region with a solvent of zero salinity. Yet, as the exploitable osmotic pressure is the difference between the osmotic pressure values of each solution, the salinity of the solvent side in the process has to be examined as well.

4.1.1.3 Osmotic pressure and the fresh water side

The term fresh water defines a salinity of < 1000 mg/l of dissolved solids (of any type)[35], and saline water with solids > 1000 mg/l. The FAO, the UN Food and Agriculture Organization, publishes a classification of water quality (see Table 5), with the focus on usability for agricultural use, especially for irrigation of crops, where the water's salt concentration has a huge impact on the usability of those waters. (Vice versa, the agricultural use of fertilizers has a huge impact on the salinity of ground water and the subsequent salinity of the discharged water.)

[35] Edwards - Freshwater

Table 5: Classification of water quality based on salinity[36]

Water class	Electrical conductivity dS/m	Salt concentration mg/l	Type of water
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 - 2	500-1500	Irrigation water
Moderately saline	2 - 10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15 000	Secondary drainage water and groundwater
Very highly saline	25 - 45	1 5 000-35 000	Very saline groundwater
Brine	>45	>45 000	Seawater

As we see from Table 5, the quality of the water used on the fresh water side of the PRO process will have a considerable impact on the osmotic pressure difference and the resulting pressure created.

Table 6: Osmotic pressure of the Neretva water (Modric, mean values) using the Lenntech online calculator[37]

Table 1: Input table

Element	Concentration	unit	example	
Ammonium ($NH4^+$)	0.1	mg/L	0.05	-
Potassium (K^+)	3.3	mg/L	3.3	390
Sodium (Na^+)	763	mg/L	36	10900
Magnesium (Mg^{2+})	6	mg/L	6	1310
Calcium (Ca^{2+})	84	mg/L	84	410
Strontium (Sr^{2+})	0.7	mg/L	0.7	13
Barium (Ba^{2+})	0.07	mg/L	0.07	0.05
Carbonate (CO_3^{2-})	0	mg/L	-	-
bicarbonate (HCO_3^-)	180	mg/L	265	152
Nitrate (NO_3^-)	4.3	mg/L	4.3	0.6
Chloride (Cl^-)	1732	mg/L	45	19700
Fluoride (F^-)	0.14	mg/L	0.14	1.4
Sulfate (SO_4^{2-})	24	mg/L	24	2740
Silica (SiO_2)	9	mg/L	9	5
Boron (B)	0	mg/L	-	5
			Brakish Water	Seawater
TDS	not used	mg/L		
Temperature	12	degree C		

Calculate osmotic pressure | Erase input values | Send the data to Lenntech

Table 2: Output table

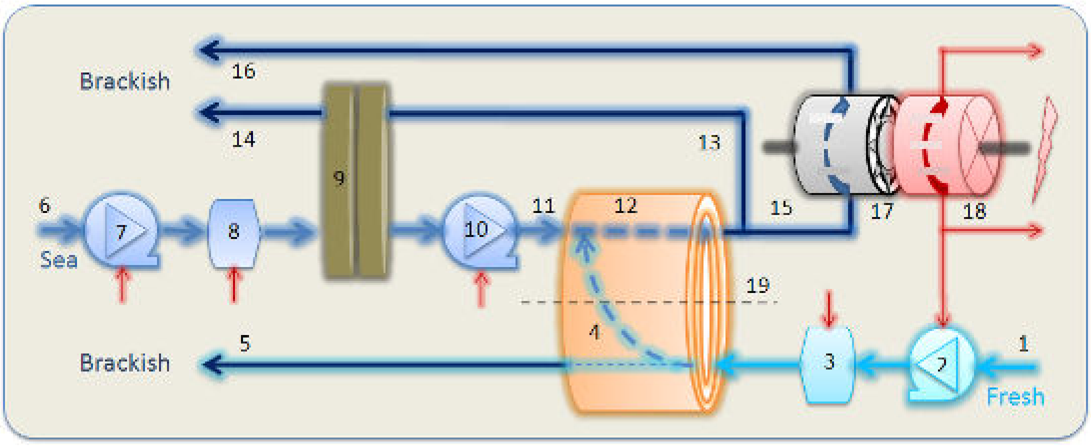
TDS	2806.6	ppm tds
Total molality (mol/kg)	87.861	
Total molar mass (g/mol)	735.15	
Osmotic pressure (bar)	1.9337	
Indication about operational pressure	6.5551	

36 Rhoades et.al. (1992), chapter 2
37 Lenntech Osmosis Calculator

By again using the Lenntech online calculator (see Table **6**) and inserting the most significant salt concentrations measured in the Neretva delta (measure point Modric, mean values Na^+ 763 mg/L and Cl^- 1732 mg/L)[38], an osmotic pressure of 2 bar results. In that case, an osmotic pressure difference of ~25 bar can be used as driving force for a PRO power generation process.

4.1.2 Pressure retarded Osmosis Process Details

In order to exploit the potential power that is inherent in the salinity gradient of sea and fresh water, the waters are dealt with in a specific process as shown in the process schema in Figure 12. Seawater and freshwater are each brought into the system by the usual pumps with pressure little above ambient pressure (0,2 bar). This also represents one of the technology's big advantages: no external water pressure (water height) is needed for PRO, making it a complementary technology able to co-exist with run-of-the-river hydropower plants on the same river.



#	Step / Item	Pressure [bar]	Flow rate [m³/s]	Salinity [ppm]	Comments
1	Fresh water intake	ambient	1	0,5 – 2,5	
2	Fresh water pump	0,2	1	0,5 – 2,5	
3	Fresh water filtration	0,2	1	0,5 – 2,5	50 ym UF membrane
4	Permeat flow	0 – 12	0,8 – 0,9	0,5 – 2,5	
5	Brackish fresh water bleed	0	0,1 – 0,2	2,5 – 25	
6	Seawater intake	ambient	2	35	Adriatic sea: 38
7	Seawater pump	0,2	2	35	
8	Seawater filtration	0,2	2	35	25 ym screen filter
9	Pressure exchanger (PX)	12->0; 0,2->11	out: 1,9 out; in: 2	-	Efficiency: ??
10	Draw solution Pressure pump	12	2	35	
11	Draw Solution membrane Input	12	2	35	
12	Draw Solution flow in membrane	12	2 -> 2,85	~25	
13	Brackish seawater to PX	12	1,9	~25	App. 2/3 of diluted solution
14	Brackish seawater after PX	0	1,9	~25	
15	Brackish seawater to turbine	12	0,95	~25	App. 1/3 of diluted solution
16	Brackish seawater disposal	0	0,95	~25	
17	Turbine (Francis, Pelton)	12 -> 0	0,95	~25	
18	Generator	-		-	App. 1 MW / ($m^3_{fresh\,water}$ /s)
19	Parallel membrane units		1/2 -> 0,15/2,85		App 2 W/m²

Figure 12: Process schema and parameters of the PRO technology[39]

[38] Romic et.al. (2008), p. 64
[39] Based on Aaberg, 2004, p. 4, Skilhagen (2008) p. 478 and Loeb (2002)

Sea water cycle[40]:

After being brought into the system, sea water needs to be filtered so that particles above a certain diameter (cut-off rate) cannot pass into the subsequent process steps of pressure exchanger and membranes. The demonstration plant in Tofte operates with screen filters with a cut-off rate of 25 microns (25 µm), sufficiently small for the subsequent pressure exchanger (PX) device.

After filtration, the sea water is pressurized to an internal pressure level of app. 12 bar or 50% of the osmotic pressure difference (sea – fresh). In order to avoid the efficiency losses of conventional pressure pumps, pressure exchangers as used in the RO desalination process are introduced.

After the pressurization by the PX device, a conventional pressure pump ensures the desired pressure level before the sea water enters the membranes.

The purpose of putting the sea water cycle under pressure is to reduce the fresh water's flux through the membranes. The flux influences various parameters of the system, e.g., the specific membrane power [/m²] and the bio-fouling of membranes.

After leaving the pressure exchanger and pump, the pressurized sea water enters the membrane unit (parallel configurations) where it serves as the draw solution, "drawing" water from the other side of the membrane into the sea water side. During this continuous flow over the membrane surface the draw solution dilutes and increases its volume via the osmosis process, retarded by the external pressure. By doing so it transfers the energy from the chemical to a mechanical potential, which constitutes the core process step in the technology.

Diluted sea water (brackish water) cycle

After leaving the membrane units, about 2/3rd of the pressurized diluted solution are re-used for the pressure exchanger flow, after which it is disposed as brackish water into the sea. The remaining 1/3rd of the diluted water is fed into a turbine that drives the generator for the electric power generation as used in conventional hydropower plants.

Fresh water cycle:

Fresh water flow volume is about 50% of the sea water flow volume. Before being brought into the membrane units, the fresh water also needs filtering. According to Statkraft, the cut-off rate for the fresh water filters in the demonstration plant is about 50 microns (µm). The higher cut-off rate has a direct impact on a higher extent of

[40] Description of the process steps based on Skilhagen (2007) pp. 477f

fouling (polluting) of the membranes, which leads to the requirement of increased membrane washing (see 4.2.1.3 Fouling, Filtering and Washing).
After filtration, the fresh water is fed into the membranes where it flows constantly over the membrane surface opposite the salty solution (cross flow). Via this flow through the membranes, approximately 80%-90% of the water gets drawn through the porous material and skin to the saltier side where it dilutes the sea water. The remaining 10%-20% of the fresh water feed are disposed as brackish water in the sea (*fresh water bleed* in Figure 12).

4.2 PRO Critical Components

4.2.1 Membranes

As already indicated in chapter 3.3.3, membrane technology and its integration in the overall process is the key for a feasible technical and economical performance of the PRO power plant.

4.2.1.1 Specific Membrane Power

As mentioned above, sea water pressure is used to control the process, especially the water flux, which is a function of the pressure difference between hydraulic and osmotic pressure. The most prevalent relationship is between hydraulic pressure and the resulting flux in the membrane, which again determines the specific power yielded. The specific membrane properties, their main and side effects are described in detail by Thorsen and Holt (2009) from a theoretical as well as an experimental perspective.

Figure 13 shows a series of measurements performed with a membrane specifically designed for the PRO process with the modelled relationship of flux and specific power over pressure. These results are based on lab scale experiments. All these findings and process dependent behaviour of the membranes and the integrated systems will be verified and optimized in the demonstration environment.

According to the Thorsen and Holt (2009) study, the specific power of a membrane has a maximum achievable specific power of about 5 W/m² (see also Figure 10).

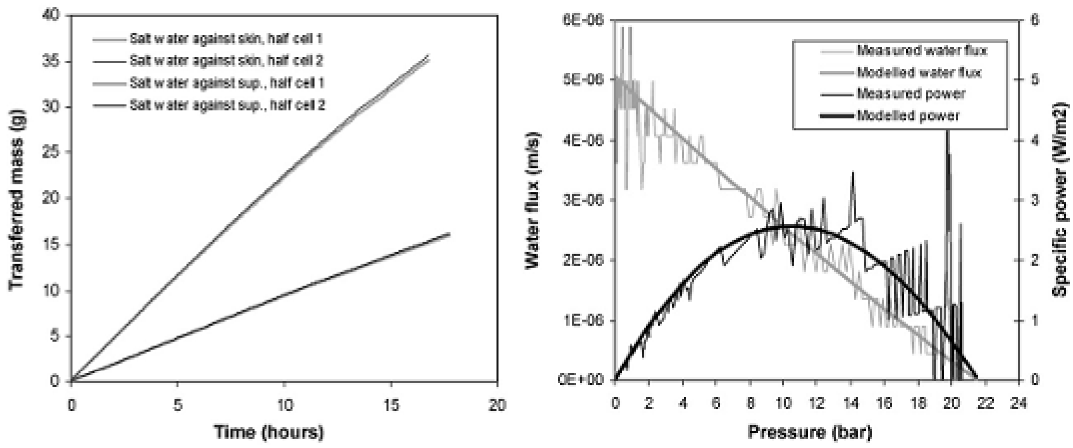


Figure 13: Transferred mass vs. time for isobaric osmotic flow experiments (left). Modelled and measured water flux and specific power as functions of pressure (right) [41]

4.2.1.2 Spiral Wound Membranes

How can membranes that only generate 1, 3 or 5 W/m² be used for power plants with an expected capacity of multiple megawatts?

First of all, the membranes (made of e.g., Cellulose Acetat or Polyamide Thin-Film Composite) are very thin material. The working layer, the *skin*, is just as thin as 0,5 µm. For mechanical support, the skin is attached to a layer of porous polymer and a backing fabric layer, each about 100 µm.

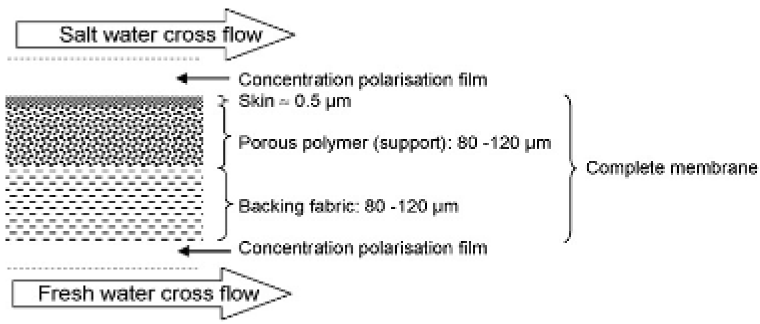


Figure 14: Structural model of a membrane (with polarization films)[42]

In order to pack large areas of membrane into as little space as possible, the thin material is wound to spirals, with the layers separated by feed spacers (< 1mm).

[41] Thorsen and Holt (2009), p. 107
[42] Thorsen and Holt (2009), p. 104

Figure 15: Spiral wound membrane[43]

The currently used membranes in the demonstration plant are prototypes and not available from industry partners yet. But the principles of production and scaling will be the same as for the already available RO membranes used for desalination.
The largest RO membrane unit found was as big as 18” diameter x 61” length (46 x 155 cm). The membrane units get serially stacked into vessels available in different dimensions. Different from the conventional RO vessels, which are engineered as pressure vessels for pressures up to 70 bar, PRO vessels will be designed for lower pressure requirements (< 30 bar).

Figure 16: Example for large size membrane and casing (Kochmembrane)[44]

Finally, the membrane vessels are stacked in racks, supporting a maximum density of membrane area per m³ as well as offering efficient piping and ergonomic maintenance. The overall volume requirement of a plant is determined by the rated capacity, the specific power of membranes and the volume efficient design of membranes, vessels and stacks.

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[43] Tate (2008)
[44] Koch MegaRO

Figure 17: The Ashkilon (Israel) desalination plant with 30.000 membrane modules[45]

Figure 17 makes it obvious that in addition to the pure membrane costs the required space establishes a significant cost and construction parameter for the total plant. Therefore, future developments must be expected to enable an even further concentration of the membrane modules, with up to about 1000 m² per unit (per m³). The current state of technology is ~200 m² per unit. Statkraft is using research membranes with ~30 m² per unit[46] in the Tofte plant.

Besides spiral wound membranes there exist other forms, such as hollow fibres, which are not elaborated further here.

4.2.1.3 Fouling, Filtering and Washing

Fouling (polluting) of membranes is the major influencing parameter for the performance and endurance of the membranes, which, typically, is about seven to ten years. Fouling can have various causes and therefore needs multilayered prevention techniques. The major fouling mechanisms in membranes used for RO/PRO technology are scaling, particulate and organic fouling and bio-fouling. Scaling is caused by inorganic compounds and, where necessary, can be controlled by using a scale inhibitor, such as a polymer or an acid. Thus, all types of fouling except bio-fouling and organic fouling, which are related types, are controllable. At the moment, bio-fouling is considered the major problem for PRO and RO membranes. In spiral wound membrane modules, two types of pressure (thus

[45] Veolia - Ashkelon
[46] Direct communication with Statkraft, March 2010

performance) drop can occur: the trans-membrane pressure drop (TMP) and the feed spacer channel pressure drop (FCP), also named longitudinal pressure drop.[47]

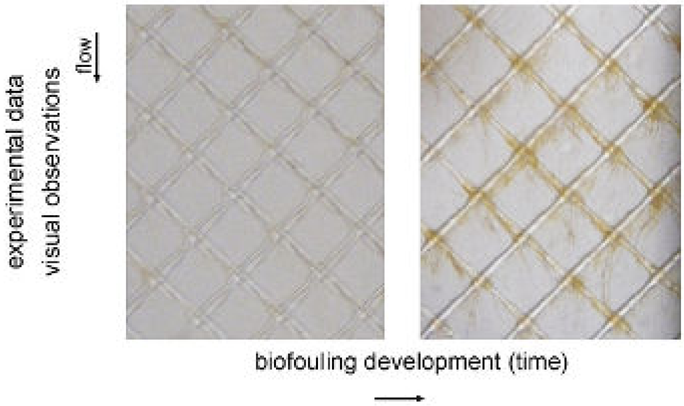

Figure 18: Bio fouling over time in the feed spacer layer of a spiral wound membrane[48]

Fouling needs to be seen as inherent challenge of the membrane usage and it is site specific due to different water compositions and process parameters. In order to control the fouling process, two main counter measures are taken:

- *Water pre-treatment* is used to filter out particulates above a certain diameter. In the Tofte plant, ultra-filtration is used for the fresh water feed with a cut-off rate of 50 µm. For the sea water side a screen filter with a cut-off rate of 25 µm is used in order to prevent fouling of the membranes and damage of the pressure exchange units;
- *Washing* is the process of flushing the membranes in the counter direction of their usual flows. During washing, the membrane is not available for power generation and therefore washing reduces the achievable full load hours of the equipment (or increases the specific investment costs [€/MWh] respectively). In the demonstration plant, a washing time of 30 min/24 hours is currently assigned.

The efforts for and costs of pre-treatment (granularity of filters) and the required duration of washing (with loss of load hours) are interdependent: the smaller the threshold for the pollutant diameter (cut-off rate), the more expensive the pre-treatment, but the less time is required for washing. The optimization of the interrelationship between pre-treatment (costs), washing time (costs) and membrane duration (costs) is part of the demonstration plant process optimization. As a result of the research on optimal washing, Statkraft has filed a patent for a specific technical washing procedure.

[47] J.S. Vrouwenvelder et al.(2010), pp.71
[48] J.S. Vrouwenvelder et al.(2010), p. 78

4.2.2 Energy Recovery Devices (Pressure Exchanger)

Seawater inflow must be pressurized before the membrane inflow. In order to avoid the losses of efficiency of conventional pressure pumps, pressure exchangers as used in the RO desalination process are implemented. Currently, several technologies for an energy recovery device (ERD) are implemented in RO plants to increase the plant's efficiency: isobaric ERD, Pelton turbine, Francis turbine and hydraulic turbocharger. The most widely used in new large SWRO desalination plants are Pelton turbines and isobaric ERDs.

A general comparison of the technologies is given in Table 7, but the selection of the most appropriate device should be made based on a plant's specific parameters according to the study of Sanchez, et.al. (2007) performed for a RO environment (with higher pressure levels involved than in PRO).

Table 7: Energy recovery technologies and main indicators like plant total energy savings[49]

Device Type	**Energy savings**	Costs
Energy recovery turbine (ERT)	**30-40%**	+
Pressure exchanger (PX)	**50-60%**	++

In the demonstration plant the pressure exchange devices with higher efficiency are used. Manufacturer ERI claims a 98% maximum efficiency of their energy recovery device as shown below.[50]

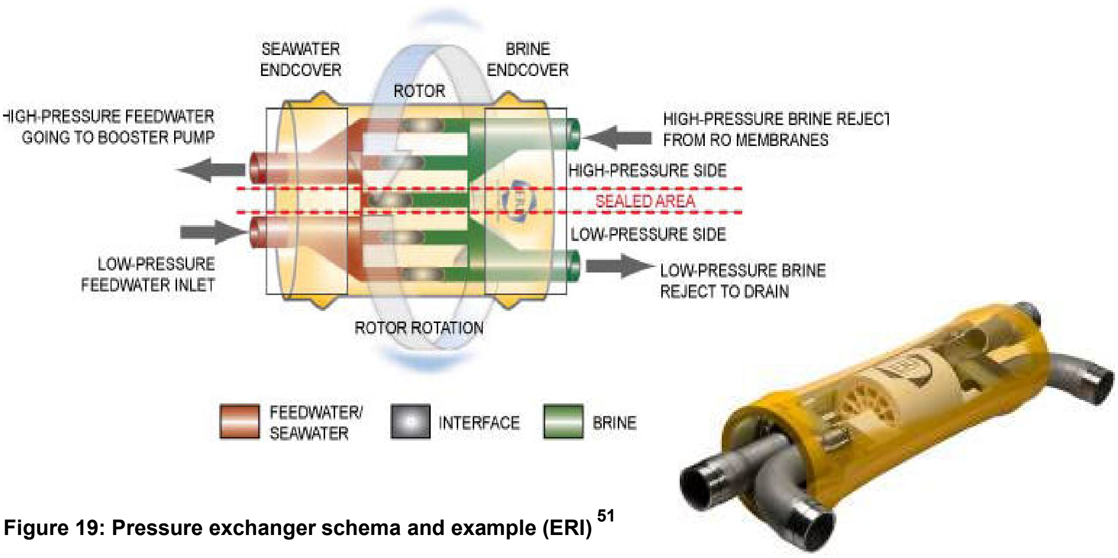

Figure 19: Pressure exchanger schema and example (ERI) [51]

49 Lenntech SWRO
50 ERI Overview
51 ERI PX Manual

Currently, ERI's model with the highest capacity (PX 300) can handle a fresh water throughput of 45–68 m^3/h.[52]

4.3 PRO Process Parameters

Performance indicators have been collected for evaluation of the technology and the understanding of requirements for a potential plant site. The indicators are based on the process overview (Figure 12) and the information acquired from publicly accessible sites, as well as on discussions with experts from Statkraft and the desalination industry.

Whereas many of the listed parameters refer to the technologies used and the internal process, others indicate a dependency on the environment and natural conditions as elaborated in later chapters.

Table 8: Selected parameters of the PRO technology and process

Category	Fact	Value	Unit	Comment
Energy	Rated power per volume freshwate	1.000	kW/m^3s	total plant net
Energy	Theoretically extractable energy at	750	Wh/m^3	from 1 m^3 fresh water, lab conditions
Membrane	Area membrane per cubic meter	1.000	m^2/m^3	theoretical density
Membrane	Area membrane per cubic meter	400	m^2/m^3	existing (Koch Megamagnum)
Membrane	Area per spiral	30	m^2/case	current
Membrane	Area per spiral	1.000	m^2/case	target state
Membrane	Membrane lifecycle	7-10	yrs	depends on treatment / conditions
Membrane	Membrane net specific power	~5	W/m^2	technical target
Membrane	Membrane net specific power	~4	W/m^2	target for ROI
Membrane	Membrane net specific power	~2	W/m^2	current state implemented
Membrane	Price Filmtech Mem 37m² 8x40	22,05	US$/$m^2$	retail price 816,- USD / unit overstoc
Plant	Footprint per MW rated capacity	4.000	m^2/MW	derived from 5 mio m^2 membrane
Plant	Internal losses	20	%	plat at sub sea level
Plant	Internal losses	22	%	plant at ground level
Plant	Targeted FLH (net)	8.000	h	includes washing (30 min)
Pressure	Input pressure fresh and sea	0,2	bar	near ambient
Pressure	Optimal operating pressure	12	bar	11-15
Pressure	Osmotic pressure general	26	bar	standard conditions used in literature
Water	Salinity drinking water	0,1	ppm or g/l	in Norway
Water	Salinity seawater standard	36	ppm or g/l	32-40; Adriatic 38
Water	Fresh to sea water ratio	1/2	▯	
Water	Fresh water bleed	10-20	%	because of fouling prevention
Water	Freshwater filtration down to	50	µm	in Tofte (ultra filtration)
Water	Seawater filtration down to	25	µm	in Tofte (Screen filters)

[52] ERI PX 300

4.4 Expected Scaling Effects

Again, the analogy from the desalination technology must be used since, at present, not enough PRO specific information is available. Through increased diffusion of RO desalination plants all over the world, the production capacity and the demand for membranes also increased. As a result, prices of membranes and other modules of the process have decreased significantly, and so have overall costs of RO-desalinated water[53] (see Figure 20).

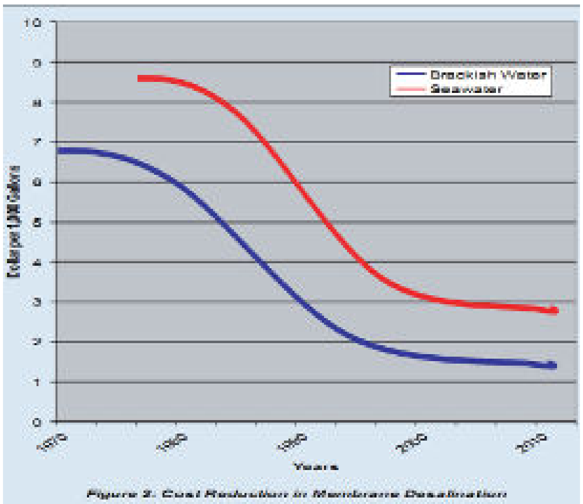

Figure 20: Specific costs of water produced by RO desalination plants[54]

Similar to the cost reduction of water desalinated by Reverse Osmosis, a cost decrease based on economies of scale and learning curve effects must be expected for the PRO process and components.

The *technology starting point* for the learning curve is already advanced due to the re-use of sophisticated RO components, such as the membrane technology and the pressure exchangers. Statkraft and research partners have already pushed the specific power from 0,1 W/m² of commercially available RO membranes[55] in 1999 to above 1 W/m² in the demonstration plant. Still there remains significant and already visible optimization potential, especially for the specific power yields of membranes:

- Currently, >1 $W/m^2_{membrane}$ is demonstrated in the existing demonstration plant,
- Currently, ~3 $W/m^2_{membrane}$ are achieved in laboratory environments,
- Expected, ~4 $W/m^2_{membrane}$ will be achieved within 2 years,
- Expected, ~5 $W/m^2_{membrane}$ will be achieved within 4 years[56].

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[53] AMTA (2006), p.1
[54] dito
[55] Skilhagen et.al. (2008), p. 479
[56] Direct communication with Statkraft, (February 2010)

The first PRO experiments started with the membrane technology as used in the RO desalination process. But due to different inherent characteristics of the materials used, the power output was not meeting the needs and expectations. Since then there is separate research and development going on for optimized membranes used for PRO. Thorsen and Holt (2006) provide theoretical background and a description of the critical performance parameters of an ideal membrane used in the PRO process, and they prove their main findings with laboratory experiments.

Commercial prices, and therefore price / performance ratios, are not yet available for PRO specific membranes. It can be expected that as soon as manufacturers are recognizing the business potential they will start building and optimizing production processes and increasing pertinent research.

The *economical starting point* for price performance figures must be taken by analogies from available cost factors and unit distribution of RO components. For membranes especially, this can be done by determining the current market size for membranes in square meters produced:
From various datasheets published, e.g., on the home page of Applied Membranes Inc. for RO desalination membranes, a flux performance of roughly 0,85 $m^3d^{-1}m^{-2}$ [57] (0,77-0,92) was determined[58]. This performance describes the volume of desalinated water that can be produced per day per square meter of membrane.
According to market share data published by Global Water International, the total volume of RO desalination plants contracted between 2008 and 2009 relates to a capacity of approximately 5.5 Mm^3 potable water produced per day (see Figure 21).

These 5.5 Mm^3/d relate, via above 0,85 m^3 per day per m^2, to approximately 6,6 Mm^2 of RO membranes sold over 2 years. The resulting estimation for the annually sold amount of desalination RO membranes is in a range of 3,3 Mm^2.

[57] Cubic meters per day per square meter of membrane
[58] Applied SWC5, Applied SW30

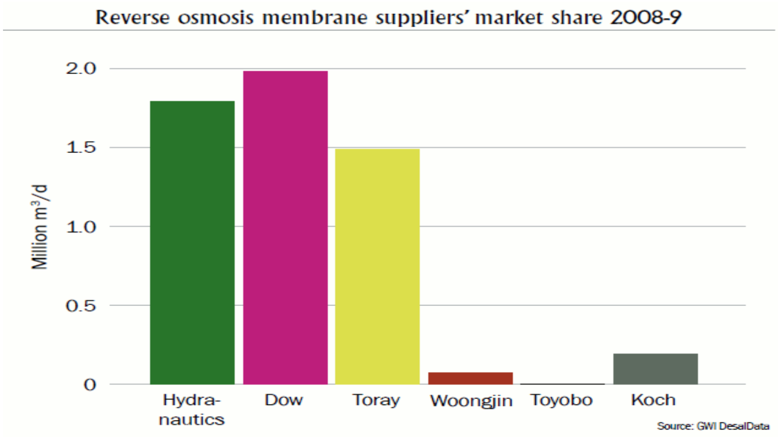

Figure 21: RO membrane suppliers' market shares 2008-9[59]

Relating this estimated membrane production to the demand for membranes in PRO applications, the same annual 3,3 Mm² of membranes (with a theoretical specific power yield of 2 W/m²) allow for an annual capacity growth of ~6,6 MW. This small amount certainly will not attract energy players to enter the market. A more attractive PRO power plant size of 25 MW will require ~13 million square meters of membrane area. This area represents the fourfold of the current annual production (double if 4 W/m² power density). According to these numbers, and provided that the PRO technology succeeds, a doubling of the membrane industry's cumulative output may occur in a very short period of time. This allowed for a quick exploitation of the learning curve throughout the supply chain, and for economies of scale in the production of critical components.

The lowest retail price found for RO-membranes was 22 USD/m² (17 €/m²) for a Filmtech SW30HRLE-400[60]. In contrast to the SWRO membranes, those used for PRO applications will not require high-pressure casings, which should result in lower specific costs. At the same time, membrane industry experts rate PRO membranes slightly more expensive due to the constructions details (as known so far). According to these experts, for a large scale application such as a PRO plant, approximately 400 - 500 US$ for 400 ft² should be taken as estimation for a ROI calculation, relating to 8 - 10 €/m².

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[59] GWI (2010)
[60] Applied Overstock Prices and Applied SW30 HRLE 400i

4.5 PRO Plant Concepts

Several ideas on how to place PRO power plants have been sketched by Sidney Loeb, et.al (1990) and later in the EU study of 2004. Mainly two concepts are pursued: plants on ground level and on sub-sea level[61]. According to Statkraft, a plant situated just below sea-level would decrease the plant's internal losses from 22% at sea-level to about 20%. This difference is due to the fact that the overall energy needed for pumping can be reduced and the gravity be used to support the suction side of fresh and sea water intake.

The sketch of a plant at sea level is taken from a Statkraft presentation at the Washington International Renewable Energy Conference:

Figure 22: Sketch of a PRO plant at sea level[62]

As shown in Table 8 there is a substantial demand for land for a PRO power plant: 100m x 200m (20.000m², equivalent to about three soccer fields) can be taken as a rule of thumb for a 5 MW plant. The size is mainly determined by:

- The membranes' power density, with an expected increase from 1 to 5 (W/m²),
- The membranes' area density, as packed in pressure vessels, with an expected increase from 200 to 1000+ (m²/m³),
- The need for loss-limiting piping designs with optimized diameters and bends,
- The need for an ergonomic maintenance access to thousands of single components.

[61] EU Project brochure (2004), p. 7
[62] Skilhagen (2008)

The implicit plant size might cause economic barriers for a potential project, such as:

- The availability of suitable land in the river delta for reasonable cost rates,
- The cost of construction, usually scaling linearly per m², and
- Should a sub-sea level design be targeted, construction costs will add up, highly dependent on the hydro-geologic and soil conditions.

An ideal plant location could be the basement of an already sealed, large area with good access conditions for construction and maintenance logistics. Such locations could be found at places like supermarkets, parking areas (also in touristic places), factory or harbour outlets, etc.

4.6 Environmental Influences and Challenges

The PRO power generation process can be regarded as minimally impacting the environment because no fossil fuels and hardly any lubricants are needed, no CO2 or particular matters are exhausted, no ecologically harming substances are used or produced and usually no river dams need to be built to produce a water head. Yet, there are several ecology parameters that either limit the potential use or impact the construction of the plant. Some of those parameters are elaborated further in this chapter.

4.6.1 Plant size

In addition to the economical barriers of land costs (see above chapter 4.5), the required size of a PRO plant may also constitute severe ecological barriers for a project:

- The competitive use of suitable land in the river delta (e.g., for touristic or agricultural use),
- Permission restrictions due to environmental concerns, especially in touristic regions and/or protected areas.

Sub-sea level designs on the one hand may not only reduce the internal losses of a plant, they may also be the only way to hide an extensive plant from the surface of a touristic area. Such construction will require additional expenses for digging and reinforcing an extensive basement, depending on soil, hydro geology and other construction conditions.

4.6.2 Water Quality

All data about membrane performance found in the appropriate literature was based on certain defined NaCl-solutions (e.g., 32 g_{NaCl}/l by Thorsen and Holt[63]) to simulate sea water and on water quality for fresh water without further definition. Although the natural composition of substances in sea water is more or less constant (with only the concentration in water being different), local imbalances of the composition can occur due to pollution in the respective area. Yet, this pollution is more likely to happen on the fresh water side due to industrial or agricultural depositions to the rivers. If the quality of the fresh or the sea water supply for a potential project substantially deviates from the lab qualities, the potential impact on the process needs to be assessed at an early stage of the project development.
As an example for changing and possibly problematic quality of fresh water supply a series of measurements of the Neretva water can be used:

Table 9: Statistical data on Na+ and Cl– concentrations in water at the Neretva monitoring site Modric[64]

Location	Statistical parameters	pH	EC_{iw} $dS \cdot m^{-1}$	Na^+ $mg \cdot l^{-1}$	Cl^- $mg \cdot l^{-1}$
Modric	mean	7.72	5.53	763	1732
	min	7.00	1.65	170	355
	max	8.60	17.20	2750	5885

The table shows variations of Na + Cl concentrations of min 525 mg/l and max 8.635 mg/l (mean ~2500 mg/l). This relates to a salinity of min 0,5 to max 8,6, with the latter constituting a significant negative impact on the salinity gradient and thus the exploitable energy in a PRO process (see also chapter 4.1.1.3).

4.6.3 Access Points

Due to losses of flow and pumping energy for transporting water over long distances, water intake points should be kept as close to the plant as possible. Depending on the geographical characteristics of the location this might constitute a challenge for the plant design:

4.6.3.1 Variation of Sea Level and River Flow

The ideal, least distant points of intake for fresh water (as pure as possible) and sea water (as saline as possible) will vary due to various factors. Those factors are foremost:

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[63] Thorsen and Holt (2009), p. 108
[64] Romic et.al. (2008) p.64

- Tidal oscillation of the sea water level,
- Weather (wind) related deviation of the sea water level,
- River flow variation due to climate influences (flood, draught, global warming effects) also resulting in
- Variations of the salinity grade at the intake points,
- River flow variation due to competitive usage of upstream water (e.g., hydropower plant, agriculture irrigation).

4.6.3.2 Transitional Waters: Estuaries, Limans, Lagoons

Transitional waters are defined as "bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows"[65]. With respect to utilization of fresh and sea water in one combined place, the existence of transitional waters is of strong impact. They are found in flat river deltas and in *estuaries* (with special appearance as limans or lagoons).

An *estuary* is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: a) a marine or lower estuary, in free connections with the open sea; b) a middle estuary subject to strong salt and fresh water mixing; and c) an upper or fluvial estuary, characterized by freshwater but subject to strong tidal action. The limits between these sectors are variable and subject to constant changes in the river discharges.[66]

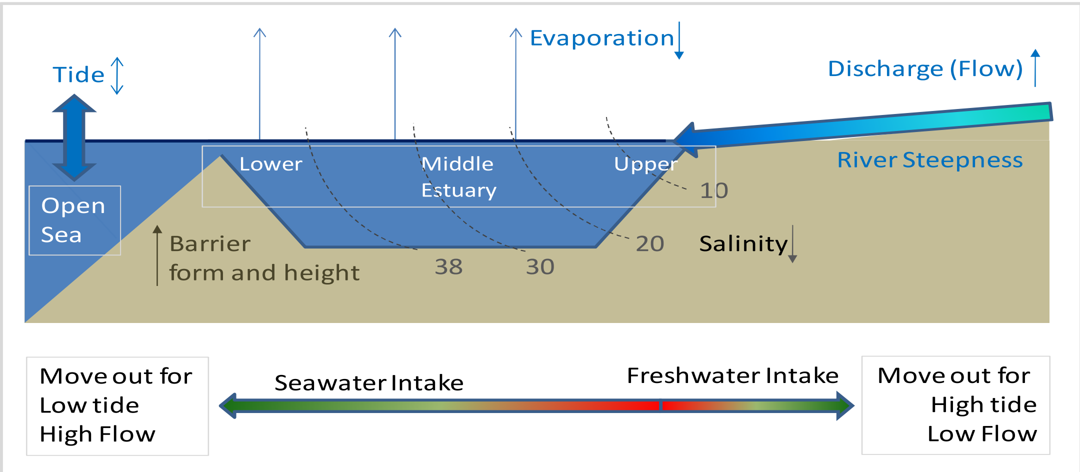

Figure 23: Influencing parameters on salinity in estuaries and positioning of water intake locations

[65] EU WFD (2000) p.6
[66] Fairbridge (1980)

Due to the cost of water inlets via long distances (construction of pipes and tunnels) and/or the energy costs for pumping sea water from lower levels to a given plant level, the horizontal and vertical distance of intake points should be kept as small as possible. But rivers discharging into estuaries can establish technical and economical challenges in the collection of sea and fresh water. As an example of how complex an estuary system can be, the river Krka is shown:

Figure 24: The Krka estuary; yellow dot shows Skradin as measurement point

Salinity can be shown as a function of water depth due to differences of the specific weight of saline and fresh water. This relationship is not stable, however varies over time, especially with the inflow of fresh water into the estuary. As fresh water has less specific weight, it will stay on top of the saltier sea water (the mixture will take place on more open sea). The more fresh water enters an estuary with limited surface area, the deeper the optimal salinity level will move. This effect is, e.g., demonstrated by the salinity of the Croatian River Krka, measured at Skradin in different sub-sea levels.

As elaborated further in chapter 5, Croatian rivers during winter months deliver significantly higher volumes of fresh water. This fact is reflected in the chart below, where salinity in the Krka estuary is significantly decreased from November to March, even at a depth of 6 meters below sea level:

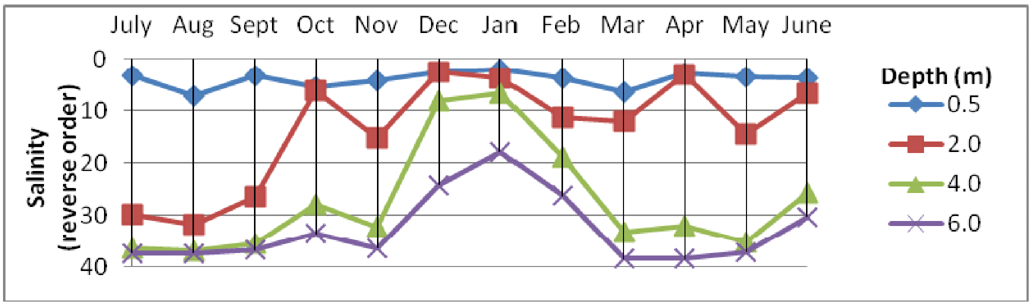

Figure 25: Salinity at Skradin as a function of depth and month[67]

As a consequence, in order to avoid pumping losses in the sea water cycle, the water intake points might need to be planned outside of the estuary. In transitional waters, a decision has to be made between lifting sea water from deeper levels or transporting water over longer distances. In ecologically less sensitive cases the construction of a dam could be an option to protect the fresh water from intruding sea water.

4.6.3.3 Competitive Water Usage Downstream

Competitive usage of water might prohibit

- The reduction of residual flow in the river bed below defined thresholds, or
- Changes to the salinity grades downstream of the outlet of brackish water.

Such requirements can be asserted by the fishery and mussel industry in a river delta. Different species of fish can adapt differently to changing salinity grades. Not all species react negatively to brackish water, though. This was demonstrated in detail by the above mentioned FAO study of 1982/83 on fish cage cultures in the Krka water estuary (see Figure 26): trouts demonstrated considerably higher growth rates in brackish water than in fresh water.

These findings indicate that the impact of a PRO power plant's intrusion into the ecosystem of the river delta can be even positive for some of those stakeholders who are expected to oppose a change in the status quo.

[67] Graph based on Edwards (1984), conclusions, table 2

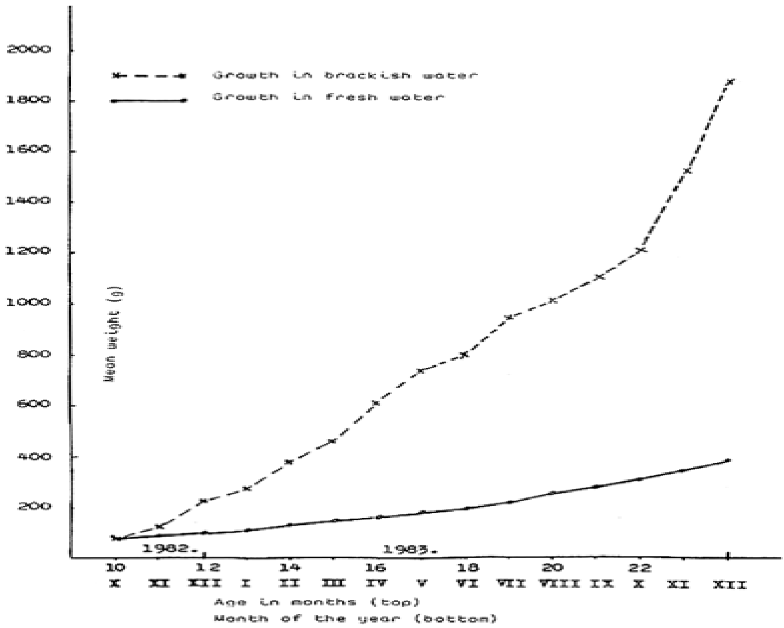

Figure 26: Growth of rainbow trout in fresh water (solid) and in Krka estuary brackish water[68]

4.6.3.4 Competitive Water Usage Upstream

Competitive use of upstream water can have a significant impact on the performance of plants. Existing competition will – of course - be taken into consideration for the business case and the ROI calculations. More challenging though, is the future water demand since this is difficult to predict. A single hydropower storage plant project can, all at once, destroy the business case of a PRO plant which is dependent on a constant water flow at a certain discharge rate. Such projects usually require thorough decision making with the stakeholders involved in the assessment phase. Therefore, such a sudden loss of water supply appears rather unlikely. More realistic, however, are the incremental losses due to a constant increase of tapping into the river water, be it for irrigation in agriculture or potable water for municipal supply. In many cases these withdrawals will be small enough to prevent (public) interest or even get recognition by governing bodies responsible for the water management. Therefore, a good assessment of the water reserves and potential future drawing of water is required in order to prevent expensive over-capacities of the developed plant.

[68] Edwards (1984) conclusions, figure 7

4.6.3.5 *Sea Level Fluctuations*

Relevant for the extent of transitional waters is the variation of sea water levels. The variation can be due to regular tidal changes, or to irregular influences of weather, mainly the wind which causes the sea water to drift towards the coastal barriers. On the Croatian Adriatic coast, tidal changes are minimal in the south and up to about a meter in the north. On top of the tide in the North Adriatic Sea, storms from the south will cause the sea level to rise significantly.

Tidal and weather influences can cause the north Adriatic sea level to fluctuate up to 2.13 meters, as measured in Rovinj: Table 10 shows the deviations to a defined mean sea level per month, measured between 1955 and 2007:

Table 10: Sea water level deviations for Rovinj (North Adriatic Sea) and Dubrovnik (South Adriatic Sea)[69]

	Mean Sea Level Deviations (cm)					
	Rovinj			Dubrovnik		
Month	Min	Max	Average	Min	Max	Average
January	90	115	-1.90	48	69	0.60
February	96	117	-4.10	60	67	-1.10
March	89	88	-5.70	61	55	-3.80
April	74	85	-2.10	44	51	-1.40
May	73	107	-2.30	43	53	-2.30
June	78	86	-1.30	35	45	-2.50
July	75	72	-1.40	36	39	-3.60
August	70	74	-0.10	36	38	-1.70
September	65	89	1.30	39	49	-0.20
October	68	109	5.40	40	54	4.00
November	78	132	8.20	35	68	6.90
December	85	117	4.00	42	70	5.20

Therefore, depending on the actual location of a developed plant, the water intake mechanism will need to take care of the maximum fluctuation of water levels.

4.6.4 General Water Usage and Residual Flow

In general, a PRO power plant will allow a rather gentle way of embedding high technology into sensitive eco-systems for the exploitation of the nature's potential energy. Yet it must be emphasized that the PRO technology does have an impact on the water management and that the goal of power generation is in obvious opposition to all of the above mentioned competitive interests. The clear advantage in the water usage of PRO is the short distance over which the river water is impacted in an ideal location. This advantage could be offset by the mandatory placing of the plants in the most sensitive areas, the river deltas. Besides other subjects in an environmental impact analysis, the mandatory residual flow – the amount of water that needs to be kept flowing naturally in the river bed - will constitute an important parameter for the plant's size and economy.

[69] Sea level

4.7 Legal perspective

4.7.1 Renewable Energy Directive 2009/28/EC

On April 23rd, 2009, the EU parliament passed the Renewable Energy Directive and provided a framework for member states' legislations to support and enforce the increased use of renewable energy sources. Annex I of the Directive[70] depicts the targeted share of RES for each member state. For EU accession candidates such targets are negotiated and recommendations given in the chapter "energy" during the accession negotiation rounds. For Croatia, chapter 15 (energy) was provisionally closed on Nov 27th, 2009[71].

4.7.1.1 Salinity Power – An Acknowledged Renewable Energy Source

Article 2 (Definitions) of the Directive 2009/28/EC defines what the possible renewable sources of energy are:

(a) 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

In the directive's preamble there is an explicit acknowledgement of salinity power included in paragraph (11):

11) It is necessary to set transparent and unambiguous rules for calculating the share of energy from renewable sources and for defining those sources. In this context, the energy present in oceans and other water bodies in the form of waves, marine currents, tides, ocean thermal energy gradients or salinity gradients should be included.

Due to the early state of osmotic power technology, it cannot be expected that member states have already included specific rules for its exploitation, such as feed-in tariffs into the electricity grid. Some regulators have defined a category "other technologies" in their catalogue of feed-in tariffs to provide a certain level of subsidy. As elaborated in chapter 7 it will require feed-in tariffs specifically set for PRO and adjusted to the incurred specific costs per MWh in order to give the technology a chance for market dissemination and maturity.

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70 EU 2020 (2009), p.46
71 EU Enlargement (2010)

4.7.2 Patents

There are several patents issued with regards to the process and technology of pressure retarded osmosis. Original patents go back to the inventor of the technology, Sidney Loeb, who filed several patents in the years between 1964 and 1980 describing the basic idea and process.

Two patents (listed by European Patent Numbers) are to be considered for an application of the technology in a project. Both are assigned to Statkraft Development AS:

A Method and a System for Performing Maintenance on a Membrane Used for Pressure Retarded Osmosis[72]

- Publication Number: EP1971420
- Application Number: EP06835734.2
- Filing date: 12/20/2006
- Publication date: 09/24/2008

Semi-Permeable Membrane, Method for Providing Electric Power and a Device[73]

- Publication Number: EP1315554
- Application Number: EP01961437
- Filing date: 07/20/2001
- Publication date: 06/04/2003

The existence of these patents makes it obvious that Statkraft is a stakeholder in a project development, at least as licenser of intellectual property in the PRO technology.

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[72] EP1971420
[73] EP1315554

5. Croatia and its Suitability for Pursuing Osmotic Power Plant Projects

5.1 General Country Information

The Republic of Croatia is a democratic and social state and belongs to the people as a community of free and equal citizens. The government in the Republic of Croatia is organised on the principle of the separation of powers into legislative, executive and judicial. The first Constitution of the Republic of Croatia was proclaimed on 22 December 1990.[74]

5.1.1 Facts and Figures

- Population (2001 Census): 4.437.460
- Number of inhabitants per km2: 78,5
- Capital: Zagreb 779.145 inhabitants
- Land area 56.542 km2
- Territorial sea area 31.067 km2
- Land boundaries 2,197 km
- Length of the coast, including islands 5.835 km
- Number of islands, cliffs and reefs 1.185 - inhabited 47
- Territorial-administrative structure
    - 21 counties (including the City of Zagreb)
    - 122 towns
    - 424 municipalities
    - 6767 settlements
- Climate
    - Continental in the Northern Croatia
    - Mountainous in the Central Croatia
    - Mediterranean along the Adriatic Coast (average of 2600 sunny hours per year)
- Internet country code .hr

[74] MFA "Political Structure"

5.1.2 Croatia and the European Union

The establishment of relations between the Republic of Croatia and the European Union began with the international recognition of the Republic of Croatia as an independent and sovereign state on January 15th, 1992. From that moment, relations developed gradually to the most recent stage of the integration process - negotiations for the accession of the Republic of Croatia to the European Union. These negotiations were opened on October 3rd, 2005.[75]

Since then, the transformation of Croatia in conforming to EU standards and regulations is ongoing at a fast pace and most of the negotiation chapters have been successfully concluded:

Table 11: EU - Croatia accession negotiation chapters – status as of February 19th, 2010[76]

CROATIA	Negotiations	
state of play: 19 February 2010	opened	closed
1 – free movement of goods	25 July 2008	
2 – freedom of movement of workers	17 June 2008	2 Oct 2009
3 – right of est. & freedom to provide services	26 June 2007	21 Dec 2009
4 – free movement of capital	2 Oct 2009	
5 – public procurement	19 Dec 2008	
6 – company law	26 June 2007	2 Oct 2009
7 – intellectual property rights	29 March 2007	19 Dec 2008
8 – competition policy		
9 – financial services	26 June 2007	27. Nov 09
10 – information society and media	26 June 2007	19 Dec 2008
11 – agriculture and rural development	2 Oct 2009	
12 – food safety, vet. & phytosanoitary policy	2 Oct 2009	
13 – fisheries	19 Feb 1010	
14 – transport policy	21 April 2008	
15 – energy 21 April 2008	27. Nov 09	
16 – taxation	2 Oct 2009	
17 – economic and monetary policy	21 Dec 2006	19 Dec 2008
18 – statistics	26 June 2007	2 Oct 2009
19 – social policy and employment	17 June 2008	21 Dec 2009
18 – statistics	26 June 2007	2 Oct 2009
19 – social policy and employment	17 June 2008	21 Dec 2009
20 – enterprise and industrial policy	21 Dec 2006	25 July 2008
21 – Trans-European networks	19 Dec 2007	2 Oct 2009
22 – regional pol. & coord. of structural instr.	2 Oct 2009	
23 – judiciary and fundamental rights		
24 – justice, freedom and security	2 Oct 2009	
25 – science and research	12 June 2006	12 June 2006
26 – education and culture	11 Dec 2006	11 Dec 2006
27 – environment	19. Feb 10	
28 – consumer and health protection	12 Oct 2007	27. Nov 09
29 – customs union	21 Dec 2006	2 Oct 2009
30 – external relations	12 Oct 2007	30. Oct 2008
31 – foreign, security and defence policy		
32 – financial control	26 June 2007	
33 – financial and budgetary provisions	19 Dec 2007	
34 – institutions		
35 – other issues		

75 MFAEI (2009), p. 8
76 EU Enlargement (2010)

5.1.3 Croatia in the International Community

Croatia participates in many international organizations, including:

ACCT (observer), BIS, BSEC (observer), CE, CEI, EAPC, EBRD, FAO, IADB, IAEA, IBRD, ICAO, ICC, ICCt, ICRM, IDA, IFAD, IFC, IFRCS, IHO, ILO, IMF, IMO, Interpol, IOC, IOM, IPU, ISO, ITU, ITUC, MIGA, MINURSO, MINUSTAH, NAM (observer), NSG, OAS (observer), OIF (observer), OPCW, OSCE, PCA, PFP, SECI, UN, UNCTAD, UNESCO, UNFICYP, UNIDO, UNMEE, UNMIL, UNMIS, UNMOGIP, UNOCI, UNOMIG, UNWTO, UPU, WCO, WHO, WIPO, WMO, WTO, ZC.[77]

On May 25th 2010, Croatia joined IRENA, the International Renewable Energy Agency[78] as its 145th member state.

5.1.4 Croatia's Economic Situation and Investment Climate

Table 12: Collection of Croatia's economic figures and forecasts by RZB Research

Key economic figures and forecasts

	2005	2006	2007	2008	2009	2010e	2011f
Nominal GDP (EUR bn)	35.7	39.1	42.8	47.4	45.4	46.5	48.4
Real GDP (% yoy)	4.2	4.7	5.5	2.4	-5.8	-0.9	2.5
Industrial output (% yoy)	5.1	4.5	5.6	1.6	-9.2	0.6	4.2
Unemployment rate (avg, %)	18.0	17.0	15.1	13.4	14.9	17.5	16.5
Average gross industrial wages (LCY, % yoy)	5.8	7.3	6.0	8.8	1.5	0.2	2.4
Producer prices (avg, % yoy)	3.0	2.9	3.4	8.4	-0.4	3.9	3.1
Consumer prices (avg, % yoy)	3.3	3.2	2.9	6.1	2.4	3.0	3.3
Consumer prices (eop, % yoy)	3.6	2.0	5.8	2.9	1.9	3.9	3.2
General budget balance (% of GDP)	-3.5	-2.6	-2.0	-1.8	-4.3	-4.4	-3.6
Public debt (% of GDP)	45.7	43.3	41.7	42.1	50.4	50.7	50.3
Current account balance (% of GDP)	-5.5	-6.9	-7.6	-9.2	-5.2	-5.4	-4.8
Official FX reserves (EUR bn)	7.4	8.7	9.3	9.1	10.4	10.8	11.4
Gross foreign debt (% of GDP)	72.1	74.9	76.9	85.1	98.5	105.3	107.8
EUR/HRK (avg)	7.40	7.32	7.34	7.22	7.34	7.32	7.35
USD/HRK (avg)	5.97	5.81	5.35	4.91	5.27	5.67	6.13
EUR/USD (avg)	1.24	1.26	1.37	1.47	1.39	1.29	1.20

Source: Thomson Financial Datastream, wiiw, Raiffeisen RESEARCH

Over the last 15 years, Croatia achieved impressive economic and social progress. Prior to the global crisis, the Croatian economy grew at a healthy 4-5 percent annually, incomes doubled and economic and social opportunities dramatically improved. Croatia's per capita income reached about 63 percent of the European Union (EU) average. However, Croatia like most countries in the region has not

[77] HR Identity
[78] IRENA

remained immune to the crisis[79]. At the beginning of 2010 the Government announced and initiated programmes aimed at reviving the economy, offering direct funding participation in working capital financing, risk participation in investment financing with a partial Government guarantee, participation in venture capital funds, and finally the restructuring of the poorest companies by means of a partial debt to equity swap, which means a temporary increase in the state's equity holdings in these companies.[80]

Croatia's overriding priority is to enter the EU with a competitive and growing economy and the institutional capacity to meet the demands of EU membership. To achieve this, several challenges need to be met, including the completion of Croatia's transition to a market economy with a focus on private sector growth, fostering greater competitiveness, and achieving convergence with EU income levels, in a way that improves the quality of life for all Croatians, and that is fiscally, socially and environmentally-sustainable.[81]

Croatia has also achieved progress in the "economic freedom" index: its overall score of 59.2 is 4.1 points higher than last year, reflecting significant improvements for government spending, investment freedom and protection of property rights. Croatia has moved up 24 places in the world rankings to rank 92 and from 38th to 37th out of 43 countries in the Europe region; yet, its overall score is still below the regional and world averages[82].

Figure 27: Croatia's *Economic Freedom Index* & details

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79 Worldbank Country Brief
80 RZB Croatia (2010)
81 Worldbank Country Brief
82 Heritage (2010)

Despite all improvements, the issuers of the ranking still see many restrictions to more economic freedom: Croatia's overall weakness stems from an excessive government interference that erodes the economy's efficiency and flexibility. In addition to high levels of government spending, government intervention in other key areas of the economy is considerable. Burdensome and unclear administrative regulations, particularly at the local level, continue to challenge entrepreneurs, resulting in lower levels of productivity and job growth. Corruption and political interference, especially with regard to the judiciary, also restrict economic freedom[83].

In terms of strengths and weaknesses, Unicredit, in line with other analysts, sees a likely EU accession soon and a disciplined monetary policy as major strongpoints for the future Croatian economy:[84]

STRENGTHS	WEAKNESSES
EU accession in 2012 looks likelier	Uncertainty over public sector borrowing requirement
Credible monetary policy response	High FX leverage in household and private sector
External imbalances adjusting quickly	2009 tax increases have adversely affected domestic demand

Figure 28: Unicredit Research - assessment for Croatia April 2010

5.1.5 Environmental Situation and Regime

In 2007, the Croatian Government assessed the state of environment in Croatia as "... relatively good compared to the situation in EU industrial countries, mainly due to the low negative impact of the heavy industries (due to their collapse in the 1990s). Croatia benefits from a number of natural advantages such as: unique and relatively well preserved natural environment, high level of biodiversity, high stores of fresh water etc. The natural environment is a crucial asset in Croatia's economic and social capital, and a driver of economic development, given its pivotal role in tourism in Croatia. .." [85]

Historically insufficient investment caused environmental protection to be less than in other developed countries, leaving substantial investment needs across all environmental sectors, of which the top three are waste management, water management and air quality.

83 Heritage (2010)
84 Unicredit CEE (2910), p. 34
85 EOP (2007), p. 6

Croatia developed a hierarchy of environmental strategies, under the Strategic Development Framework 2006-13, particularly the National Environmental Strategy, National ISPA (Instrument for Structural Policies for Pre-Accession) Strategy, various related sector strategies (energy, transport, planning, etc.), and strategies for environmental sub-sectors, including the Waste Management Strategy, and the Water Management Strategy.[86]

The Ministry of Environmental Protection, Physical Planning and Construction (Ministarstvo zaštite okoliša, prostornog uređenja i graditeljstva) maintains a list of all international treaties signed and all the national regulations relevant for environmental protection[87]. Mainly relevant for assessing a prospective project development for an Osmotic Power plant is the “Regulation on environmental impact assessment”.

5.1.6 Environmental Impact Assessment

In line with international standards, Croatia issued a Regulation on Environmental Impact Assessment (EIA) on May 29th 2008 with OG No. 64/08.

The EIA the regulation clearly sets out for which prospect projects an EIA is mandatory (Annex I) and for which projects an evaluation of the necessity of an EAI is necessary under the competency of the ministry (Annex II) or under the competency of an administrative body in the county (Annex III).

5.1.6.1 Mandatory EAI for PRO projects

A PRO project needs to undergo an EIA if it falls into one of the categories:

a) According to Annex I - Mandatory:

Item 3:

- Power plants and other combustion installations with power exceeding 30 MW_{el}

Item 31 (eventually):

Exploitation of mineral resources:

- …
- all types of salts and salt waters
- mineral and geothermal waters from which mineral raw materials may be extracted or accumulated heat may be used for energy purposes
- …

[86] EOP 2007, p. 6
[87] MZUPO regulations

b) According to Annex II – Subject to Evaluation:

Energy, item 1:

- Industrial installations for the production of electricity, steam and hot water with power exceeding 1 MW_{el} with the use of:
    - Fossil and solid fuels
    - Renewable energy sources (water, sun, wind, biomass, biogas, geothermal energy, waves, tides, etc.)

Subject to the nature of a PRO power plant, it will most likely be located in a *Protected Coastal Area (PCA)*, which is defined as the coastline including islands and, from the coastline, an area within 1.000 m inland and 300 m into the sea. This fact might lead to other relevant environmental conditions which may be applied during the EIA, especially as the plant's dimension and logistics access is expected to be intrusive for a fragile landscape.

5.1.6.2 Process

The process of determination of the need and competency levels needed for the EIA requires the mandatory involvement of a certified consulting company or institute. For preparation of an EIA, there are 12 companies currently certified and listed on the ministry's web-page[88] (second table: "POSLOVI STRUČNE PRIPREME I IZRADE STUDIJA O UTJECAJU ZAHVATA NA OKOLIŠ", entries with from/to dates). Some of these consulting companies are either faculties of universities or "institutes". The name *institute* indicates a company owned by the government but operating under free market conditions performing special services of public interest. In many cases such institutes collect, own and sell the data needed to evaluate and perform the environmental impact assessment.

Examples for such institutes in the context of PRO power plant projects are the DHMZ (Meteorological and Hydrological Institute[89]: weather, climate, hydrology, marine data), or the EIHP (Energy Institute Hrvoje Pozar: expert and scientific research in the field of energy[90]).

Much of the data required for a site selection and project development will already be needed in early stages but there is no free public access to them. So advice from project practitioners is to involve such certified consultants (as listed on the ministry's web page) from the very beginning.

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[88] EIA Consultants (2010)
[89] DHMZ home
[90] EIHP Mission

5.1.7 Protected Areas

Protected areas will require special attention and possibly costly provisions for a power plant project. Due to the nature of the PRO technology (being situated in or at the river deltas) chances of falling into a protected or Natura 2000 area are high.

As early as 1949 the first National Parks in the boundaries of today's Croatia were established (Plitvice Lakes and Paklenica). Today, there are 8 National Parks, ten Nature Parks and 2 strict reserves defined[91].

Table 13: List of Nature and National Parks[92]

National parks	Nature parks
The Plitvice Lakes	Kopacki Marshlands
The Kornati Islands	Papuk (Slavonian highlands)
The Brijuni Islands	Medvednica (Zagreb highlands)
The island of Mljet	Lonjsko field
Krka Falls	Zumberak - Samobor Mountains
Risnjak Mountain massive	Ucka massif
Paklenica	Telascica Bay - Dugi otok
Mountains of North Velebit	The Vransko Lake
	Mount Biokovo
	Mount Velebit
	The island of Lastovo

Of those, especially the Krka National Park is relevant as it encloses the Krka river estuary.

In addition to the parks listed, there are several sites designated for Natura 2000, which will make certain areas sensitive to, but not impossible for, PRO power plant projects. Those Natura 2000 areas are governed by the EU 1992 Habitats Directive and/or the EU 1979 Birds Directive[93]. The State Institute for Nature Protection (SINP) has prepared a list of potential Natura 2000 sites for Croatia in anticipation of the EU accession. These areas cover nearly 40% of Croatia's territory[94] and many of them are situated in Coastal regions (see Figure 30: Reserved areas for Natura 2000 in Croatia).

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[91] Protected areas
[92] National Parks
[93] Natura 2000
[94] N2000 leaflet (?)

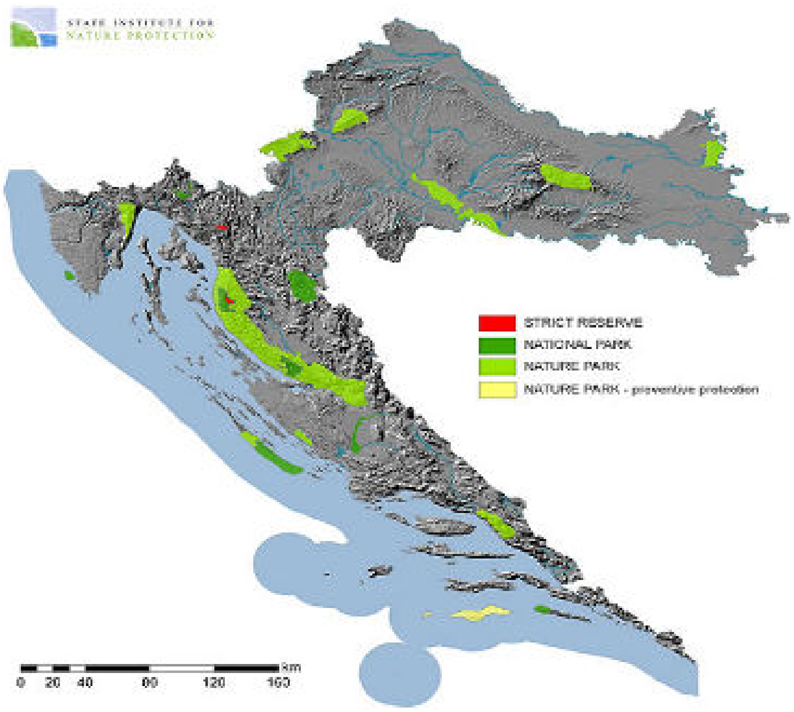

Figure 29: Protected areas in Croatia[95]

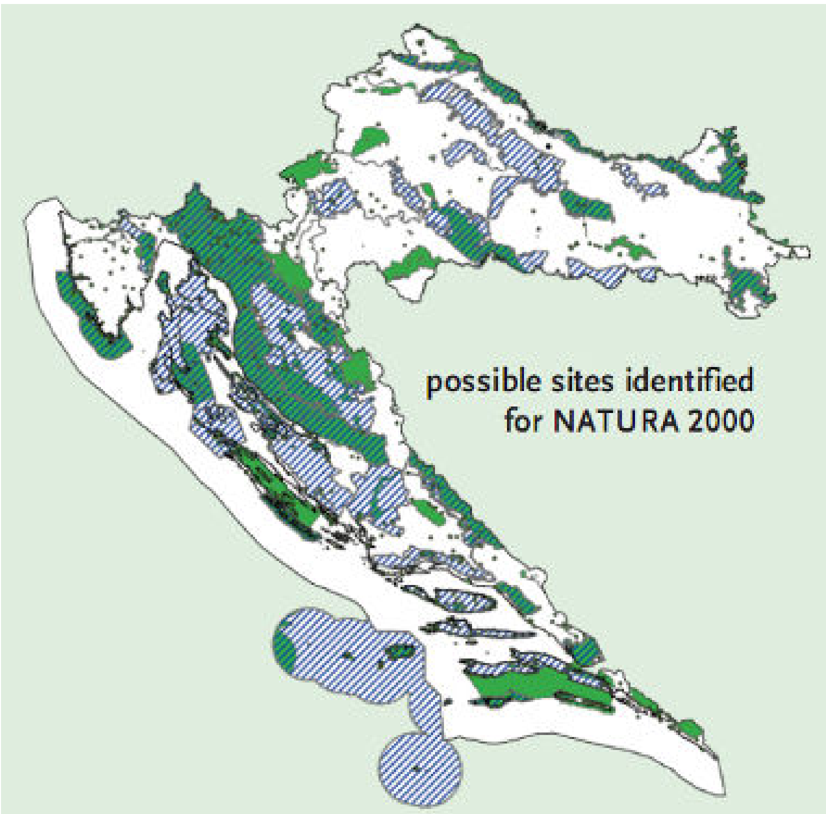

Figure 30: Reserved areas for Natura 2000 in Croatia[96]

[95] EOP (2007), p. 30
[96] N2000 leaflet (?)

5.2 Electricity market and conditions

5.2.1 Electric Power Sector and Market Players

Since 2000, the energy sector has undergone a significant transformation process, primarily performed by[97]:

- introduction of competition in energy production and supply;
- liberalised choice of energy supplier;
- the public character of the transmission network/transport system remains under state supervision;
- establishing a public character of the network with state or regional community ownership with the goal of equal, non-discriminatory access and competition;
- introduction of an independent national regulator for the energy business (HERA – Croatian energy regulatory agency).

5.2.1.1 HEP - Hrvatska Elektroprivedna

Croatia's transmission, distribution and electricity supply, as well as nearly all of the electricity production, are organised within the state owned HEP Group that consists of HEP d.d.[98] as the leading company plus many affiliated companies. The privatisation act for HEP (Official Gazette, No. 32/2002) sets out restructuring and privatisation rules under which the Republic of Croatia retains a 51% of shares until Croatia becomes an EU member.

The Krško Nuclear Power Plant located in Slovenia is jointly owned by Slovenia and Croatia, each owning 50 %, while the thermal power plant Plomin II is jointly owned by HEP and German company RWEE.[99]

HEP Group has ~4.000 MW of installed capacity for electricity production. In addition HEP operates the transmission and distribution networks with a total of 24 thousand transformer stations and 128 thousand kilometres of lines of different voltage levels[100] (see also chapter 5.2.4).

5.2.1.2 HROTE - Croatian Energy Market Operator

On April 4th 2005, the Croatian Energy Market Operator (HROTE) began its operation. As a public service, HROTE organizes the electricity market under

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[97] Energetika (2008), pp 3-6
[98] d.d. = abbreviation for Croatian joint stock company
[99] Energetika (2008), pp 3-6
[100] HEP

supervision of the Croatian Energy Regulatory Agency (HERA). HROTE's activities include[101]:

- Issuing electricity market rules,
- Registration of contractual obligations among market participants,
- Keeping records of suppliers and eligible customers,
- Preparation of a day ahead market plan,
- Settlement of balancing energy,
- Collecting fees for incentivizing the renewables and cogeneration from suppliers and its distribution to eligible producers,
- Analysing the electricity market and recommending improvements.

5.2.1.3 HERA - Croatian Energy Regulatory Agency

The Croatian Energy Regulatory Agency (HERA) was established as an autonomous, independent and non-profit public institution in order to develop and implement regulations of energy activities.

Fundamental goals of these activities are:

- Ensure objective, transparent and non-discriminative carrying out of energy activities;
- Take care of the implementation of principles of regulated access to the network/system;
- Adoption of methodologies for determination of tariff items of tariff systems;
- Establishment of efficient energy market and market competition;
- Protection of energy consumers and energy operators.

5.2.1.4 Legislative Framework

A compilation of all legislative and institutional frameworks was achieved by the RELEEL project[102], financed under the EU CARDS 2004 program. A short overview including a process flow is issued in a leaflet[103] and the complete legal framework is documented in detail by Tiložanec[104]. The collection of the main laws and regulations (in full text) that describe the rights and duties of a (potential) producer is presented at the HEP OPS web page[105].

[101] HROTE
[102] RELEEL (2007)
[103] RELEEL Guide (2007)
[104] Tiložanec (2009)
[105] HEP-OPS Laws

5.2.2 Electricity Supply, Demand and Price Levels

Table 14 shows Croatia's electricity balance of 2008, published by HERA in their Annual Report 2008. It reveals that Croatia is an electricity importing country; even if Croatia's 50% stake in the Kržko Nuclear Power plant is treated as domestic, there is still a gap of 3.6 TWh between the gross consumption of ~18 TWh versus a domestic production of 14.4 TWh. Secondly, the electricity balance reveals that Croatia is involved in significant electricity transmission business to and from neighbouring countries.

Table 14: Croatia's Electricity Balance 2008 [GWh][106]

Ord.No.	Electricity balance	2006	2007	2008.
1.	Total production[1]	11.566,2	11.268,6	11.418,8
2.	Production of nuclear power plant Krško for HEP d.d.	2.644,5	2.713,9	2.985,8
3.	Other input into Croatia	10.570,9	9.172,3	9.258,5
4.	Input into Croatia (2+3)	13.215,4	11.886,2	12.244,3
5.	Total procurement (1+4)	24.781,6	23.154,8	23.663,1
6.	Output from Croatia	7.593,2	5.525,1	5.667,3
7.	Total consumption (5-6)	17.188,4	17.629,7	17.995,8
8.	Immediate procurement to the distribution network	443,3	374,8	394,9
9.	Losses in transmission network	544,0	547,1	483,8
10.	Transmission consumption (7-8-9)	16.201,1	16.707,8	17.117,1
11.	Direct customers	947,4	919,7	978,6
12.	Pumping work (Velebit Pump Storage Power Plant) and other own consumption	221,0	272,0	192,9
13.	Delivery to distribution (10-11-12)	15.032,7	15.516,1	15.945,6
14.	Transit (min(4,6))	7.593,2	5.525,1	5.667,3
15.	Transmission losses % (100x9/(10+9+14))	2,2%	2,4%	2,1%

[1] Including the energy taken over from industrial power plants and wind power plants and the generation taken over directly into the distribution network

Source: HEP-OPS

According to a water rich climate and geography, Croatia operates a multitude of small (1.4 MW) to large (500 MW) hydropower plants and reaches an impressive share of 52% of hydropower capacity in the overall production mix:

Elektrane u sustavu HEP-a Hep's Power Plants	Raspoloživa snaga proizvodnih kapaciteta Available electricity Generation Capaciy	Udio Share
Hidroelektrane Hydro power plants	2.056,26 MW	52%
Termoelektrane Thermal power plants	1.397,00 MW	35%
TE Plomin d.o.o. TE Plomin, Ltd	192 MW	5%
Ukupno RH Total in Croatia	3.645,26 MW	92%
NE Krško Krško nuclear PP	338,0 MW	8%
Ukupno / Total	3.983,26 MW	100%

Figure 31: Electricity generation capacity mix 2007[107]

Figure 32: Hydro (HE) and thermal (TE) power plants of HEP[108]

[106] HERA (2008), p.34
[107] Energetika (2008), p.4
[108] HERA (2008) p. 36

Yet, looking at the achieved hydropower energy generation per capita and comparing it to the EU 27 countries (see Figure 33), it reveals that

a) The amount of ~1,300 KWh/capita is about 50% higher than the EU 27 average, but
b) The total electricity demand of 3,740 KWh/capita (2008) is still lagging behind the EU level (EU 27 average ~6,500 KWh/Capita),
c) Leading to a strong pressure to pursue sustainable energy sources to prevent a drastic increase of the fossil and nuclear share in the electricity production mix.

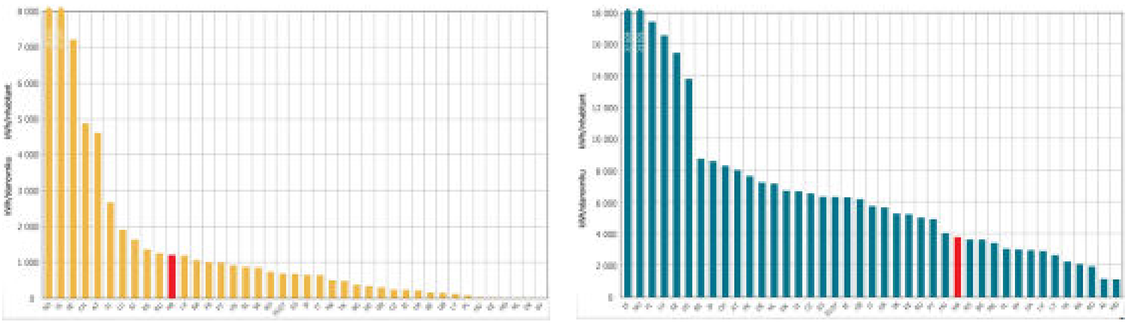

Figure 33: Electricity demand and Hydropower production per capita in Hrvatska vs. EU 27 countries[109]

Hence, the future growth of energy demand (see chapter 5.2.3), and especially the share of electricity in the overall demand mix, require a set of investment strategies These strategies must meet the demand but also fulfil the goals of the reduction of greenhouse gas emissions and to achieve sustainable growth.

From an electricity price perspective, Croatia can still be seen as a low-price market, with a tendency to end-user price increases similar to other European countries:

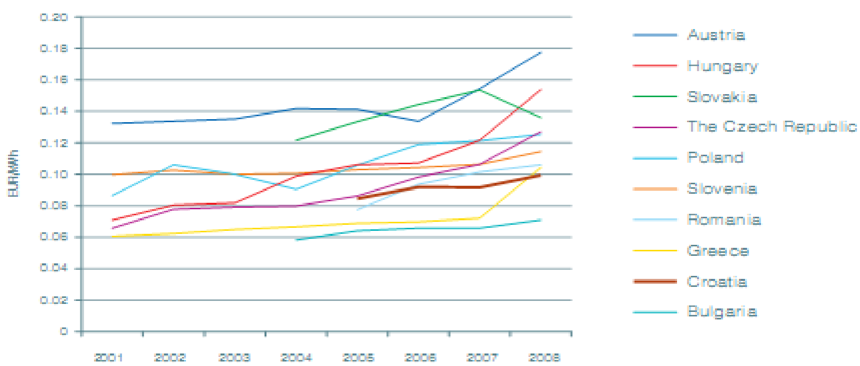

Figure 34: Electricity prices for household customers in €/KWh incl. network, taxes and fees[110]

[109] Kuližić (2010), pp 5-6
[110] HERA (2008), p. 43

As in most other markets, the purchasing power of large customers results in significantly lower energy costs (see Figure 35).

Customer category	2005	2006	2007	2008 (1-6.)	2008 (7-12.)
High voltage customers	0,31	0,31	0,31	0,30	0,35
Medium voltage customers	0,43	0,45	0,45	0,44	0,54
Customers on low voltage - businesses, without street lighting	0,57	0,59	0,59	0,59	0,70
Customers on low voltage - street lighting	0,47	0,49	0,49	0,49	0,60
Customers on low voltage - businesses total	0,56	0,58	0,58	0,58	0,69
Low voltage customers - households	0,56	0,58	0,58	0,58	0,70
Total customers on low voltage	0,56	0,58	0,58	0,58	0,70
Total tariff customers	0,52	0,54	0,54	0,54	0,64

Source: HEP ODS

Figure 35: Electricity prices per customer segment in HRK/KWh incl. taxes and fees, excl. network[111]

For reasons of comparison, the feed-in tariff for small hydropower up to 10 MW capacity is listed here: 0.42 Kuna/KWh.

For the average household customer, the electricity bill falls into these category shares:

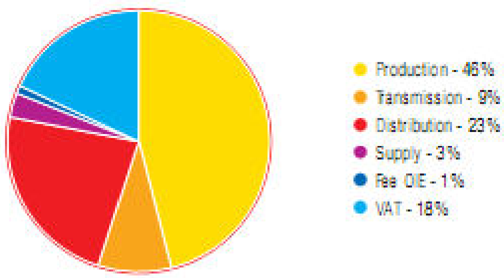

Figure 36: Price structure for customers (households), second half of 2008[112]

5.2.3 Consumption Trends and Supply Strategies

In Croatia's Energy Strategy, drafted in 2008 and approved by the parliament in 2009, the ministry shows growth scenarios for final energy consumption of 3.7% in the sustainable scenario to 4.3% in BAU scenario:

Year	2006.	2010.	2020.	Growth rate of energy demand 2006.-2020. in %	2030.	Growth rate of energy demand 2020.-2030. in %
Final energy consumption according to business as usual projections [TWh]	15,00	17,68	27,00	4,3	36,87	3,2
Final energy consumption according to sustainable scenario [TWh]	15,00	17,38	24,86	3,7	33,04	2,9
Total electricity consumption according to sustainable scenario [TWh]	18,05	20,57	29,24	3,5	38,66	2,8

Figure 37: Final electricity demand according to various scenarios[113]

111 HERA (2008), p. 44
112 HERA (2008), p. 47
113 Energy Strategy (2008) p. 36

From 2001 to 2006 the electricity consumption grew by 4,1% annually.
The Energy Strategy, based on the sustainable scenario (with growth rate 3,5%), indicates an increasing gap of generation capacity up to 6 GW until 2030:

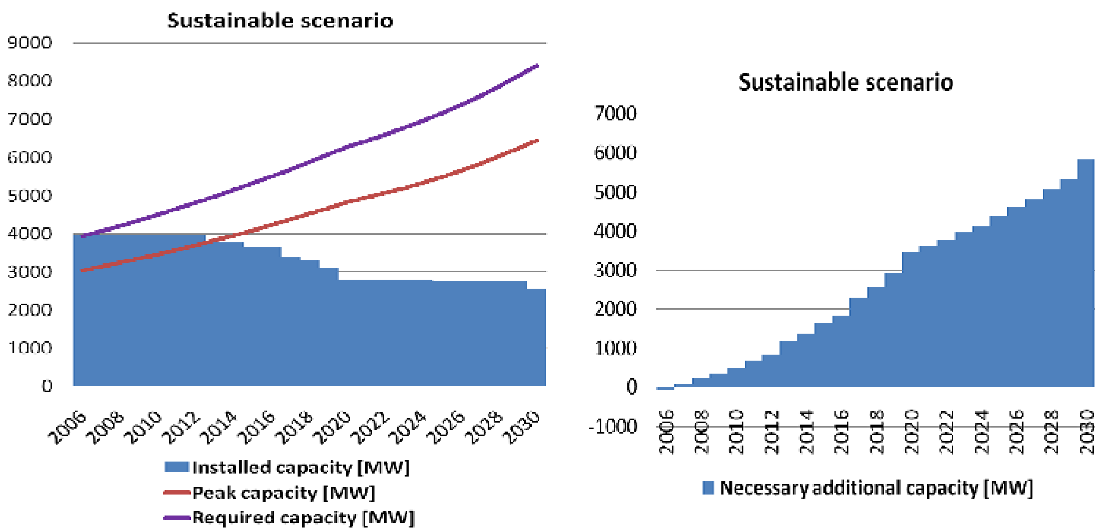

Figure 38: Predicted generation capacity installed and needed (left) and resulting gap until 2030 (right)[114]

When attending the Visegrad Four Summit on March 1st, 2010, Croatia's Prime Minister Jadranka Kosor talked about an electricity consumption growth of 4.3% until 2020, which is projected in the Energy Strategy as the growth rate in the BAU scenario. At the same summit, Kosor predicted a € 15 bn investment into Croatia's energy sector until 2020.[115]
The development directions of the Energy Strategy with regards to the needed capacities state:

- Constructing new production capacities to satisfy growing domestic electricity demand and replacing existing deteriorated plants;
- Utilizing renewable energy sources in the electricity generation and encouraging distributed production;
- Stimulating efficient electricity end-use.

Three main scenarios were evaluated, all of which rely heavily on fossil thermal and nuclear power generation, due to the large gap to be filled until 2020. The preferred scenario finally suggests a fossil thermal capacity of 2.350 MW, a nuclear plant with

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[114] Energy strategy (2008), p. 39
[115] Visegrad Four (2010)

1.000 MW, plus an additional capacity of 1.845 MW to be based on various renewable resources (including hydropower facilities of 300 MW):

Facility/Unit/Part of plant	Nominal power on generator, MW	Foreseeable year for entry into operation
TE-TO Zagreb unit L	100	2009.
TE Sisak unit C	250	2012.
TE PLIN 1	400	2013.
TE UGLJEN 1	600	2015.
NUKL 1	1000	2020.
COGENERATION	Progressive yearly increasing by 30 MW, additional total 300 MW	2011.-2020.
HPP other	Progressive yearly increasing by 50 MW, total 300 MW (0,75 TWh new energy from HPP)	2015. – 2020.
Renewable	1545 MW Ren with production of 4000 GWh in 2020.	2011. – 2020.
Total GAS	1050	
Total COAL	600	
Total NUCL	1000	
HPP + REN	1845	

Figure 39: Suggested (white) scenario for new generation capacity until 2020[116]

According to this sustainable (white) scenario, the required capacity and planned up-scaling should match accordingly:

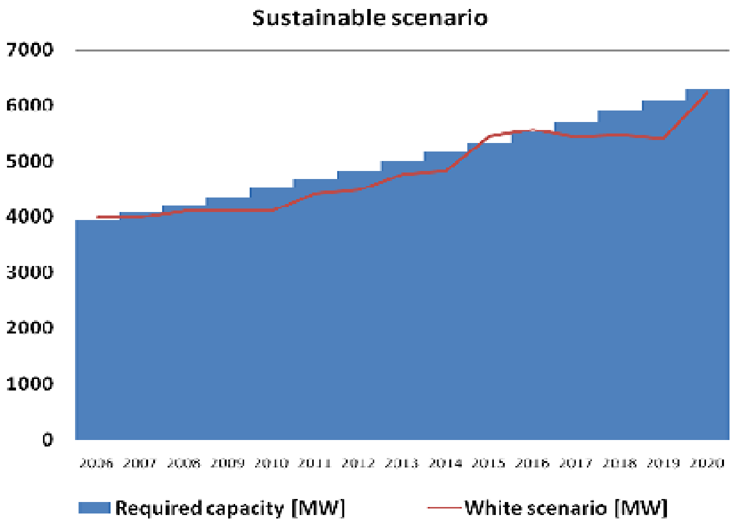

Figure 40: New capacity and capacity demand according to sustainable "white" scenario[117]

5.2.4 Grid and Grid Access

In Croatia there is one transmission system operator, HEP-OPS, who is in charge the electric power system operation and proper coordination of the production, transmission and distribution grid systems.

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[116] Energy Strategy (2008), p. 42
[117] dito

Transmission network: Electricity transmission is carried out at three voltage levels - 400, 220 and 110 kV – through a total of 7,230 km of lines. Within the transmission system there are 112 disjunction plants.

Distribution network: is comprised of the following sub-stations: 110/35(20) kV, 110/10(20) kV, 35/10 and 10/0.4 kV, as well as lines (overhead and cables) up to 110 kV. In the field of middle and low voltage there are 25,123 disjunction plants and 101,573 km of lines.

Figure 41: Transmission network and production facilities of the Croatian electric power system[118]

According to the Energy Strategy, the following changes must be made to the distribution network in the near future[119]:

[118] HERA (2008), p.20
[119] Energy Strategy (2008) p. 48

- Gradual transition to two-level transformation;
- Installation of gauging devices with the possibility of a two-way communication at the user's gauging locations;
- Construction of simple distribution complexes and apparatuses at all voltage levels of the distribution network where this can be justified;
- Automation of plants and networks and significant application of information-communication technology.

Roles and Responsibilities for providers who need to connect to the grid are regulated in the "Grid Code"[120].

5.2.5 RES-E Policy and Framework

According to the Energy Strategy, the development directions for the power sector include[121]:

- Utilizing renewable energy sources and encouraging distributed production;
- Stimulating efficient electricity end-use.

5.2.5.1 Goals

In addition to the 300 MW of additional conventional hydropower capacity, the strategy foresees 1,545 MW of new capacity based on renewable energy sources until 2020 (2,900 MW until 2030). The goals and for each of the technologies fall into those sub-goals (until 2030 in brackets)[122]:

- 1,200 MW installed power in wind power plants (2,000 MW),
- 140 MW installed power in biomass power plants (420 MW),
- 40 MW installed power in waste-to-energy plants (60 MW),
- 20 MW installed power in geothermal power plants (30 MW),
- 45 MW installed power in solar power plants (250 MW),
- 100 MW installed power in small hydropower plants(140 MW).

The strategic goal for electricity produced from all renewable sources (including all large hydropower plants) in 2020 amounts to around 10.7 TWh, or around 35% of total electricity produced. *New renewable* sources for electricity production account for 4.1 TWh or around 13%. The goal to be achieved by December 31, 2010 is as follows:

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[120] Grid Code (2006)
[121] Energy Strategy (2008) p. 36
[122] Energy Strategy (2008) p. 36

- Minimum share of renewable energy sources amounting to 5.8% of the total electricity consumption;
- Minimum share of electricity from cogeneration plants which is delivered into transmission, i.e., distribution network, amounting to 2.0% of total electricity consumption.

Compared to the actual picture, this goal seems to be more than optimistic. The achieved shares in 2008 for RES-e, excluding large hydropower, are:

- 1,3% of total electricity production, or
- 0,8% of total electricity consumption.

Despite a strong interest from investors, only very few RES-e projects were given final rulings from HERA, amounting to a total capacity of ~37 KW (see Figure 42). When in operation, they will contribute with calculated 210 MWh additionally to the grid, representing a share of about 0,0012% of total 2008 consumption.

Type of plant	No. of issued rulings		Plant power	
	Preliminary	Final	Prior	Final
Solar power plants	2	1	19 kW	7,14 kW
Hydro power plants	-	2	-	30 kW
Wind power plants	4	0	63,6 MW	-
Total	6	3	63,619 MW	37,14 kW

Figure 42: RES-e projects with final rulings of HERA, 2008[123]

5.2.5.2 Feed-in Tariffs

These facts emphasize that the goals stated are very far reaching and, as seen in many other countries, additional capacities based on RES-e will hardly offset the expected growth, if no drastic measures are set into operation.
One of the main measures taken in order to stimulate investments into new renewable energy is the introduction of feed-in tariffs that are granted to eligible producers for the period of 12 years and are adjusted to the consumer price index. For 2010, those tariffs are:

Table 15: RES-e feed-in tariffs for 2010 with relevance to the PRO technology[124]

	FIT 2010 Kn/MWh		FIT 2010 €/MWh	
RES-e Power Plant Type	**≤ 1 MW**	**≤ 10 MW**	**≤ 1 MW**	**≤ 10 MW**
Small Hydropower ≤ 5000 MWh	765,5	765,5	108,9	108,9
Small Hydropower ≤ 15000 MWh		610,2		86,8
Small Hydropower > 15.000 MWh		466		66,3
Other Renewable Energy Source	665,6	554,6	94,7	78,9

As of June 12th, 2010: 1 Euro = 7,03 Kuna

[123] HERA (2008), p. 49
[124] RES Tariffs (2010)

5.2.5.3 Investment Subsidies

Additional subsidies for renewable energy projects might be given via the Environmental Protection and Energy Efficiency Fund (FZOEU)[125]. Based on public tenders, this fund grants to finance programs, projects and other activities in accordance with the provisions of the Law on Fund for Environmental Protection and Energy Efficiency. Funds are granted to legal and natural persons by loans, subsidies, financial assistance or donations. Activities funded include:

- The protection, preservation and improvement of air quality, soil, water and seas, and climate change mitigation and protection of the ozone layer,
- Implementation of national energy programs,
- Encouragement of the use of renewable energy sources (sun, wind, biomass, etc.),
- Promotion of sustainable development,
- Encouragement for education, research and development studies, programs, projects or other activities, including demonstration activities.

[125] FZOEU

6. Potentials for Osmotic Power in Croatia

6.1 Definitions

The definitions for potentials are applied according to the specification untroduced by the International Energy Agency.

"***Theoretical potential:***
This represents the theoretical upper limit of the amount of energy that can be generated from a specific resource, over a defined area, based on current scientific knowledge. It depends on physical flows only (e.g., average solar irradiation on a certain region).

Technical potential:
The technical potential can be derived on the basis of technical boundary conditions, e.g., efficiencies of conversion technologies, or overall technical limitations such as available land area for wind turbine installation. For most resources, the technical potential is dynamic: e.g., with improved research and development, conversion technologies may be improved, with resulting improvement in the technical potential.

Realisable potential:
The realisable potential represents the maximum achievable potential, assuming that all existing barriers can be overcome and all development drivers are active. In this respect, general parameters such as market growth rates and planning constraints are taken into account. It is important to note that realisable potential is also time-dependent: it must relate to a certain year. In the long run, the realisable potential tends towards the technical potential.

Mid-term potential:
The mid-term potential is defined as the realisable potential in 2020.

Economic potential:
The economic potential is defined as that potential which can be exploited without the need for additional support, i.e., whose exploitation is competitive compared with conventional incumbent technologies."[126]

6.2 Theoretical Potential for PRO

Given the above definition, the theoretical potential is determined by the amount of water flowing into the Adriatic Sea per year and the potential of the mixing of sea water and fresh water under certain conditions. Those basic conditions are set as follows:

- Fresh water salinity corresponds to a standard salinity of ~0,5 across all rivers;
- Fresh water does not carry pollutants that make the PRO technology inappropriate;
- Sea water salinity is expected to be 35 (standard) or above;

[126] IEA (2008), pp. 61-62

- Water temperature influences are neglected;
- Average water flows will not decline in the future;
- The yearly peak flow of a river determines the rated capacity for this river, regardless of achievable utilization;
- The inherent energy content of the process of mixing 1 m³ fresh with 1 m³ sea water is about 1.5 MJ[127] (= 416.7 MWh), which means that a flow of 1 m³/s represents a theoretical capacity of 1.5 MW.

Hence, the theoretical maximum *power potential* results from all rivers' peak flows, and the theoretical *energy potential* is the sum of each river's flow accumulated over the year. For this reason, the hydrological situation of Croatia has to be examined and the available data analyzed.

6.2.1 Hydrological Situation and Discharge

Croatia is to be seen as a water rich country with strong precipitation especially east of the Adriatic coastal regions.

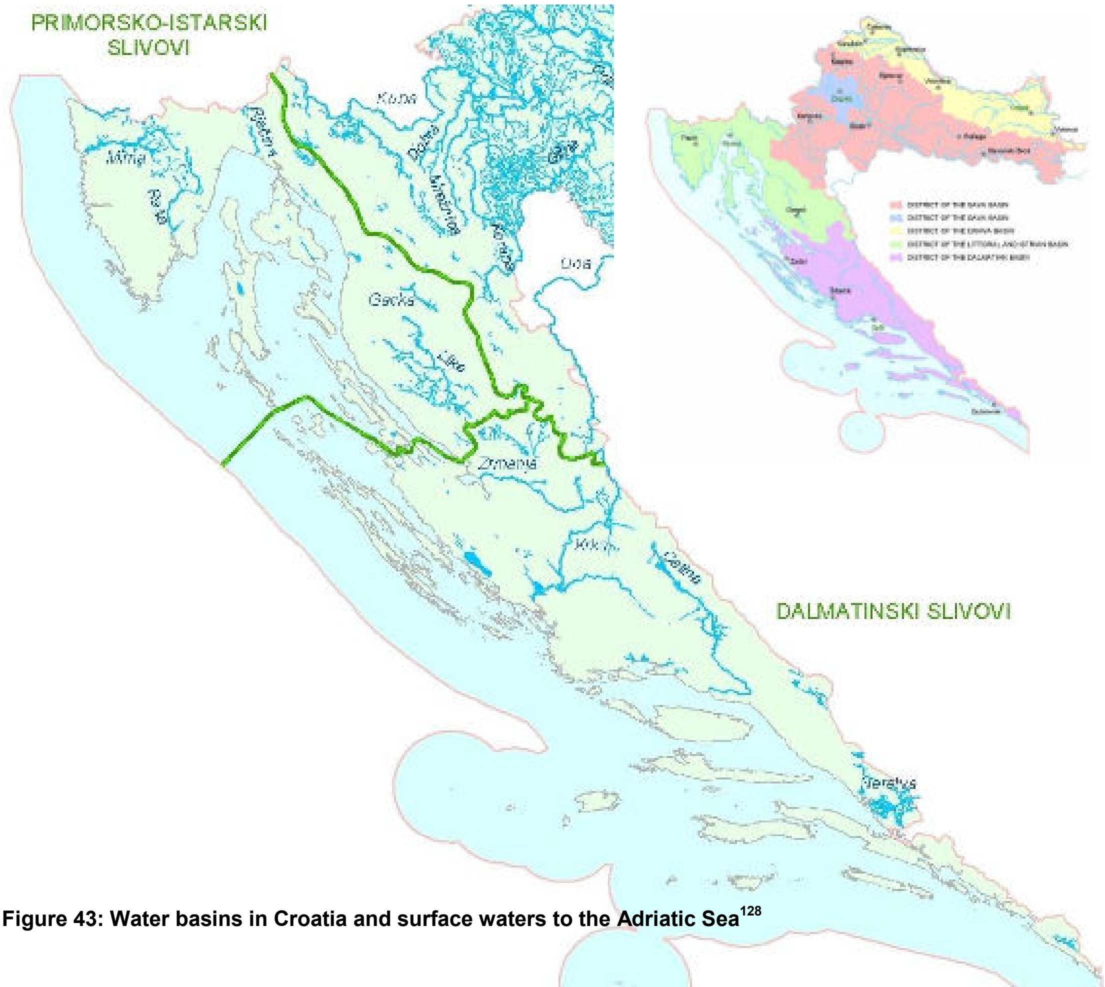

Figure 43: Water basins in Croatia and surface waters to the Adriatic Sea[128]

[127] Post et.al. (2006) p. 222
[128] WFD-Croatia Maps

Croatia's main water bodies Save, Drave and Dunava are situated in Europe's largest catchment area of the Danube and do not discharge into the Adriatic Sea. For the PRO technology only those rivers that discharge a catchment towards the sea are of interest. In Croatia these catchments are the Littoral-Istrian river basin and the Dalmatian river basin as shown in Figure 43.

Table 16: Average discharge to the Adriatic Sea[129]

	River according WMS	Q_{avg} m³/s		Other sources	Q_{avg} m³/s
Dalmatian	Zrmanja	37	Not listed	Ombla [2)]	24
	Krka	55		Trebisnjica [3)]	63
	Cetina	99		Lika - Senj [4)]	31
	Neretva	342	Runoff exploitable		673
Primorsko-istarski	Mirna	8	TOTAL Runoff		687
	Raža	1	*1) karstic sinks, not exploitable*		
	~~Boljuncica~~ [1)]	~~1~~	*2) karstic spring, short river bed*		
	Rječina	13	*3) art. tunnel to Dubrovnik HPP; Q_I = 90 *)*		
	~~Lika~~ [1)]	~~7~~	*4) artificial tunnel to Senj HPP, Q_I = 60 *)*		
	~~Gacka~~ [1)]	~~13~~	**) $Q_{avg} = Q_T * FLH/8760$*		

Table 16 shows the water bodies that discharge to the Adriatic Sea as listed in the Water Management Strategy paper of Hrvatske Vode. On the one hand, Lika, Gacka and Boljuncica cannot be exploited for the technology examined as they discharge into karstic sinks, where water disappears through the karst. On the other hand, three waters were added to the list as they may be interesting for the PRO technology:

- Ombla, which is a karstic spring at Komolac (near Dubrovnik) with a river bed as short as 4 km and with a natural sub-sea-level storage siphon[130]. It is fed by the waters of Trebišnjica in Bosnia and Herzegovina, which disappear in karstic sinks after being exploited by hydropower stations and drained into the
- Trebišnjica tunnel, which is an artificial drain of the tail water of the Trebinje Hydropower plant[131], leading to the hydropower plant of HEP in Dubrovnik, where its tail water discharges into the sea, and
- Lika tunnel to the Senj hydropower plant in St. Jurai with the tail water running off to the sea[132].

[129] based on Water Management Strategy (2009), p. 11; DHMZ direct communication and Watersee-Trebišnjica
[130] Watersee-Trebisnjica
[131] HE Dubrovnik
[132] HE Senj

As the PRO technology does not need a water head but just flow, both Ombla and the Trebišnjica – via the HE Dubrovnik tail water – and the HE Senj tail water are included in the potential calculation.
The annual aggregation of the daily discharges (average from 1961 to 1990) of all Croatian rivers amount to ~5,900 m³/s. Out of these, 673 m³/s, which are only ~11% of the total water, flow into the Adriatic Sea.

6.2.1.1 Theoretical Potential Calculation

Based on this average discharge data the theoretical energy potential can be calculated by simply multiplying the average flow with the specific energy content:

$$416.7\ Wh/m^3 * 673\ m^3/s * 3{,}600\ s/h * 8{,}760\ h = 1{,}010\ MW * 8{,}760\ h \approx 8.8\ TWh$$

Compared to 22.8 PWh of the world's theoretical potential of Salinity Energy (see Chapter 1.1), the 8.8 TWh theoretical potential of Croatia take about a share of 0.038%.

6.3 Technical Potential

6.3.1 Further Definitions and Specification

According to the definitions as used in the Croatian Tariff System for renewable energy sources, the following definitions are used for further calculations[133]:

- *Installed Power* of the plant is the sum of nominal outputs of all generators in the plant;
- *Nominal Output* is the permanent output of a production unit according to which the unit was ordered and designed.

In this context the definition applies to a PRO power plant as follows:

- *Installed Power* is defined by the generator's rated capacity (~1MW per 1 m³/s flow) and
- *Nominal Output* is defined by the maximum power connected to the grid, requiring the full supply of the water flow to which the Installed Power is designed.
- The plant's *Full Load Hours* describe the plant's utilization as defined by annual energy delivered to the grid per installed (turbine) power.

[133] RES Tariffs (2010), Article 2 (2) 1 and 3

6.3.1.1 Technical Reductions

The following technical conditions reduce the *theoretical potential* to a smaller *technical potential*:

- Process related, the capacity that can be achieved from 1 m³/s of fresh water when mixing with 2 m³/s sea water is 1 MW (installed power);
- Up to 25% of the electric energy (ex turbine) is used for internal losses and processes such as pumping and washing; these losses are dependent on site and construction such as the plant height related to the sea-level. Losses are assumed to tend towards 20% over the next 20 years);
- By now, a maximum output capacity of 750 KW can be connected to the grid out of 1 m³/s of flow, or in terms of utilization a maximum of 6.570 FLH for 1 MW rated (but internal) capacity;
- Process related down-times for washing of membranes (0,5 h per day or 2%) reduce the 6.570 FLH by another 2% to 6.439 FLH of installed capacity (this relates to ~8.600 plant full operation hours).

6.3.1.2 Natural Technical Reductions

In addition to the purely technical reductions, the PRO technology will face many natural and environmental related cutbacks (see chapter 4.6), which can be taken as “technical reductions”. Those reductions can be time-dependent; e.g., the expected future technical evolution will reduce the plants’ foot prints, hence the technology’s need for valuable land.
Natural technical reductions are mainly due to:

- Restricted areas (e.g., Krka National Park);
- Available space for the plants‘ constructions;
- Technically complicated access to the water resources of required quality;
- Finally, there are hydrological conditions that restrict the optimal size of a PRO plant: strong fluctuations of the water flow due to seasonal precipitation fluctuations. This phenomenon can be seen particularly in the south of Croatia with draughts during summers resulting in dry rivers.

None of those natural restrictions can be calculated without site specific pre-screening, and actually nearly all of the restrictions can be transposed into economic restrictions by increasing investment costs. Therefore, it has been decided to neglect those restrictions for the calculation of the technical potential and to account for them in the realisable potential analysis.

6.3.1.3 *Technical Potential Calculation*

Based on this average discharge data and above parameters the technical energy potential can be calculated as follows:

In 2010: 0.*75 KW/(m³/s)* 673 m³/s * 8,760 h * 98% = 505 MW * 8,760 h ≈ 4.33 TWh*
In 2030: 0.*80 KW(m³/s) * 673 m³/s * 8,760 h * 98% = 505 MW * 8,760 h ≈ 4.62 TWh*

Compared to the above calculated 8.8 TWh of Croatia's theoretical potential, the 4.33 TWh technical potential represent a share of 49%.

6.4 Realisable Potential

6.4.1 Introduction of the "Reasonable Potential"

Although the river flow pattern sets a natural limitation, by definition it cannot be factored in as a reduction of the theoretical or the technical potential for the PRO technology. By being a "naturally given" barrier it can only be overcome by absurd efforts to deploy the maximum PRO capacity. This is exactly the challenge of the definition of a "realisable potential": not all that is technically realisable and therefore part of the technical potential can reasonably be pursued.
Therefore, the category of the *reasonable potential* is introduced to mark the target line for the introduction of a new technology. It defines that fraction of the technical potential which allows a *reasonable* business case in the foreseeable future and sets the maximum target for the realisable potential.

To analyse what can be a reasonable business case for PRO it needs to be emphasized that one of the preconditions to exploit the calculated energy potentials is the implementation of the maximum capacity per river which is determined by each river's peak flow. Only under this condition can the river's maximum discharge be fully processed for power generation. Depending on the characteristics of a river's flow pattern, this can either make good business sense or be a complete waste of efforts.
As outlined in chapter 7, the concept of a PRO-plant is that of a base load operation, hence it is not well suited for strongly fluctuating water resources. Over-capacity that results from configuring a plant based on a river's peak flow means over-investment and sets the primary economic constraint for the realisable potential. Based on a

river's flow pattern the rated capacity should be set in such a way that the achievable full-load hours can achieve an economic return. This means that next to the purely economic conditions (costs vs. tariffs) the achievable utilization will be the main factor for the determination of a reasonable potential.

Therefore, as a first step, the flow characteristic of each water source is analyzed. In a second step the necessary capacity, that supports the reasonable utilization of the investment in a PRO plant, is determined.

6.4.2 Analysis of Croatian Rivers' Discharge

Detailed flow data was made available by the Meteorological and Hydrological Institute[134] for these rivers: Cetina, Krka, Mirna, Ombla, Raža, Zrmanja and Rjecina. The data sets are reports of the daily discharge in m^3/s delivered in the form of text files. Flow data reports include the years 1999-2008 or a subset of those years. Unfortunately, the Rjecina flow data report does not show the required quality to allow analysis with statistical methods.

For the Neretva river, data was obtained from the "Agency for Adriatic Sea Watershed in Bosnia and Herzegovina" (Jadran) as DHMZ does not own this data. The data is collected from the hydrological station „Zitomislici" which is the closest hydrological station to the Adriatic Sea with an established flow (Q in m^3/s) to water height (H in cm) relation. According to Jadran, all other downstream hydrological stations are under sea tide impact, so that it is not possible to establish a Q (m^3/s) to H (cm) relation and thus derive data for discharge[135]. „Zitomislici" is about 47 km away from the Neretva river mouth.

A comparison with the summary data published in the Water Management Report which was also used for the calculation of the theoretical and technical potential, shows a reduced flow and also a different flow pattern especially in winter months. This could indicate a change of water regime over time by the river's exploitation for hydropower, but no further investigation has been performed to clarify the differences.

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[134] DHMZ – Direct communication and delivery of flow data
[135] Jadran – Direct communication and delivery of flow data

In some cases other methods than analysing the daily data series were used:

- Dubrovnik and Senj Hydropower Plant tail waters:
  - The installed hydropower flow (Qi) is used to set the rated capacity (Q_i=Q_{max});
  - The plants' calculated full-load hours allow the calculation of the average flow (Q_{avg});
  - Their monthly distribution of flows is approximated in analogy to the average monthly of the closest rivers (Raža for Senj and Ombla for Dubrovnik);
- Rjecina:
  - The average monthly discharges from the Water Management Strategy paper are used[136];

Three different categories of the resource waters can be summarised:

- Seven small rivers:
  - Raza, Mirna and Rjecina in the Littoral-Istrian river basin,
  - Zrmanja, Krka, cetina and Ombla in the Dalmatian region;
- Neretva, with a discharge greater than all seven small rivers in total,
- Tail water flows of the Dubrovnik and Senj Hydropower plants.

[136] Water Management Strategy (2009), p. 14

6.4.2.1 *Seven Small Rivers*

The analysis of the flow data reveals substantial challenges for a base-load type power plant:

- Each river demonstrates an individual pattern of daily flows,
- Each year demonstrates its individual character,
- Daily average flows fluctuate up to the ratio of 1:100 with draughts in late summer and floods in winter months,
- Some of the rivers dry up during summer.

Not just within a year, but also over the years, the discharge and distribution varies irregularly and significantly for most rivers:

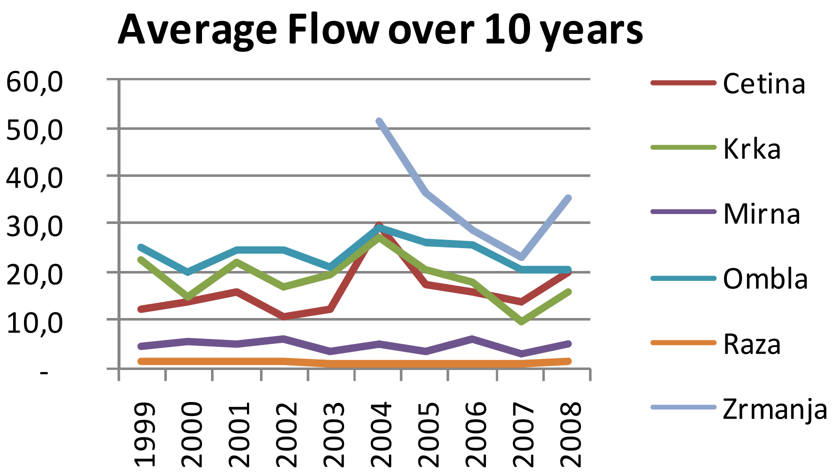


Figure 44: Average discharge of small Croatian rivers 1999 to 2008

Below charts about average discharge demonstrate the individual flow patterns of those rivers for which daily data was made available:

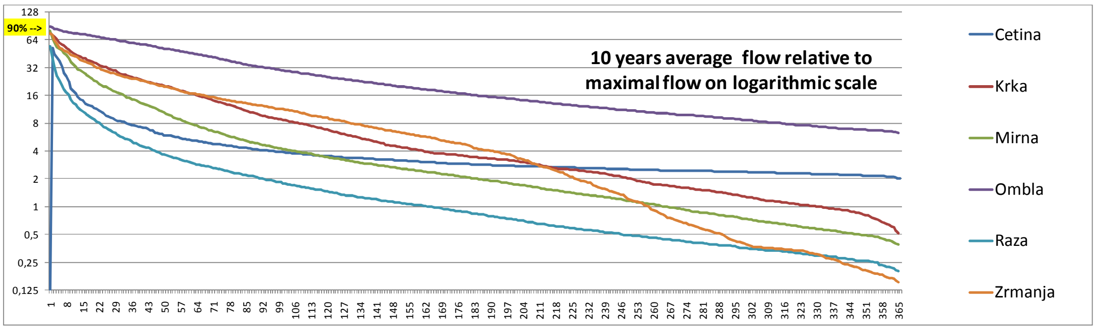


Figure 45: Ten years average flow as the percentage of the maximum flow measured

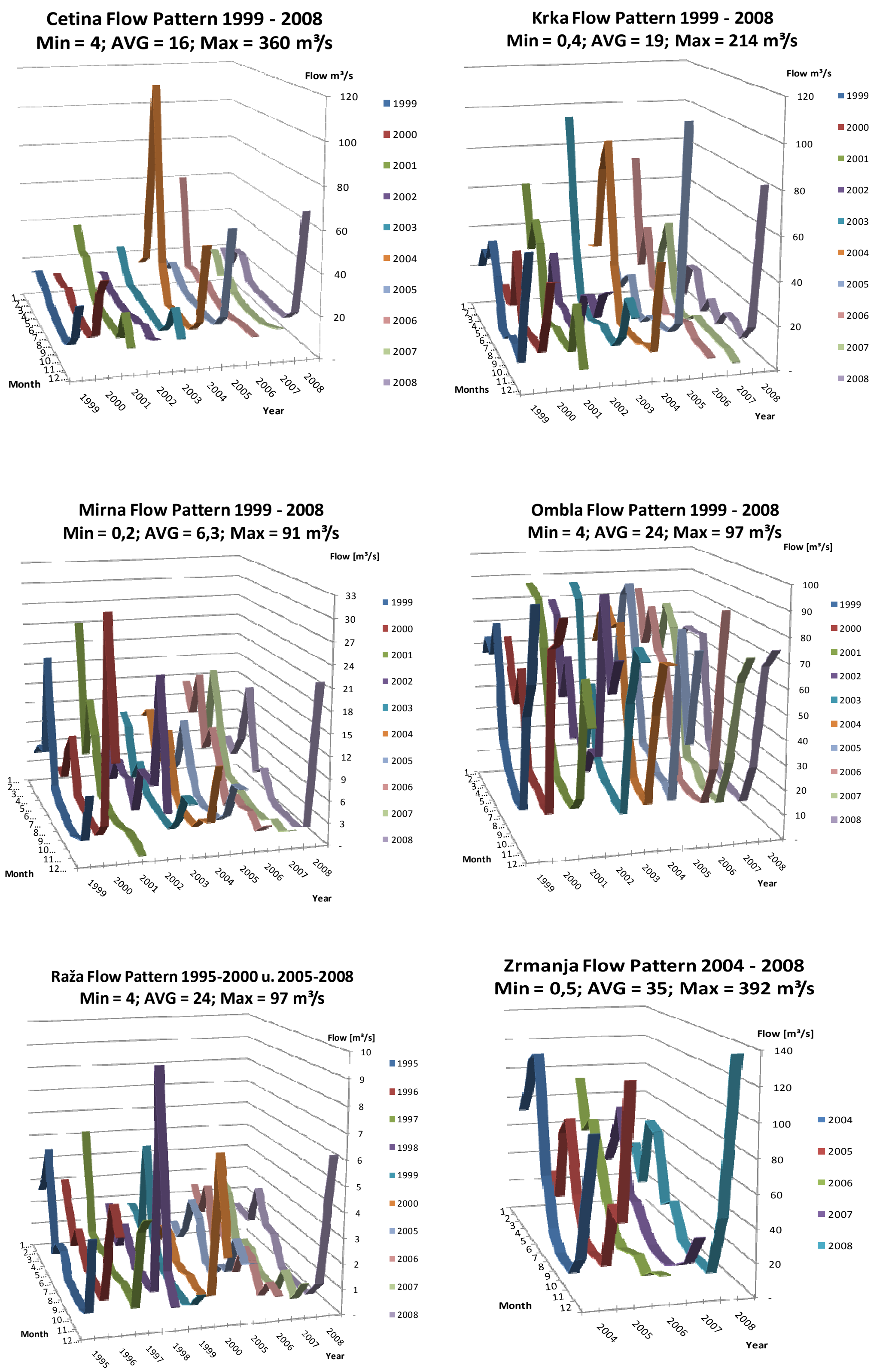


Figure 46: Flow patterns of 6 small rivers (average flows per months and years)

The charts make clear that using average flow data for sizing a plant will lead to wrong decisions. Therefore, for the determination of the reasonable potentials, each river's data of the daily flow will be used, except for Rjecina for which the data is not available. For each daily flow the respective maximum capacity is determined and then averaged accordingly. For calculating the maximum capacities, several parameters have to be factored that require certain basic condition assumptions:

- The *residual water* that - for environmental and fishery reasons - needs to stay minimally in the river bed:
  - The basic condition is set to a residual water flow of 100% of the *average of yearly minimum values* of daily flow through-out 10 years of data. This reflects the prevention of an artificial drying-out of the river bed.
- A *minimal amount of full load hours* (FLH) is requested for economic reasons:
  - The calculation of energy yields is based on the daily flow data to accommodate the residual water and a variable, assumed rated capacity,
  - The resulting installed capacity and energy yield are shown as a function of an expected utilization expressed in full load hours.
- A *reference capacity* is introduced to allow the sensitivity analysis in certain calculation steps: for the calculation of the achievable potential it was decided that no plant below 2 MW installed capacity (= turbine power) is considered:
  - Therefore, a river is not included in the calculation if only less than 2 MW of rated capacity would achieve the expected full load hours (which does not prevent a smaller power plant from being feasible).

The function of the achievable energy yield over the rated capacity confirms the above indicated lack of stable and sufficient water flows of various rivers. Only Zrmanja, Ombla and Krka return significantly more energy yield if the rated capacity increases:

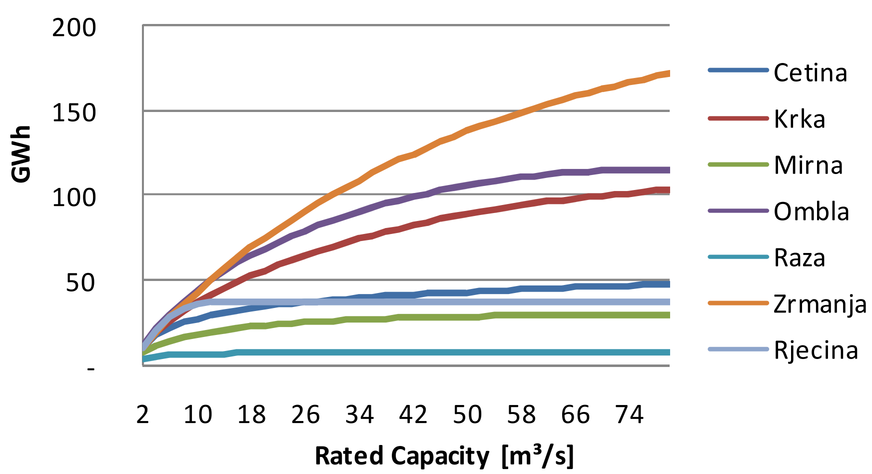


Figure 47: Achievable energy as a function of the rated capacity (installed turbine) per small river

Table 17: Basic conditions for reasonable potential calculation and results for small rivers

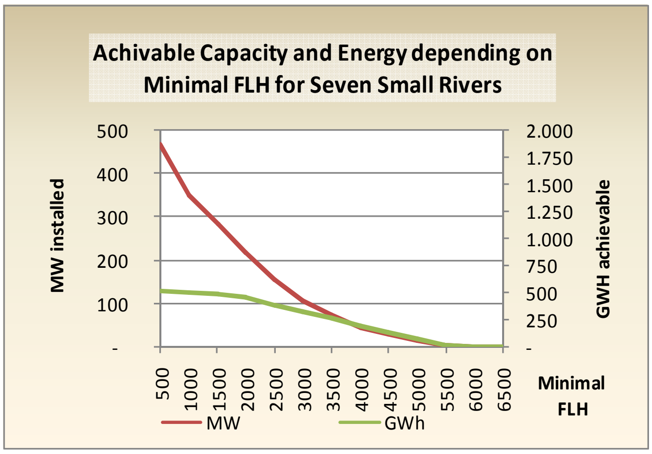
		7 Small Rivers	
Minimum Full Load hours	5,000	Plants bigger than min FLH	5
Minimum residual water	100%	MW installable at min FLH	14
Reference capacity [MW]	2.0	GWh sellable above min FLH	75
achievable MW per 1 MW	0.735		

By setting basic conditions (yellow table), including a required utilization of 5.000 FLH, neither Mirna nor Raža could provide enough constant flow to qualify their inclusion in the potentials calculation.

The resulting sensitivity of the achievable energy over the expected full load hours reveals a very steep dependency, reflecting the strongly fluctuating flow patterns.

Table 18: Realisable power and potential as a function of full load hours expected for Croatia's small rivers

Small Rivers (7)			
FLH	MW	GWh	Plants
500	468	514	7
1000	350	502	7
1500	284	485	7
2000	218	454	7
2500	154	393	6
3000	106	326	6
3500	74	266	6
4000	46	192	5
4500	30	141	5
5000	14	75	5
5500	4	23	2
6000	-	-	0
6500	-	-	0



The two rivers (plants) that would qualify for an economic expectation of 5.500 full load hours are Krka and Ombla, but with a strong reduction of achievable energy.

6.4.2.2 River Neretva

Regarding its discharge, the river Neretva is by far the largest water body in Croatia. Its annual average flow of 342 m³/s[137] exceeds the total of 258 m³/s of all small rivers. Neretva is a so-called "trans-boundary" water for which Bosnia and Herzegovina (owning ~90% of the 177 km river length) and Croatia are the responsible governing nations. The Neretva river basin is connected with the Trebišnjica, which disappears in karstic sinks after undergoing heavy hydropower

[137] Water Management Strategy, p. 11

exploitation. Neretva and Trebišnjica both are heavily stressed by agricultural irrigation (of ~5.000 ha mainly in the lower delta area), by hydropower plants (10 existing, more planned), by reclamation of wetlands for agricultural use and by pollution due to unsustainable agriculture and lack of waste water treatment in the large upstream settlements. Among other reasons, the environmental treasure of the area is constituted by the largest remnants of the Mediterranean wetlands on the eastern Adriatic coast (lower course of the Neretva)[138]. The area is one of the focal points of European trans-boundary water management and massively supported by EU, World Bank and UN support programs.

Changes to the water regime in one part of the basin can have unexpected - and unwanted - side effects in other parts, as the whole watershed is connected via karstic aquifers (underground waterways), siphons, caves and artificial tunnels.

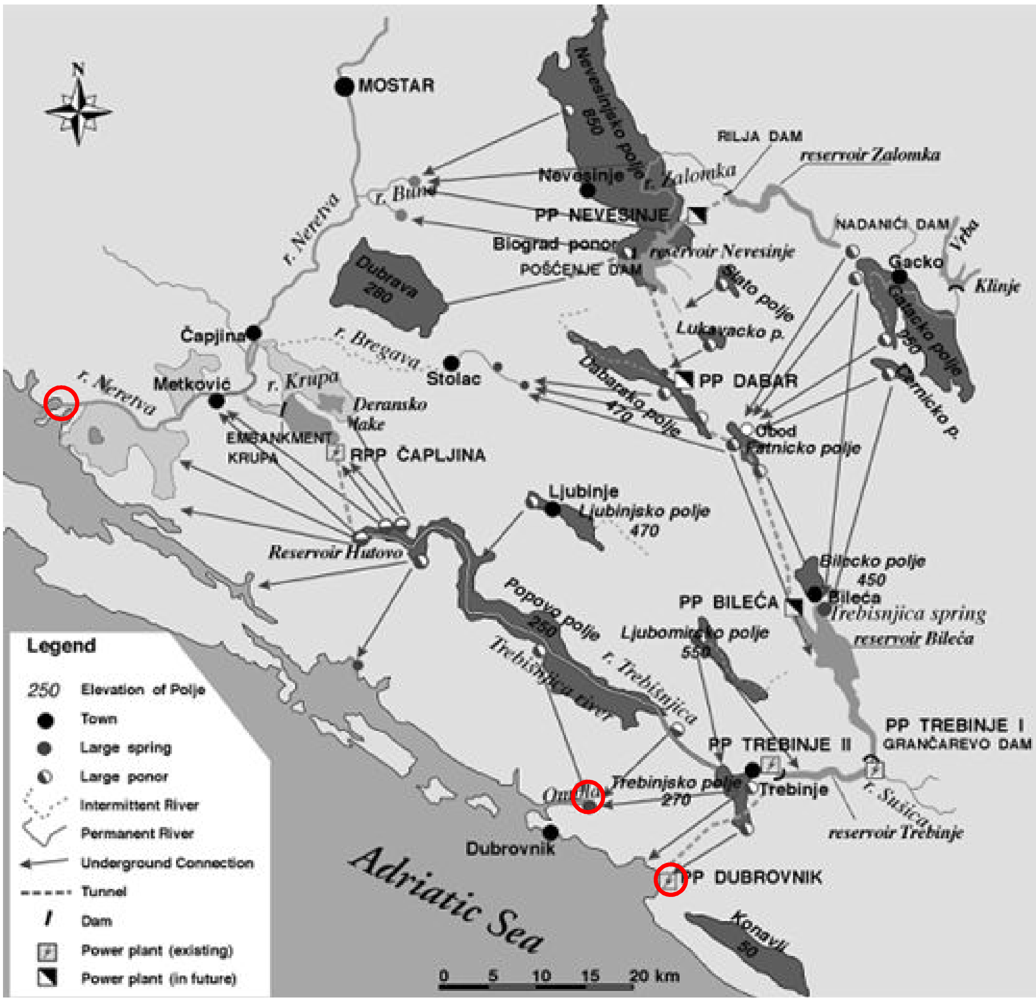


Figure 48: Natural and artificial connections in the Neretva-Trebišnjica river basin[139] and potential PRO plant locations in red circles (from upper left: Neretva, Ombla, HE Dubrovnik)

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[138] Watersee Trebsinjica and Kupusovic (2010), p
[139] Milanovic (2002), p.14

Figure 49: Neretva delta satellite view (Google Maps)

The complex natural structures (e.g., long and flat delta), the environmental and development pressures and the fact, that the Neretva discharges via a long and flat estuary make it difficult to predict how the actual realisable potential will evolve over time and what the additional “bypass” investments need to be to develop projects in an acceptable, sustainable manner.

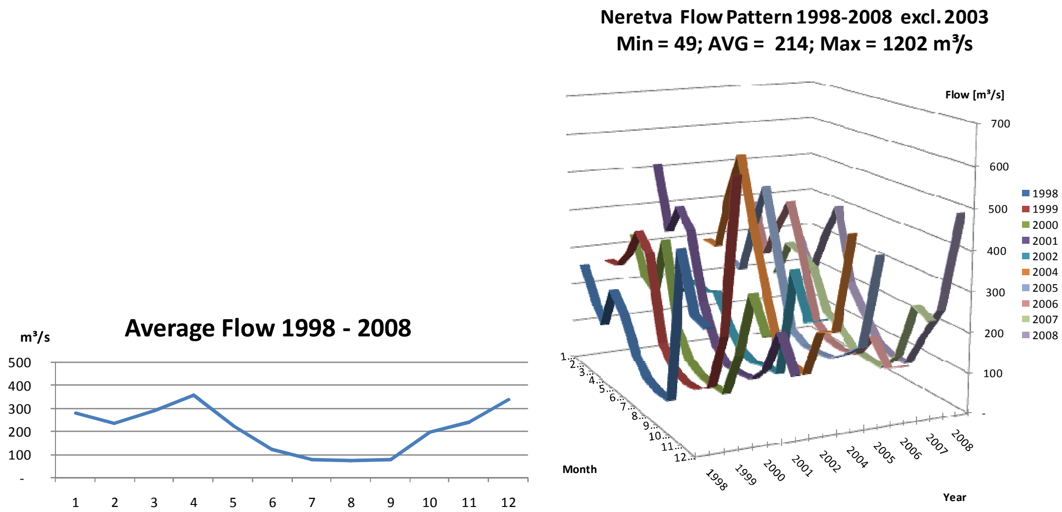
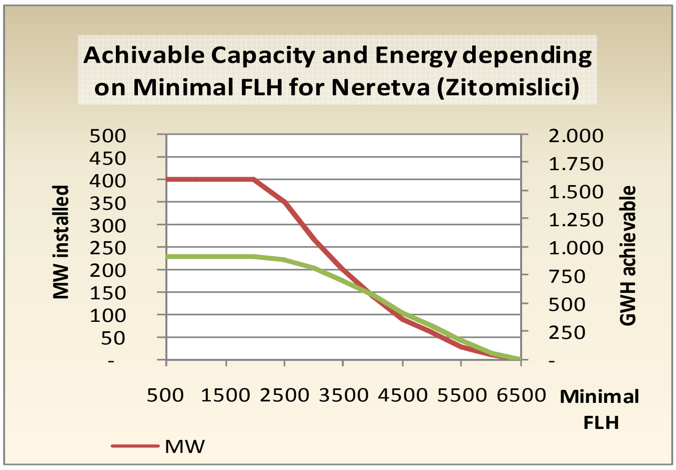


Figure 50: Neretva monthly flow pattern 1998 – 2003 based on daily data from Jadran

Purely from a flow perspective, the technical potential looks impressive. But a closer look reveals that, similar to the smaller rivers and due to the same reasons, the energy yield steeply declines as soon as expectations for a reasonable utilization (minimal full load hours) are applied:

Table 19: Realisable power and potential as a function of full load hours expected for Neretva

Neretva (Zitomislici)		
FLH	MW	GWh
500	400	913
1000	400	913
1500	400	913
2000	400	913
2500	350	884
3000	270	812
3500	200	705
4000	140	568
4500	90	414
5000	60	301
5500	30	166
6000	10	60
6500	-	-



For theoretically required 5.000 FLHs, Neretva supplies a realisable potential of 301 GWh per anno from an installed capacity of 60 MW.

6.4.2.3 Tail-Water Utilization of HE Dubrovnik and HE Senj

HE Dubrovnik

As described above, HEP-OPS in Dubrovnik operates a hydropower plant which is fed – via an underground tunnel – by the water of the Trebišnjica River. The intake for HE Dubrovnik was achieved by the construction of the Gorica dam, situated downstream of the Trebinje hydropower plant, so that the tail water of Trebinje is the head water of HE Dubrovnik.[140] The installed flow is 90 (2x45) m³/s and the installed capacity is 216 (2x108) MW. The average production is 1,321 GWh, resulting in a utilization of 6,115 FLHs and a calculated mean flow of 62.8 m³/s (further used for the calculation of the potential). Peak flow (90), mean flow (62.8) and the monthly flow distribution of Ombla were used to calculate the flow pattern of HE Dubrovnik and the resulting dimensioning of the realisable potential.

HE Senj

The Senj hydropower plant is a diversion type plant utilizing the water of Lika and Gacka rivers, both of which are connected to each other and “disappear” in karstic sinks. Below maps show the hydrological situation and the pipeline (marked) to the Senj power plant:

[140] HE Dubrovnik

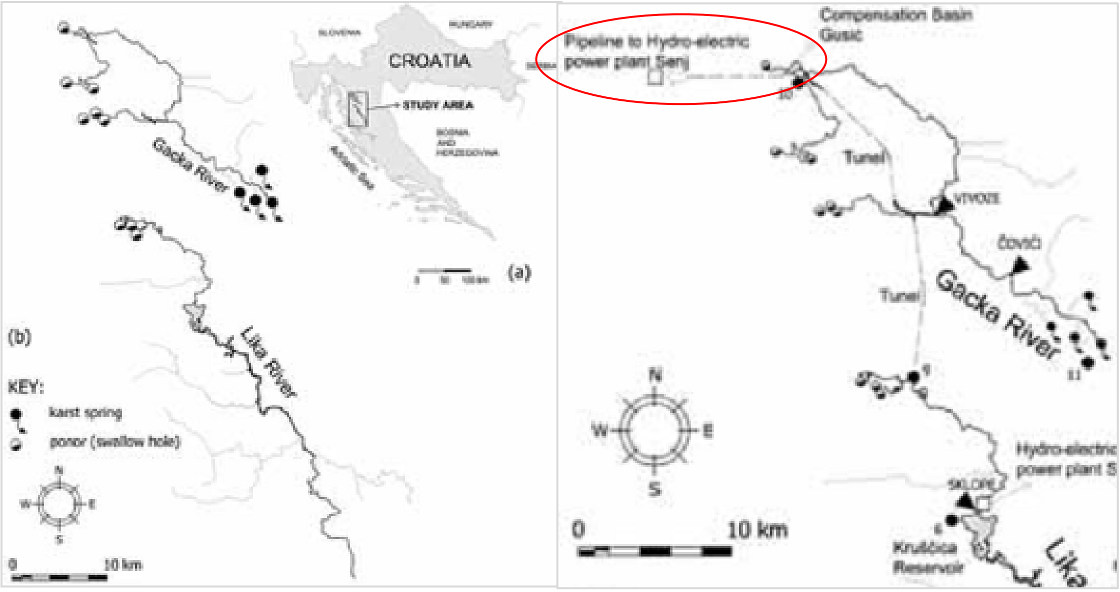
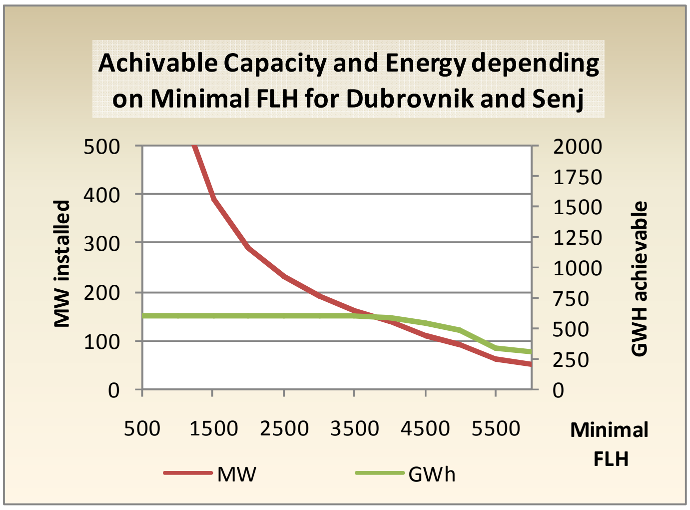


Figure 51: Gacka and Lika hydrology and HE Senj pipeline[141]

The HE Senj installed flow and capacity are 60 (3*20) m³/s and 216 (3*72) MW respectively. With an average of 972 GWh of production[142], the plant achieves 4,500 FLHs, which are comparably less than those of HE Dubrovnik. This static data and the monthly flow distribution of Raža were used to calculate the flow pattern of HE Senj and the resulting dimensioning of the achievable energy.

Table 20: Realisable power and potential as a function of full load hours expected for HE tail-waters

Dubrovnik+Senj Tailwater			
FLH	MW	GWh	Plants
500	790	603	2
1000	590	603	2
1500	390	603	2
2000	290	603	2
2500	230	603	2
3000	190	603	2
3500	160	596	2
4000	140	579	2
4500	110	544	2
5000	90	477	2
5500	60	340	1
6000	50	302	1
6500	0	0	0



Due to the very good flow situation of HE Dubrovnik, which can already be seen in the FLH of the hydropower plant, a PRO power plant could reach 6.000 full load hours of an installed power of 50 MW, achieving ~300 GWh annually.

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[141] Bonacci and Andrić (2008), pp. 186 & 187
[142] HE Senj

6.4.3 Reasonable Potential = Total Realisable Potential

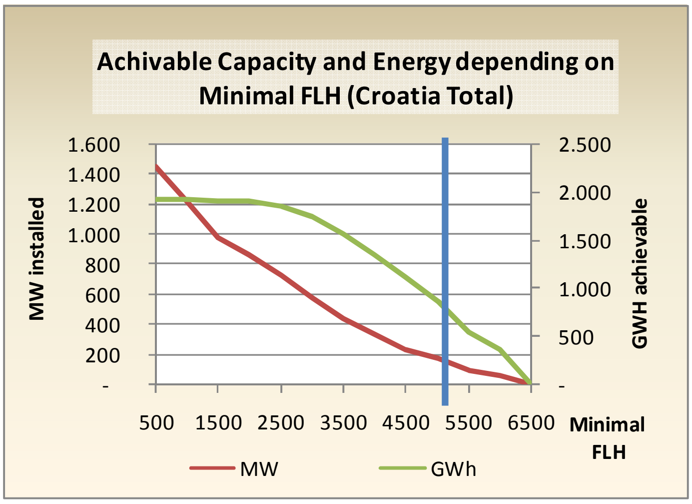
In summary, the reduction of the technical potential due to economic restrictions of hydrology results in a *reasonable potential*. The reduction is dependent on the flow patterns and an expected utilization of the technology.

Starting point:

As a basic condition for determining the reasonable potential, the utilization requirement is set to a minimum of 5.000 full load hours of installed capacity. These relate to about 6.800 full load hours of plant operation. Although arbitrarily set, the required 5.000 FLHs reflect the high investment costs of the technology and the expectation that public funds should not subsidise poorly utilized plant capacities.

Table 21: Achievable power and energy as a function of full load hours expected for total Croatia

Total Croatia Realisable		
FLH	MW	GWh
500	1,444	1,931
1000	1,219	1,927
1500	976	1,917
2000	855	1,908
2500	717	1,854
3000	568	1,746
3500	435	1,569
4000	330	1,352
4500	234	1,113
5000	**167**	**866**
5500	97	545
6000	61	368
6500	-	-



Starting from a theoretical potential of 8.8 TWh and a technical potential of 4.3 TWh, a *reasonable potential* of 866 GWh can be derived under the set condition of a minimum utilization of 5,000 full load hours. This condition is achieved with a total of 167 MW installed turbine capacity.

866 GWh of reasonable potential represent a share of about 4.2% of Croatia's 2010 electricity consumption.

Future development:

For the outlook into 2030, an additional condition is assumed:

- The development of the technology's economies of scale, learning curve, higher energy costs and increased demand for electricity will allow the production under economic conditions with only 4,500 FLHs in 2030 with a linear decrease. This increases the reasonable potential linearly (assumed) to ~1.1 TWh in 2030.

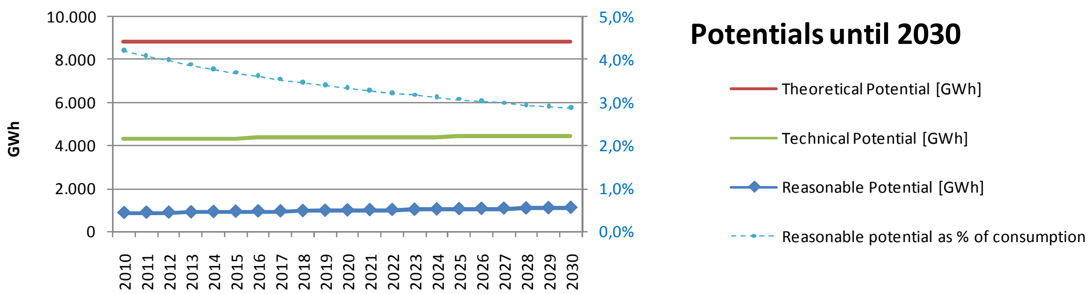


Figure 52: Potentials for PRO and reasonable potential as % share of projected total consumption

6.4.4 Realisable Potential up to the Year 2030

For the realisable potential, a scenario should be drawn to show how the reasonable potential can be realised over time until 2020 (midterm), 2030 (horizon) and beyond. For the realisation scenario some assumptions are necessary about the development of the technology itself, the economies of scale achievable and its public support for dissemination. Last but not least, some environmental barriers need to be factored in (as they were neglected so far in a potentials calculation) but within a climate for a positive development.

6.4.4.1 Assumptions on Drivers and Barriers

The assumptions supporting the realisable growth potential for the PRO technology and its capitalization in Croatia are as follows:

- PRO will be actively promoted by (a) financially strong stakeholder(s) and marketed to decision makers as an alternative energy source that deserves the support of Croatian politics, administration and society,
- PRO gets integrated in HEP Group‘s production strategy and portfolio, as they already own large portions of the data, expertise and infrastructure necessary for such long-term development projects,
- By end of 2011, PRO will be defined as a separate category in Croatia’s feed-in tariff system to allow economic boundary conditions for positive project ROIs. To foster rapid capacity ramp-up, tariffs should not be bound to plant sizes, be in the range of 400 €/MWh, and eventually be dependent on the achievable average utilization,
- A first pilot plant with 5 MW will open in 2013; scaling up in the subsequent years will follow the least barrier and biggest utilization (ROI) goals as outlined below;

- Membrane industry will pick up the market potential in time and – together with the first movers – sell membranes with a specific power of 3 W/m² in 2012 to 5W/m² in 2020,
- After 2020, additional learning curve effects will allow for gains in price/performance of membranes, by a reduction of costs per Watt, of required footprint and improvement of auxiliary process modules (as outlined in chapter 4.4),
- Investments will start with „low hanging fruits"; these are waters with high achievable FLHs and the re-use of already existing infrastructure (e.g., tail-water of HE Dubrovnik),
- A maximum of 15 MW p.a. will be installed per year and this annual implementation capacity can be achieved from 2024 onwards; this also means a plant with 50 MW is implemented in several blocks or phases,
- Existing barriers based on protected areas will be avoided until the technology is fully proven and accepted. Permanent reductions include:
    - The Krka National Park with 12.5 MW capacity or 28 GWh (at required 4,500 FLH) eliminated from the potential, and
    - A limitation of the Neretva exploitation to a maximum capacity of 30 MW, resulting from additional environmental protection provisions that require at least 5.500 FLH for a positive ROI (this leads to a further reduction of 248 GWh from the reasonable potential of 1,113 GWh (at required 4,500 FLH),
- Annual extension of installed capacity is assumed to follow the pattern in Table 22, taking into account the barriers of time consuming capacity building and the future optimization of the PRO technology implementation.

Table 22: Capacity extension projection scenario 2010-2030

POTENTIALS / Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Theoretical Potential [GWh]	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844
Technical Potential [GWh]	4,333	4,337	4,341	4,346	4,350	4,355	4,359	4,364	4,368	4,372	4,377	4,381	4,386	4,390	4,394	4,399	4,403	4,408	4,412	4,417	4,421

A summary of the projected scenario development is shown in Figure 53

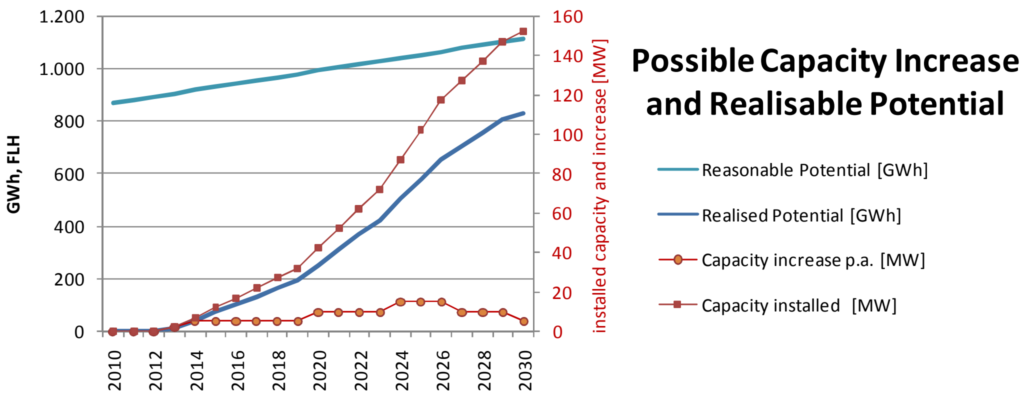


Figure 53: A possible scenario for the realisable potential

6.4.4.2 *Total and Midterm Realisable Potential*

In total, after accounting for the above listed environmental barriers and scaling delays, the *realisable potential in 2030* amounts to 830 GWh (at required 5,000 FLH), relating to ~9% of the theoretical or ~19% of the technical potential and 2.1% of Croatia's projected electricity consumption in 2030.

According to above scenario, the *midterm potential* (realisable by 2020) is 252 GWh, or 2.8% of the theoretical and 5.8% of the technical potential, meeting 0.9% of the total consumption demand projected.

6.4.5 Existing or Planned Hydropower Projects Impacting PRO Projects

A major boundary condition is neglected in the scenarios described above: the influence of the existing and planned hydropower plants' water regimes. Many of the existing plants are exploiting the waters that are potential sources for the PRO technology.

Figure 54: HEP hydropower plants[143]

[143] HEP Hydro

The influence of these plants on the potential yield of a PRO plant in the tail water of a hydropower plant has not been factored in into the potentials calculation.

Rivers with existing plants might show discharges with strong short term fluctuations that might destroy the technical and economic potential of a site. Storage plants especially, will produce an unpredictable tail water flow and the water regime of the plant needs to be analysed first before a site can be investigated for further project development.

Existing power plants on the rivers analysed are[144]:

- Krka - Ozalj (run-of-river, Qi=85 m³/s),
- Rječina – Rijeka (run-of-river, Qi = 21 m³/s),
- Lika and Gacka - Senj (diversion and run-of-river, Qi = 60 m³/s),
- Cetina – Peruća (adjacent to dam, Qi = 120 m³/s), Orlovac (storage, Qi = 70 m³/s), Đale (storage, Qi = 220 m³/s), Zakučac (diversion, Qi = 220 m³/s), Kraljevac (diversion, Qi = 55 m³/s) power plants and Buško Blato pumping station,
- Trebišnjica - HE Dubrovnik (storage, Qi = 90 m³/s) and Zavrelje (storage, Qi = 3 m³/s);
- Neretva – several in Bosnia i Herzegovina.

Hydropower plants are not always a disadvantage should they exist in a river investigated for a PRO power plant. If close to the sea, they already provide valuable infrastructure such as grid and logistics access, organizational infrastructure, tail water canals supporting the water intake, and a controllable – at least known – discharge. This will be investigated further in chapter 8 for the HE Dubrovnik as potential site for a PRO power plant.

[144] HEP Hydro, West, South and Dubrovnik links

7. PRO Project and Performance Characteristics

7.1 Characteristics of the PRO Power Generation

7.1.1 Base Load Supply

In its supply pattern, PRO behaves similarly to hydropower by delivering constant amounts of electricity provided by a constant flow of fresh water. 8000+ full load hours (plant operation) should be achievable, given that the capacity of the plant is adjusted to the low flow capacity of the fresh water supply.

7.1.2 Expected Maintenance Demand

Process experience in production scale is not yet available. The following facts predict a relatively high demand of maintenance work and cost:

- Dependency of the optimal process on natural – and changing – conditions of the fresh water resource (draught, flood, pollution, organisms),
- Aggressive saline sea water accelerates the corrosion of materials,
- The planned life cycle of key components (membranes and filters) are much shorter than the plant life cycle,
- Implementation of a multitude of single components (membranes, valves, pipes, pressure exchangers, pumps, etc.) make constant monitoring complex.

7.2 Characteristics of a PRO Project Development

7.2.1 Complex decision making and certification process

Although in its essence the PRO concept must be seen as a very sustainable renewable energy, various factors can make a project development decision a comparably challenging exercise. A project developer will require strong political and financial backing:

7.2.1.1 Stakeholder interests

Similar to any other power generation project, a project developer will face multiple opposing and conflicting interests in the decision making process. Most likely the process will be governed by an environmental impact assessment procedure. Stakeholders and interests include:

- Marine: water protection and coastal traffic control
- Hydrology: municipal and agricultural water management

- Fishery: Protection of typical fish species, fish and mussel farms
- Tourism: Protection of scenery, especially in protected areas and attractive landscapes, typical for river deltas
- Environmentalists: protection of habitats, landscapes, water quality, denial of grid connections, large construction and logistics facilities, etc.
- Utilities: competing rights for (upstream) water management according to hydropower demand

No stakeholder opposition must be expected regarding certain environmental hazards based on pollution. There are no emissions into sea, rivers or the air that are caused by the PRO process as such. Only auxiliary processes for production and maintenance might cause relevant exposures that would need to be accounted for in a plant's life cycle assessment.

7.2.1.2 High investment costs

Compared to other RES-e technologies, high investment costs will be typical for PRO power plants. In contrast, a high utilization level expressed in full load hours is expected to enable a final payback of the investment after a reasonable period.
As elaborated in the chapters above, uncertainties exist in the required specific membrane surface (m²/W), the membranes' actual life time, the required process and facilities for water pre-treatment, the density (space) of components necessary for 1 W and ultimately their resulting demand for the total plant footprint. No industry benchmarks exist for an accurate investment calculation; only some analogies can be taken from the PRO technology's closest relative, the reverse osmosis desalination process.

7.3 A Simplified ROI-Model

As PRO is a completely new technology, at least in its core, only rough estimations can be given for the cost of construction and – even more – for the operation of a plant. As mentioned earlier, an analogy can be taken from the sea water desalination industry since many of the same components are used. At the same time the differences will be huge, especially for the necessary water pre-treatment in the desalination process which requires large amounts for chemicals in the operation. The below estimations for a 5 MW plant have been elaborated based on discussions with representatives from the SWRO desalination engineering, the membrane industry, the construction business and from small hydropower industry.
Three scenarios are developed:

- best estimate,
- worst case and
- best case.

Three levels of confidence are considered for each item in the calculation:

- A: very confident – costs levels might vary +/- 10%,
- B: confident – cost levels might vary +/- 20%,
- C: less confident – cost levels should be in a variation of +/- 30%,
- D: very unsecure – cost levels to vary within arbitrarily set boundaries based on personal judgement.

The ROI scenario does not take into account:

- Potential impact of taxes,
- Financing costs for the implementation period,
- Opportunity costs of CO2 omissions,
- Earnings for an operator and return for the investor other than those included in the discount rate.

The ROI calculation should show a high-level estimation of the magnitudes in terms of investment requirements and operational costs for the PRO technology. It should also reveal the sensitivity of the economic performance – the project's net present value - to specific cost factors.

7.3.1 Input Parameters for ROI Scenarios

Table 23 displays the main technological parameters for a PRO power plant and the estimated or calculated values for these parameters for each of the scenarios. All variable fields which allow input are coloured yellow, green or red.
The feed-in tariffs are calculated (goal seek) for each scenario so that net present values are zero for a calculation period of 20 years. Then, details of the ROI calculation are shown for the *best estimate* scenario and only the main results are given for the best and worst case scenario.

Table 23: Parameters for the ROI calculation

PARAMETERS for PRO	estimated	BEST	Worst	unit	Conf.	lifetime	deviation	maintenance
Rated capacity	5.0	5.0	5.0	MW				
Turbine Full Load Hours (FLH)	8,000	8,500	6,000	h/yr	D			
Energy yield / year to grid	30,800	33,703	22,410	MWh				
Internal losses	23%	20.70%	25.30%	%	A		10%	
Freshwater feed	5.0	5.0	5.0	m³/s				
Seawater feed	10	9.5	9.5	m³/s				
Plant base area	20,000	16,000	24,000	m²				
Space cost per m²	20	0	100	€/m²	D			
construction costs per m²	500	300	1000	€/m²	D	50		1.00%
Intake construction costs per m³/s	500,000	250,000	750,000	€/m³/s	D	50	50%	0.50%
Specific Membrane Power	3	5	2	W/m²	C			
Membrane excess for washing (0,5h/d)	2.08%	1.67%	2.50%	%	B		20%	
Membrane area needed	1,701,389	1,016,667	2,562,500	m²				
Membrane costs / m²	8.5	6.0	11.05	€/m²	C	10	30%	0.0%
Pressure exchanger (PX300) unit costs	20,000	16,000	24,000	€/unit	B	20	20%	1.5%
PX throughput	65	65	65	m³/h				
Intake filter unit costs (1 unit per 1 m³/s)	250,000	200,000	300,000	€/m³/s	B	20	20%	3.0%
pump costs +2 bar (per m³/s)	70,000	56,000	84,000	€/m³/s	B	20	20%	1.5%
Turbine/generator full unit	350,000	315,000	385,000	€/MW	A	40	10%	2.0%
Balance of Plant costs	25%	20%	30%	%	B	20	20%	3.0%
Fees from Revenue	2.00%	1.00%	3.00%	of revenu	D		50%	
Number of staff for 3 shifts	10	8.00	12.00		B		20%	
Admin services int/ext	2	1	2		C			
FTE costs	40,000	28,000	52,000	€/FTE/p.a.	C		30%	
1 EURO =	1.30	1.04	1.56	USD	B		20%	
1 KUNA =	0.13	0.16	0.10	EUR	B		20%	
Investment subsidy (ex Proj. Dev.)	10%	20%	0%	%	D			
electricity revenue producer to grid	50	60	40	€/Mwh	B		20%	
Internal discount rate	6.0%	4.0%	10.0%	%	D			
cost inflator work	1.0%	1.0%	2.0%	%	D			
cost inflator retail	0.0%	0.0%	0.0%	%	D	costs/revenues with real prices		
cost inflator electricity	2.0%	3.0%	0.0%	%	D			
cost inflator PX and Filters	-1.0%	-2.0%	0.0%	%	D			
cost inflator membrane	-3.0%	-5.0%	0.0%	%	D			
Feed-in tariff for break even after 20 yrs	259	79	685	€/MWh	x			
Feed-in tariff grant period	12			years				

7.3.2 Best Estimate Scenario

For the *best estimate* scenario, the investment costs per main item and group show the following magnitudes and weights:

Table 24: Best estimate scenario investment costs in €

Investment	Quantity	Unit	€/unit	Investment [€]	Weight	Group Weight		Lifetime
Membranes	1,701,389	m²	8.5	14,461,806	26%			10
Pressure exchangers	277	units	20,000	5,540,000	10%			20
Intake filters	15	units	250,000	3,750,000	7%			20
Pumps	25	units	70,000	1,750,000	3%	46%	Water	20
Intake Construction	15	units	500,000	7,500,000	13%			50
space + construction	20,000	units	520	10,400,000	19%	32%	Constr.	50
Balance of plant costs	25%	of above		10,850,451	19%			20
turbine/generator	5	MW	350,000	1,750,000	3%	22%	BoP	40
Total				56,002,257	100%			

Total and Specific Investment			Investment [€]	€/KW
Total Investment at T0			56,002,257	11,200
Subsidy	10%	of sum of costs	-5,600,226	-1,120
TOTAL Capital Needed			50,402,031	10,080

Static operating costs (for period t_0) are calculated as follows (the dynamic ROI calculation is shown further below):

Table 25: Best estimate scenario operating costs (static)

Category	Base	Lifetime	Maint.	Maint. costs
Membranes	14,461,806	10	0.0%	0
Pressure exchangers	5,540,000	20	1.5%	83,100
Intake filters	3,750,000	20	3.0%	112,500
Pumps	1,750,000	20	1.5%	26,250
Intake Construction	1,750,000	50	0.5%	8,750
space + construction	7,500,000	50	1.0%	75,000
Balance of plant costs	10,850,451	20	3.0%	325,514
turbine/generator	1,750,000	40	2.0%	35,000
Staff costs	12			480,000
Fees from revenue (grid, insurance, ...)	7,987,477		2%	159,750
Total				**1,305,863**

Operational costs bottom up	OPEX/p.a.	MWh p.a.	€/MWh
Maintenance per anno	666,114	30,800	21.6
Staff	480,000	30,800	15.6
Fees	159,750	30,800	5.2
Total	**1,305,863**	**30,800**	**42.4**

Revenues are calculated based on feed-in tariffs (FIT) that allow for the project breaking even within a 20 years investment horizon. Table 26 shows the parameters that lead to a revenue calculation. After the feed-in tariff period an estimated electricity price is used, taking into account a set electricity price index. The feed-in tariffs are set for a period of 12 years and they are adjusted with the consumer price index according to the feed-in regulation in Croatia (see also chapter 5.2.5.2) .

Table 26: Best estimate scenario revenue assumptions and NPV

Category	Assumption	Unit
FLH	8000	h
MWh	30,800	MWh
Feed-in Tariff	259.3	€/MWh
Feed-in Tariff time	12	yrs
Retail price index	0%	
Electricity price	50	€/MWh
Electricity index	2%	
p.a. FIT (t_0)	7,987,477	€
p.a. market revenue (t_0)	1,540,000	€

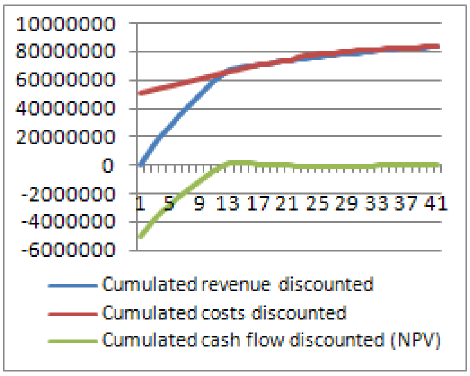
7.3.2.1 Return of Investment

Net Present Values (NPV) have been calculated for the cost and revenue side for 30, 20 and 12 years each, the latter to show the result of the investment after the expiry of the eligibility for a feed-in tariff (FIT) in Croatia. Via the goal seek function of MS Excel for the 20 years' NPV being zero, the amount of the required feed-in tariff resulted to ~260 €/MWh. This scenario equals a break-even time for operation of 20 years. In comparison, the current maximum feed-in tariff in the Croatian tariff scheme is granted for Photo Voltaic electricity generation, with 490 €/MWh for plants ≤10 KW and 303 €/MWh for plants >30 KW[145].

Throughout this *best estimate* scenario, the annual operation costs are higher than the achievable revenues based on market prices. Therefore, any operation longer than 20 years must result in losses should the estimated parameters stay valid:

Table 27: Best estimate scenario ROI for 30, 20 and 12 years in €

Discounted TOTAL COSTS	80,401,391	30 yr
Discounted TOTAL REVENUES	79,331,917	30 yr
NPV Investment Project	-1,069,474	30 yr
Discounted TOTAL COSTS	73,521,959	20 yr
Discounted TOTAL REVENUES	73,521,959	20 yr
NPV Investment Project	0	20 yr
Discounted TOTAL COSTS	66,039,441	12 yr
Discounted TOTAL REVENUES	66,965,758	12 yr
NPV Investment Project	926,317	12 yr



7.3.2.2 *Levelized electricity costs and yield*

For the calculation of the levelized costs of electricity (cost per MWh over the expected life time) the NPV of total costs is divided by the NPV of the generated MWh. Likewise, the project's revenues are calculated as specific (levelized) yields for the various lifetime periods.

Table 28: **Best estimate scenario - levelized cost of electricity and specific yield**

Years of production	30 yr	87.0	NPV costs / Total MWh produced [€/MWh]
MWh produced	924,000	189.6	Levelized cost of electricity [€/MWh]
MWh produced discounted	423,957	-2.5	Specific yield [€/MWh]
Years of production	20 yr	119.4	NPV costs / Total MWh produced [€/MWh]
MWh produced	616,000	208.1	Levelized cost of electricity [€/MWh]
MWh produced discounted	353,274	0.0	Specific yield [€/MWh]
Years of production	12 yr	178.7	NPV costs / Total MWh produced [€/MWh]
MWh produced	369,600	255.7	Levelized cost of electricity [€/MWh]
MWh produced discounted	258,222	3.6	Specific yield [€/MWh]

Levelized costs of electricity (LCoE) for a 20 years operation in the *best estimate* scenario amount to ~208 €/MWh or ~190 €/MWh for a 30 years operation. These

[145] RES Tariffs (2010)

LCoE are significantly higher than the costs of electricity which are propagated by Statkraft. Statkraft estimates the competitive price level for PRO to about 50 – 100 €/MWh and the costs to be "in line with the costs of wind off-shore" by 2015[146] (see also chapter 7.5).

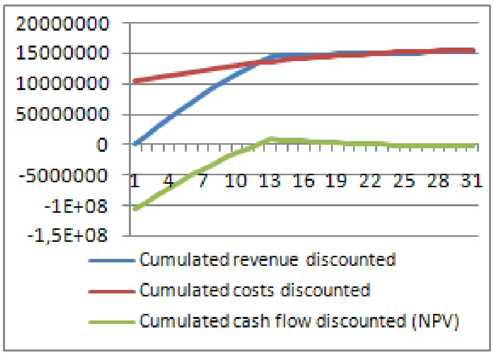
7.3.3 Worst Case Scenario

The worst case scenario is the scenario where all parameters are set to the worst extreme for the ROI calculation. In this scenario, a theoretical amount of the feed-in tariff needed for a break-even operation after 20 years would be 685 €/MWh. (The current maximum feed-in tariff in the Croatian tariff scheme is granted for Photo Voltaic electricity generation, with 490 €/MWh for plants ≤10 KW and 303 €/MWh for plants >30 KW.[147])

7.3.3.1 Return of Investment

Table 29: Worst case scenario ROI for 30, 20 and 12 years in €

Discounted TOTAL COSTS	155,068,717	30 yr
Discounted TOTAL REVENUES	151,068,703	30 yr
NPV Investment Project	-4,000,014	30 yr
Discounted TOTAL COSTS	147,750,493	20 yr
Discounted TOTAL REVENUES	147,750,493	20 yr
NPV Investment Project	0	20 yr
Discounted TOTAL COSTS	136,281,568	12 yr
Discounted TOTAL REVENUES	143,980,905	12 yr
NPV Investment Project	7,699,337	12 yr



As expected, also in the *worst case* scenario the revenues do not cover the operating costs, so that the NPV deteriorates and turns negative after feed-in tariffs seize.

7.3.3.2 Levelized electricity costs and yield

Table 30: Worst case scenario - levelized costs of electricity and specific yield

Years of production	30 yr	230.7	NPV costs / Total MWh produced [€/MWh]
MWh produced	672,300	502.7	Levelized cost of electricity [€/MWh]
MWh produced discounted	308,470	-13.0	Specific yield [€/MWh]
Years of production	20 yr	329.7	NPV costs / Total MWh produced [€/MWh]
MWh produced	448,200	574.8	Levelized cost of electricity [€/MWh]
MWh produced discounted	257,041	0.0	Specific yield [€/MWh]
Years of production	12 yr	506.8	NPV costs / Total MWh produced [€/MWh]
MWh produced	268,920	725.4	Levelized cost of electricity [€/MWh]
MWh produced discounted	187,882	41.0	Specific yield [€/MWh]

[146] Skilhagen et.al. (2008), p. 480
[147] RES Tariffs (2010)

The *worst case* scenario is not of real value from a project development perspective, as the combination of only a few worst case parameters would immediately stop the development work and is also not realistically assumed. In the worst case scenario, LCoE of >500 €/MWh are about the five- to ten-fold of the stated target line for electricity generation.

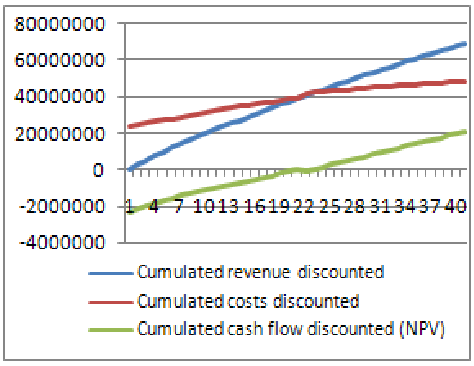
7.3.4 Best Case Scenario

The *best case* scenario is the scenario where all parameters are set to the positive extreme, best possible for the ROI of a project. It represents the target scenario from a project development perspective with regards to those parameters which are site specific. This scenario also comes close to a target scenario from a technology evaluation perspective as many parameters reflect a “to be expected” state of technology and/or their corresponding costs that appear achievable in mid-term.

7.3.4.1 Return of Investment

Table 31: Best case scenario ROI for 30, 20 and 12 years

Discounted TOTAL COSTS	45,171,076	30 yr
Discounted TOTAL REVENUES	54,682,257	30 yr
NPV Investment Project	9,511,181	30 yr
Discounted TOTAL COSTS	38,870,517	20 yr
Discounted TOTAL REVENUES	38,870,517	20 yr
NPV Investment Project	0	20 yr
Discounted TOTAL COSTS	33,710,847	12 yr
Discounted TOTAL REVENUES	25,073,859	12 yr
NPV Investment Project	-8,636,987	12 yr



In the *best case* scenario, the feed-in tariff required for a break-even point at 20 years is ~80 €/MWh. Compared to the current maximum feed-in tariff in Croatia of 490 €/MWh for PV plants ≤10 KW and 303 €/MWh for PV plants >30 KW[148] the break-even calculation should leave enough flexibility to define a FIT that allows for an operator’s and an investor’s margins to be included.

7.3.4.2 Levelized electricity costs and yield

With ~100 €/MWh, the LCoE in the *best case* scenario come close to the expectations stated by Statkraft (50-100 €/MWh). Except the fact that Statkraft is

[148] RES Tariffs (2010)

using a bigger plant capacity (25 MW) as basis of their calculations, there are no conditions and parameters available as applied by Statkraft. Hence, no detailed comparisons can be analysed to unveil where the differences occur beyond the apparent economies of scale.

Table 32: **Best case scenario - levelized costs of electricity and specific yield**

Years of production	30 yr	44.7	NPV costs / Total MWh produced [€/MWh]
MWh produced	1,011,075	97.4	Levelized cost of electricity [€/MWh]
MWh produced discounted	463,909	20.5	Specific yield [€/MWh]
Years of production	20 yr	57.7	NPV costs / Total MWh produced [€/MWh]
MWh produced	674,050	100.6	Levelized cost of electricity [€/MWh]
MWh produced discounted	386,565	0.0	Specific yield [€/MWh]
Years of production	12 yr	83.4	NPV costs / Total MWh produced [€/MWh]
MWh produced	404,430	119.3	Levelized cost of electricity [€/MWh]
MWh produced discounted	282,557	-30.6	Specific yield [€/MWh]

7.4 Sensitivity Analysis for Selected Parameters

7.4.1 Sensitivity of Capital Expenses (Best Estimate Scenario)

The net investment in the Best Estimate scenario amounts to about 50% of the overall costs (NPV). Within the investment costs, the sensitivity is shown towards changes in the specific construction costs and, representing the new technology, towards changes in the specific membrane costs as well as the specific power per membrane square meter.

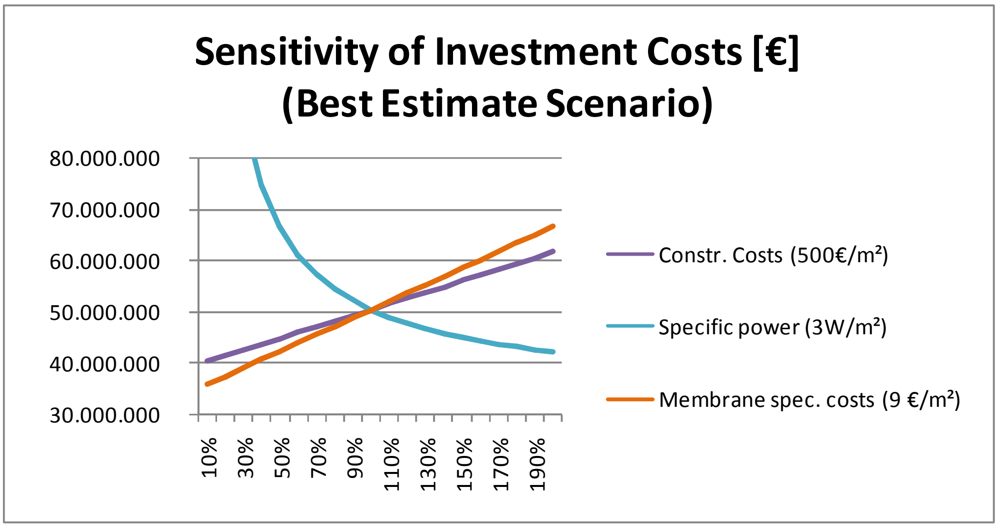


Figure 55: Sensitivity of investment costs in the best estimate scenario

7.4.2 NPV Sensitivity to Operating Costs and selected Indices (Best Estimate Scenario)

This analysis shows a clear dependency of a positive return on investment on the maintenance costs that are necessary for keeping the plant operational. This appears as a weak point in the overall assessment as, compared to the estimation of investment costs, even less analogies to the desalination technology can be derived since no process experience is yet available. Within the maintenance costs, the biggest portion is dedicated to the balance-of-plant costs (BoP), which are a rule-of-thumb percentage applied during project feasibility studies. BoP costs represent several different cost categories from project management to plumbing and IT. A careful planning of the BoP and their related maintenance costs will lead to a more accurate NPV calculation, as well as the first experiences with the water process elements (pre-treatment and membranes).

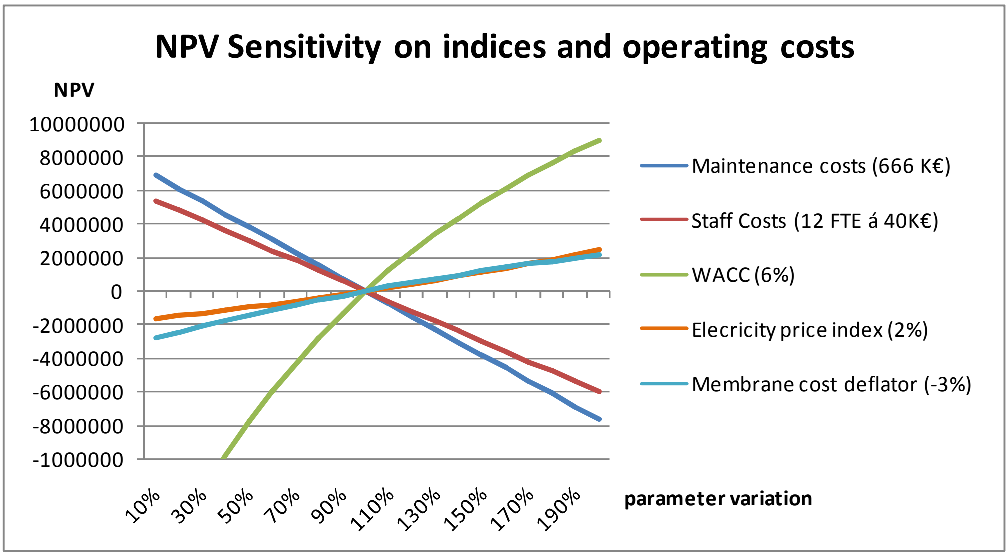


Figure 56: Sensitivity of NPV to operating costs and indices (best estimate scenario)

Also not surprisingly, the applied discount rate (usually the WACC – Weighted Average Cost of Capital is applied) plays a major role in the project's economic assessment. As in the best estimate scenario the future annual costs after the feed-in tariff grant period are higher than the annual revenues, a higher WACC will increase the overall NPV of the project.

7.5 Required Subsidies – Feed-in Tariffs

As for most renewable energies, electricity generation from osmotic power will need enormous financial, technical and political efforts to develop the technology until market maturity and cost competitiveness are achieved. Various subsidy instruments can be used to stimulate research, development and dissemination of RES technologies. Feed-in tariffs are the most widely used instrument and also implemented in Croatia, where those tariffs span from 490 €/MWh for small PV down to 66 €/MWh for small hydro with best utilization.

As PRO is in a very early research stage, feed-in tariffs might not yet be the proper way to facilitate the technology's dissemination in the real world. Other than for PV, wind or hydropower, where already relatively mature industry with economies of scale and market prices is established, PRO projects will have very individual cost calculations. As shown in the investment sensitivity analysis, especially construction costs demonstrate a huge impact and they will certainly be very site specific.

But feed-in tariffs are already popular benchmarks for investment conditions for various renewable technologies. They also relate strongly to the levelized costs of electricity that are inherent in an established RES-e technology like solar, wind or hydropower. Hence, they are used here as a theoretical target line for the revenues necessary to achieve break even conditions in a PRO power plant operation under certain conditions.

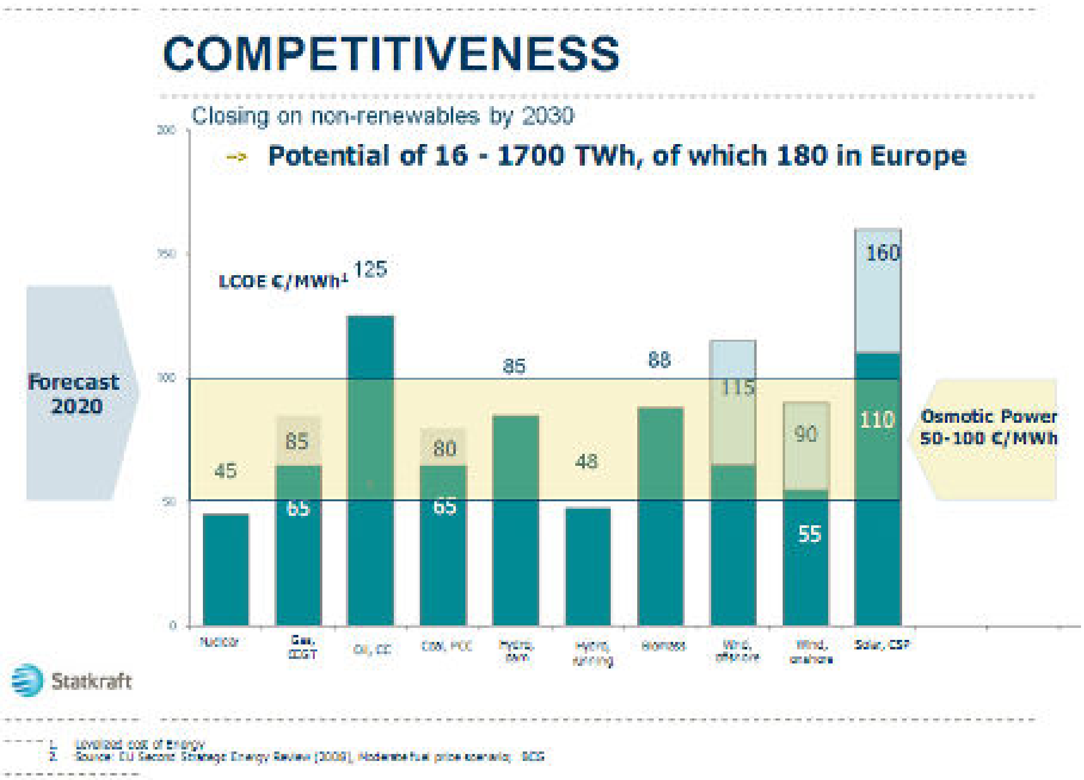


Figure 57: PRO Levelized Cost Of Electricity expectations for 2020[149]

[149] Skilhagen (2009), p. 11

Statkraft states that the LCoE shall be in the range of 50 – 100 € by 2020, competing with several other technologies (see Figure 57). But as shown above, the expectation of current cost levels are between ~100 €/MWh (best case scenario) and 260 €/MWh (best estimate scenario). In addition to specific subsidies for basic research and development, feed-in tariffs must be introduced to bridge the innovation gap and stimulate the dissemination of PRO like for any other renewable energy. The expectation of sufficient and secured income, at least over the grant period, will attract applied research, suppliers, operators and investors to develop the PRO technology towards market maturity.

To indicate in which range a feed-in tariff would need to be set in order to incentivize investments, some comparative scenarios are drawn:

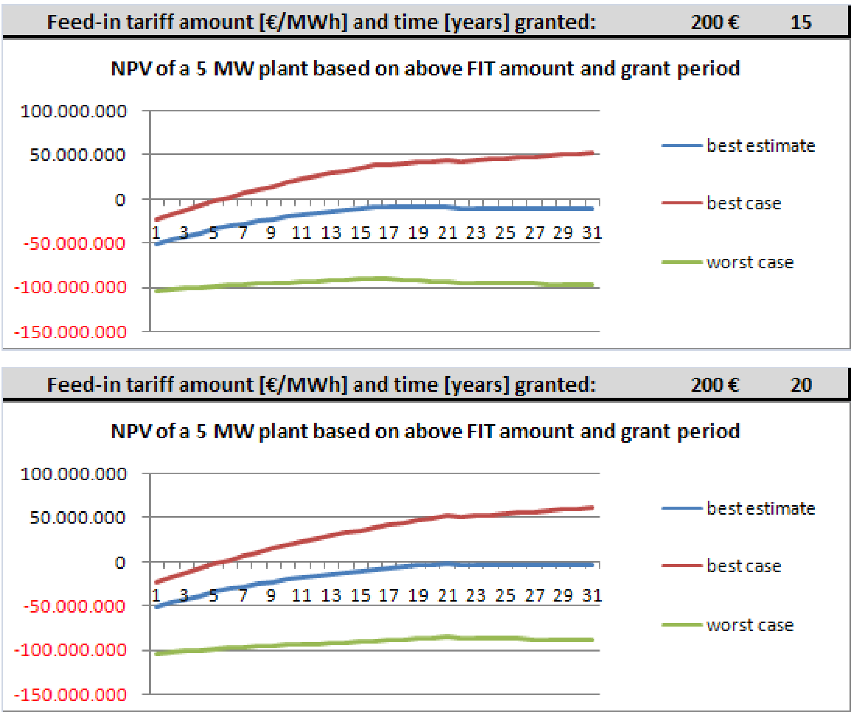


Figure 58: NPV scenarios with Feed-in Tariff = 200 €/MWh and 15 or 20 years grant period

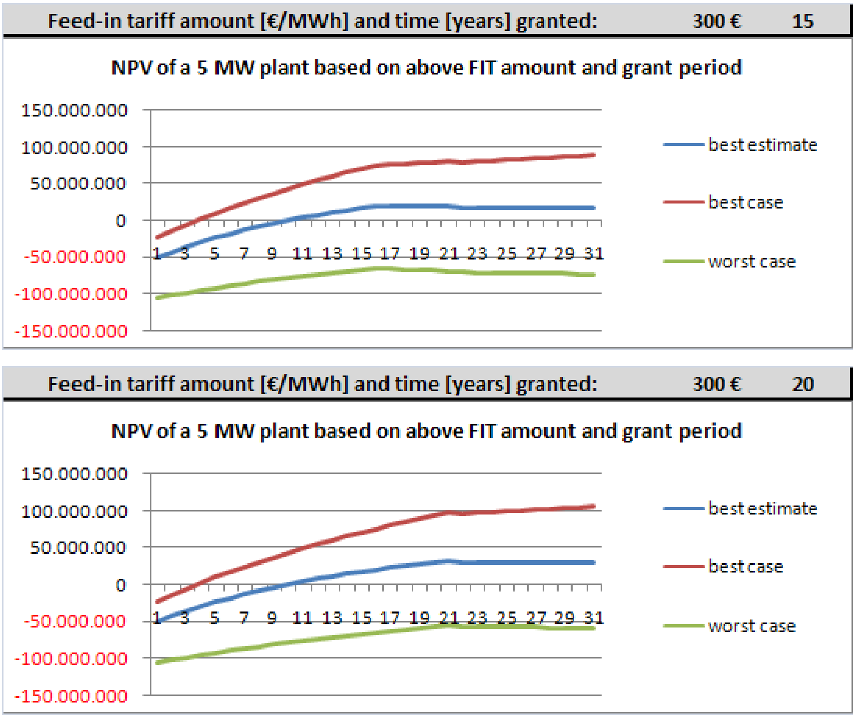


Figure 59: NPV scenarios with Feed-in Tariff = 300 €/MWh and 15 or 20 years grant period

Since investors and operators will only be attracted if profit can be predicted with certain probability, feed-in tariffs would need to start in the area of 200 – 300 €/MWh with a long-term horizon of 20 years. Depending on the pace of development, tariffs shall be lowered accordingly and the granting period reduced.

Alternatively, the feed-in tariffs could be set or adjusted between defined boundaries based on the individual cost structures of a projected plant. This would enable the reflection on specific environmental, hydrological or geological conditions which are influencing the specific investment costs.

8. Investigating a Feasible Pilot Site: HE Dubrovnik

8.1 Site Description

The HE Dubrovnik plant is a joint operation between Croatia and Bosnia & Herzegovina, built in 1964. It utilizes the waters of the Trebišnjica catchment, which covers a karstic area of about 1.630 m². Before the Hydroelectric exploitation the Trebišnjica was a lost river, springing near Bileca and disappearing after the town of Trebinje in the fields of Popovo Polje and discharging via underground conduits into the Adriatic Sea. Parts of the Trebišnjica water joined the Neretva river and the Ombla is also fed from these waters.[150]

Figure 60: The Trebišnjica catchment area[149]

[150] HEP - Croatia Power Plants, pp. 236

Before the Trebišnjica hydropower system was built, the winter floods were accumulated in the Popovo Polje fields for a couple of months. As such, the river could not be properly used, neither for agricultural nor for power generation. The construction of a series of dams, reservoirs, artificial waterways and hydropower stations enabled a multi-purpose water usage throughout the year: electricity generation of about 1,500 GWh/yr, flood control, agricultural irrigation and drinking water usage.

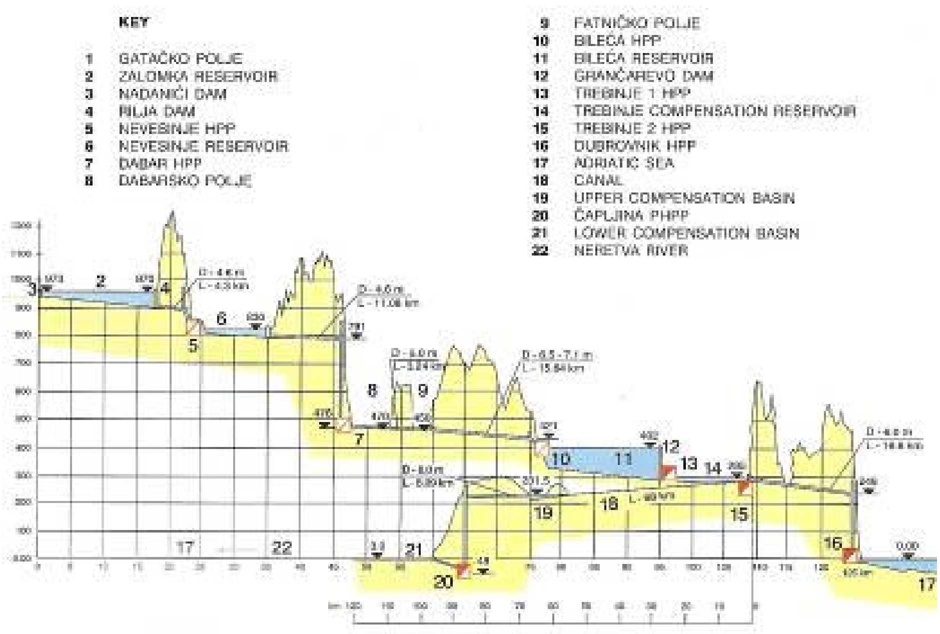


Figure 61: Longitudinal section of the Trebišnjica HP system structure[151]

The HE Dubrovnik plant is the furthest downstream of the Trebišnjica hydropower system. It is built completely underground and, since 1964, was planned to house 4 penstocks and turbines, 2 headrace tunnels and 2 tailrace tunnels. The powerhouse is built as an artificial cave for the originally planned size, but only 50% of the capacity is implemented, with the other 50% still waiting for realization. Out of the 2 turbines, one is owned by Croatia and one by BiH.

[151] HEP - Croatia Power Plants, pp. 236

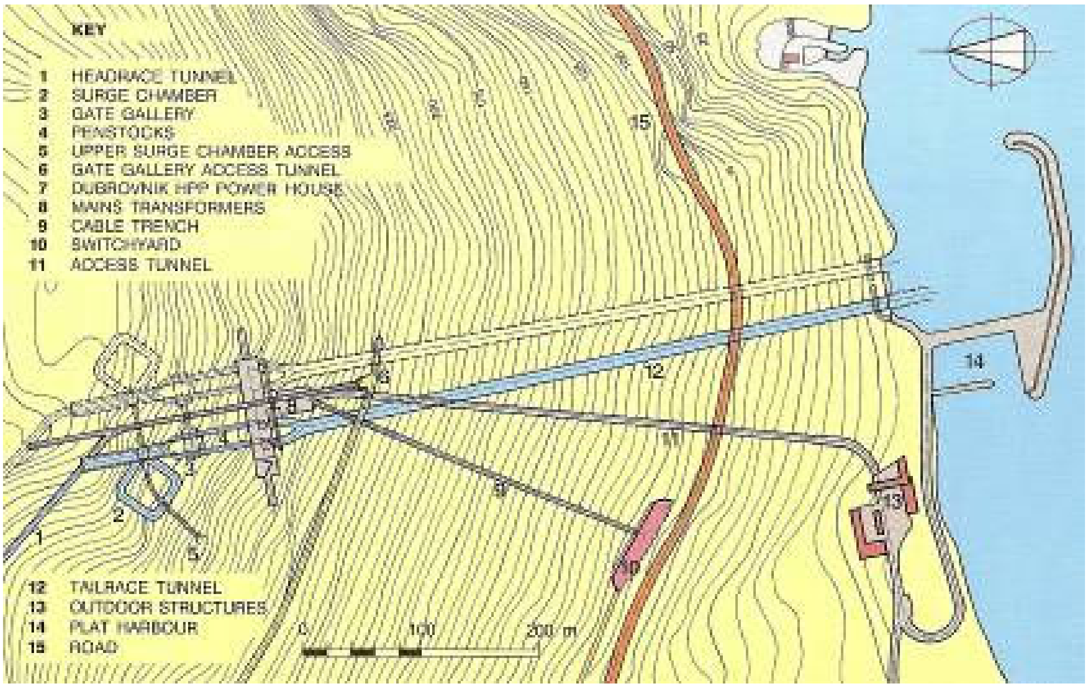


Figure 62: Powerhouse structure plot plan[152]

The headrace tunnel total length is 16.5 km with a diameter of 5.5 - 6 m, carrying a maximum of 90 m³/sec. The penstock is 2*282 m with 3.9 – 3.3 m diameter.

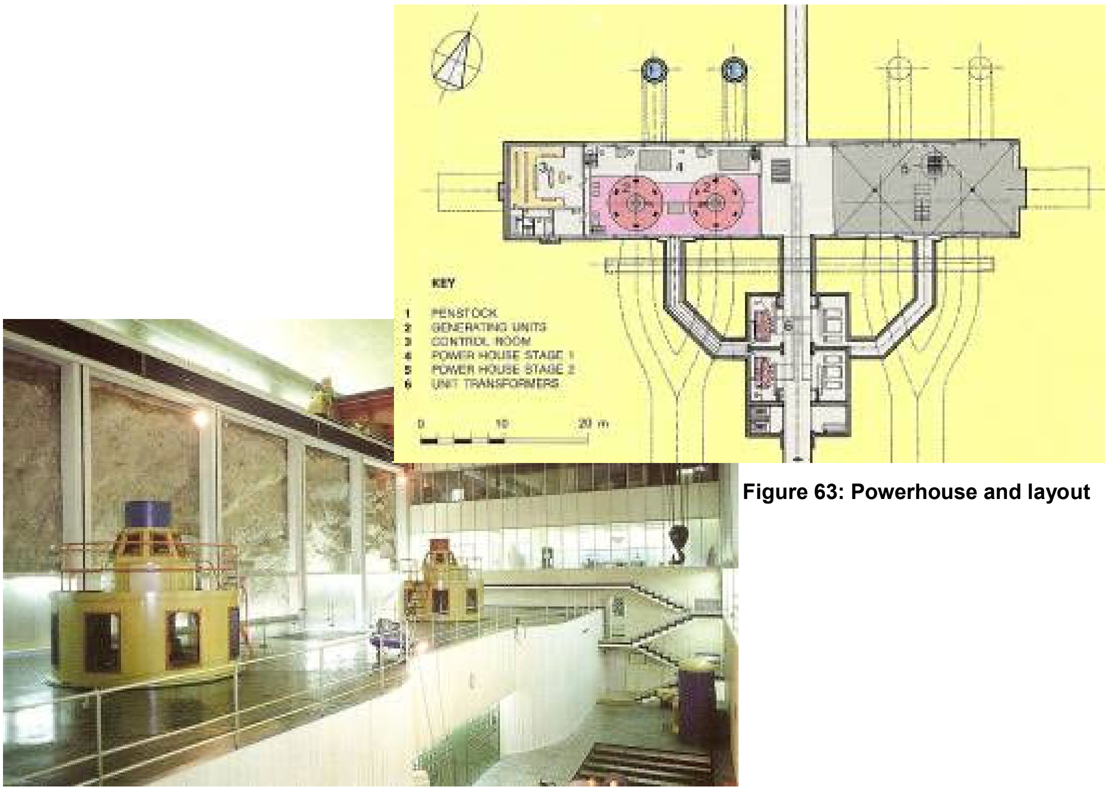


Figure 63: Powerhouse and layout

[152] HEP - Croatia Power Plants, pp. 236

Since all of the construction is excavated from the rock, only the switchyard and the transmission lines are visible from outside. The tail-race tunnel is an open underground channel with a horse-shoe cross-section of 4,35 x 8,0 m and a length of 510 m.

In front of the tail-race tunnel's mouth there is a breakwater of 210 m length to protect the tail-water and the plant from the influences of the sea waves. It also diverts the discharged water into the open sea.

Figure 64: Bird's eye view of the plant and detailed view of the tail-water discharge

About 6 m of the tunnel's 8 m height is below the level of the sea, which fluctuates with a maximum of 70 cm above and a maximum of 61 cm below the mean sea level[153]. This also means that when the plant is shut down the sea water enters the tail-race tunnel.

8.2 Site Applicability for a PRO Power Plant

It was stated as a goal of this study to outline if and where a feasible site in Croatia could be to build a PRO power plant. It is not the target to perform a feasibility study but to indicate, based on the available information, where a feasibility study would qualify for a potential project development.

The hydropower plant HE Dubrovnik was pre-selected for the following reasons:

[153] Sea level, Dubrovnik data

8.2.1 Fresh Water

The tail-water flow of the hydropower plant is:

- Available in an excessive amount for a pilot plant size,
- Relatively constant flowing with the best possible full-load hours expectations,
- Already regulated in a race tunnel, hence intake construction should be relatively cost effective,
- Available with minimal distance to a plant.

8.2.2 Sea Water

Sea water supply shows

- Good and stable salinity grade since there are no large rivers discharging close by,
- Steep sub-surface gradient enabling intake close to the plant,
- Although in a very touristic coastal area, due to the HEP property ownership there is no touristic and marine usage currently in the very near vicinity, except for a small fishery,
- Limited tidal influence,
- No extraordinary pollutants known that could negatively influence the process.

8.2.3 Infrastructural

Due to the existing power plant, all infrastructure pre-conditions exist, such as:

- Road access,
- Full administrative and technical staff and organization,
- High voltage grid access,
- Monitoring and maintenance features and staff,
- Land ownership by HEP,
- Second phase of the plant still in a development state, so that additional measurements for integrating a PRO implementation can be included in the final plans.

8.2.4 Limiting factors

Two limitations became obvious during the site visit:

- Space availability:
  Although the plant area is owned by HEP it does not show the flat space necessary for a 5 MW plant, which is for about 20.000 m².
- Tail-race tunnel:
  As about 75% of the tail-race tunnel height are sub-sea surface, sea water floods the tunnel when the hydropower plant is stopped.

For the second limitation, a relatively simple control mechanism for shutting down the PRO plant's water intake should be possible if no fresh water is supplied to the intake.

For the first limitation, a by-pass can only be found by carving out the plant from the rock, as was already done for the first stage of the power plant, including the powerhouse. From the planning of the second phase, where head race tunnel, penstock and tail race tunnel need to be carved out of the stone as well, certain investment numbers are known and used for a site specific cost calculation, with substantial increase as surcharge for the pure rock volume to be disposed or re-used, e.g., in a cement mill.

At the same time, the carving of the plant would allow a sub-surface construction, which allows, according to Statkraft calculations, the most efficient operation of the PRO process[154].

8.3 Site Parameters and ROI for a 5 MW PRO Plant

Based on the numbers and the calculation methods used for the scenarios exposed in Chapter 7.3, a calculation was performed with project parameters more precisely defined and aligned to the selected site.

These changes have been applied:

- Administration staff reduced as existing team could be re-utilized,
- Construction costs for the plant according to in-rock design,
- Construction costs for water intake due to „ideal“ constellations,
- Introduction of an area compression factor to reduce footprint and volume in exchange for slightly higher maintenance costs for membranes and pressure exchangers (more difficult handling),
- Balance-of-plant costs reduced as many facilities can be reused from existing HE operation and existing HEP infrastructure,
- A higher cost deflator for membranes since the starting point is with 3 W/m² only and a future increase to 5 W/m² is not included in the calculation elsewhere,
- Introduction of the Adriatic salinity feature of a 8% higher osmotic pressure due to the salinity of 38 instead of 35,
- Internal losses set to 20% due to sub-sea level design.

The list of estimated parameters is found in Table 33.

[154] Skilhagen et.al. (2008) p. 479

Table 33: List of parameters for a theoretical 5 MW PRO plant at HE Dubrovnik

PARAMETERS for PRO	estimated	unit	eviation	intenance
Rated capacity	5.0	MW		
FLH	8,000	h/yr		
Energy yield / year to grid	32,000	MWh		
Internal losses	20%	%	10%	
Adriatic Salinity effect	108%	%		
Freshwater feed	4.6	m³/s		
Room height needed	8	m		
area compression effort result	25%	%		
Required footprint	15,500	m²		
Required volume	124,000	m³		
constr. cost per m³ tunnel in karst known	100	€/m³		
constr. cost per m³ plant in karst est.	200	€/m³		
construction costs per m²	1600	€/m²		0.50%
Intake construction costs fresh	500,000	€	40%	0.50%
Intake construction costs sea	2,000,000	€	40%	0.50%
Specific Membrane Power	3	W/m²		
Membrane excess for washing (0,5h/d)	2.1%	%	20%	
Membrane costs / m²	9.0	€/m²	30%	0.5%
Pressure exchanger (PX300) unit costs	20,000	€/unit	20%	1.8%
PX throughput	65	m³/h		
Intake filter unit costs (1 unit per 1 m³/s)	250,000	€/m³/s	20%	3.0%
pump costs +2 bar (per m³/s)	70,000	€/m³/s	20%	1.8%
Turbine/generator full unit	350,000	€/MW	10%	2.0%
Balance of Plant costs	20%	%	20%	3.0%
Fees from Revenue	2.00%	% of revenue	50%	
Number of extra staff for 3 shifts	5	FTE	20%	
Admin services extra staff	1	FTE		
FTE costs	30,000	€/FTE/p.a.	30%	
1 EURO =	1.30	USD	20%	
1 KUNA =	0.13	EUR	20%	
Investment subsidy	20%	%		
Feed-in tariff	250	€/MWh		
Feed-in tariff grant time	20	years		
electricity revenue producer to grid	50	€/Mwh	20%	
Internal discount rate	5.0%	%		
cost inflator electricity	2.0%	%		
cost inflator PX and Filters	-1.0%	%		
cost inflator membrane	-3.0%	%		

Table 34: Investment costs of HE Dubrovnik 5 MW PRO plant

Investment	Quantity	units	€/unit	Investment [€]	Weight	Group Weight	
Membrane costs	1,701,389	m²	9.0	15,312,500	22%		
Pressure exchangers	475	units	20,000	9,500,000	14%		
Intake filters	13	units	250,000	3,300,754	5%		
Pumps	22	units	70,000	1,524,348	2%	42%	Water
Intake Construction	1	units	2,500,000	2,500,000	4%		
space + construction	15,500	units	1,600	24,800,000	35%	39%	Constr.
Balance of plant costs	20%	of above		11,387,521	16%		
turbine/generator	5	MW	350,000	1,750,000	2%	19%	BoP
Total				70,075,123	100%		
Total and Specific Investment				Investment [€]	€/KW		
Total Investment at T0				70,075,123	14,015		
Subsidy	20%	of sum of costs		-14,015,025	-2,803		
TOTAL Capital Needed				56,060,099	11,212		

As expected, the total investment costs are very much influenced by the massive construction costs due to in-rock design.
Also visible is the strong factor that membrane costs play, with a good outlook in the future due to expected increase of specific power and reduction of specific costs.

According to the estimates and the resulting ROI figures, the proposed feed-in tariff is set to 250 €/MWh for 20 years, which results in a positive ROI for an investor, with the project breaking even after ~15 years.

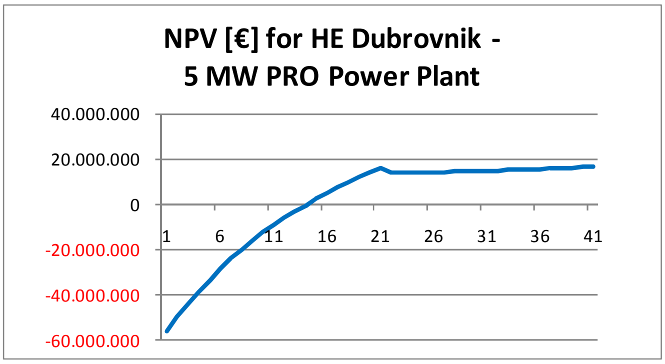


Figure 65: NPV for HE Dubrovnik 5 MW PRO plant

Overall, the of HE Dubrovnik can be seen as a nearly ideal site for a pilot project with the PRO technology. It shows that even with the biggest restriction of “no space” and the most expensive bypass – placing the whole plant into the rock - a plausible project calculation is possible.
A feed-in tariff, as proposed with 250 €/MWh for 20 years, appears to be a very high cost burden for the electricity consumers. Yet, it is still moderate compared to 490 €/MWh (even if only for 12 years) for an already very much established technology such as PV.

Table 35: Levelized costs of electricity for the HE Dubrovnik 5 MW PRO plant

Years of production	30 yr	96.6	NPV costs / Total MWh produced [€/MWh]
MWh produced	960,000	188.4	Levelized cost of electricity [€/MWh]
MWh produced discounted	491,918	29.8	Specific yield [€/MWh]
Years of production	20 yr	130.9	NPV costs / Total MWh produced [€/MWh]
MWh produced	640,000	210.0	Levelized cost of electricity [€/MWh]
MWh produced discounted	398,791	40.0	Specific yield [€/MWh]
Years of production	20 yr	130.9	NPV costs / Total MWh produced [€/MWh]
MWh produced	640,000	210.0	Levelized cost of electricity [€/MWh]
MWh produced discounted	398,791	40.0	Specific yield [€/MWh]

Although the HE Dubrovnik site is regarded as a well suited pilot site, the LCoE are still significant compared to current alternatives and also to the stated future target costs. But considering that the PRO technology is still evolving from its research and development phase, the numbers look very promising.

Additional benefits from the plant could be generated, as about 15% of the fresh water feed are not used in the actual osmotic process but are spilled as fresh water bleed into the sea. This water already has undergone the pre-treatment process (filtering) and hence could be used for backing up the potable water supply of the surrounding settlements.

9. Summary

9.1 Croatia's Preconditions for Renewable Energy

The Republic of Croatia presents itself as a market ready for renewable energy generally, and the investigated osmotic power generation with the PRO technology specifically. With the accession to the European Community, which is expected within the next few years, numerous legislative preconditions for new projects have been established. These include state-of-the-art procedures to ensure environmental protection (environmental impact analysis), to foster the use of renewable energies (feed-in tariffs, grid connection grants), to liberalize the electricity market and, last but not least, to create a positive climate for foreign investments.

Even if current numbers about the renewable energy adoption do not reflect this openness, pressure will increase to accelerate, due to an ever growing electricity hunger, to the growing competition in the European energy markets, and to the predicted increase of prices of fossil fuels, on which the current and planned power generation relies.

9.2 Hydrology Preconditions for Power Generation

Croatia has relatively good preconditions for hydro based power generation and has a strong heritage in harnessing it, with roots going back tol Nicola Tesla. Croatia's most opulent water resources are in the Danube catchment area, but there are still considerable catchments discharging into the Adriatic Sea via small and medium scale rivers. Of these, only the Neretva River can be seen as a stream-like river carrying more water than all of the small rivers together. The Neretva already suffers from water demand competition, agricultural irrigation pollution and her delta spans kilometres of flat land which makes PRO-utilization considerations more difficult.

All of the rivers are already heavily exploited by hydroelectric power plants, with still a tremendous potential left for additional small and medium classical hydropower stations. All hydropower plants have one problem in common: the big variations in precipitation, often causing floods in winter and draughts in summer. The counter measure was building dams and reservoirs to regulate and stabilize water resources, but there remains a strong dependency on the amount of water available for power generation, leading to a reduction in achievable full-load hours of the plants.

9.3 Hydrology Conditions for PRO Potential Calculation

Comparable to the classical hydropower generation, osmotic power constitutes a base load power supply technology. It relies on a constant fresh water supply and quality, hence requires stable conditions in the rivers' flow (usually measured in m^3/sec). In order to derive the achievable energy potential of osmotic power, the daily flow data of the rivers for the last ten years from the Hydrology Institutes of Croatia and BiH (for Neretva) were used. For waters where no flow data was available, analogies have been drawn to trace the flow dynamics. For ecological reasons, a minimum residual water flow equal to 100% of the average minimum flow of the last 10 years has been applied to the potentials calculation.

In addition to the fresh water conditions, the salinity of the Adriatic Sea with a salinity grade of 38 is exceptionally good, as the average salinity stated in literature and applied in research is about 35. These conditions will achieve a slightly (~ 8%) better power yield through the osmotic process. This Adriatic feature has not been included in the overall potentials calculation as it would require also the consideration of the actual salinity grades of the fresh water side.

The *Theoretical Potential* was derived from the sum of average flow data of all rivers and a physical constant for specific osmotic power yield from mixing fresh and sea water. Croatia hence shows a theoretical energy potential from salinity gradient via osmosis of 8.8 TWh p.a.

9.4 Reasonable and Realisable PRO Potential in Croatia

The gross power yield of the PRO process is 1 MW per 1 m^3/s of fresh water with an efficiency of 75% to 80% based on various factors. The Technical Potential is calculated based on those process parameters which are expected to change within the next 20 years due to efficiency gains. The *Technical Potential* for 2010 is calculated with 4.33 TWh p.a. and for 2030 estimated to 4.6 TWh p.a.

For the *Realisable Potential* in Croatia, actual flow data and environmental restrictions (Natural parks, etc.) have been considered, but also a "common sense" economic barrier that limits the overall potential and is inherent in the technology. Therefore, a *Reasonable Potential* was introduced, defined as the Technical Potential limited by a minimum utilization, which was set to currently 6,000 FLHs, degrading to 5,000 FLH in 2030. Full load hours are expressed as the plant's annual energy generation per its rated turbine capacity.

This *Reasonable Potential* currently amounts to 0.83 TWh and grows to 1.1 TWh in 2030. This maximum realisable potential is ~4% of current electricity consumption and, respectively, ~3% of the predicted consumption in 2030.

9.5 Inhibitors for the Realisable PRO Potential

A scenario for a realisable potential has been drawn until 2030 with a list of certain limitations and preconditions for dissemination of the technology. The PRO technology's limiting factors are mainly the very early state of technology which requires lengthy capacity building, the availability of efficient membranes in the market and, especially in areas where land is scarce and expensive, the massive requirement for plant area. Despite the fact that PRO can be seen as ecologically friendly, there are other natural inhibitors to a fast dissemination. Especially the fact that fresh water is taken from the river bed, at least for a small distance but in the ecologically important river mouth, will find opponents in ecology and fishery. Where river discharge is flat or into estuaries, the necessary distances for fresh and/or sea water intake will put additional burdens on the environmental and economic balance of the project.

Given the fact that PRO power plants can only be built where rivers meet the sea it must be acknowledged that these areas usually are either touristic – as in Dalmatia - or industrial zones. Both scenarios work against the PRO requirement for large space occupation (~20,000 m² for 5 MW gross).

9.6 The State of PRO Technology and its Economics

The PRO technology can be called "bleeding edge" in the sense that its implementation is not proven yet in a scaled production. The demonstration plant of Statkraft is built for a capacity of 10 KW and will prove the functioning of components and process. Key modules such as the membranes are hand-crafted and the complete process, including water pre-treatment, is being verified and optimized for the local conditions. The vast amount of membrane area necessary (5 million m² for 5 MW) will challenge an industry that is currently focusing on water treatment such as the sea water desalination with similar, but still different membrane products. Should PRO succeed, this industry will have to produce a multitude of their current membrane capacities. In addition, other components such as energy (pressure) recovery devices are taken from the RO desalination technology (Reverse Osmosis). Although available and proven, the technology is expensive and long-term total cost of ownership for the PRO usage is still to be verified.

Therefore, many assumptions have to be made for a “general” economic assessment of the technology use. A scenario approach has been selected with a “best estimate”, a “best case” and a “worst case” scenario. For the parameters that influence a plant’s investment and operation costs, the “best estimate” has been derived from discussions with project representatives of the hydropower, desalination and construction projects development as well as from membrane production. Based on the confidence in the accuracy of the estimate, deviations for best and worst case are calculated. No differentiation has been made about possible root causes of best- or worst case realisation (technology, site, hydro-geology, environment, etc.).

For each scenario and the project lifetimes of 20, 30, 40 and 50 years a Return of Investment calculation was performed, plus for 12 years, which is the current grant period for feed-in tariffs in Croatia. In order to analyse the required subsidies, a feed-in tariff has been introduced that allows for a project’s break-even after a 20-year operation per scenario.

Accordingly, feed-in tariffs of ~260 €/MWh in the best estimate scenario, or ~80 €/MWh in the best case scenario, allow to break even after 20 years under the set conditions per scenario.

For the best case scenario, and a 20 year investment horizon, the LCoE amount to ~100 €/MWh, comparing well to a target level of 50-100 €/MWh as stated by Statkraft for 2020.

9.7 Potential Pilot Site Selection and its Economics

In order to deliver more precise estimations and a realistic scenario for a pilot plant, the most promising site has been looked for with regards to water supply and other facts such as infrastructure or possible ownership of land and project development.

The tail-water of the existing hydropower plant of HEP in Dubrovnik (HE Dubrovnik) has been selected as a nearly ideal pilot site. After a site visit and discussions with the plant staff, the parameters list for the ROI calculation was adapted with site-specific information. This includes the fact that although HEP owns a large plot of land in which the power plant is placed, there is no available space to accommodate the 20,000 m² required for a 5 MW PRO power plant. The only solution to bypass this restriction was included in the investment calculation: to carve the plant into the rocks, as was done in the 1960s for the existing power plant structures.

Despite this huge burden on the investment costs, a surprisingly positive return resulted from investment calculation: The levelized costs of electricity (LCoE) within an investment horizon of 20 years are 210 €/MWh, or 190 €/MWh for 30 years. Taken into account that for small scale PV (<10 KW) a feed-in tariff of 490 €/MWh is granted for 12 years, there must be a realistic subsidy scenario possible for the PRO power generation technology. An ROI for investment horizons up to 50 years is shown with a proposed feed-in tariff of 250 €/MWh and a grant period of 20 years. The project would break even after ~15 years.

10. Conclusions

Croatia's technical potential for the PRO power generation has been assessed to 4.3 TWh. Thereof, the reasonably realisable potential of ~1 TWh constitutes about 4% of the country's current (predicted) 2010 electricity demand. This demand will steeply increase over the next 30 years, and so does the requirement for adding additional production capacity. Based on favourable natural conditions, renewable energy technologies like hydropower, wind and PV, have a great potential to grow in capacity installed. These technologies, however, are strongly competing for limited investment funds for national infrastructure, which puts large scale / least cost solutions up on the investors' priority list.

At the same time, the PRO technology has evolved from a research & development to a prototype stage, with Statkraft (Norway) pursuing the technology's market maturity. Harnessing the salinity gradient of sea and fresh water with the PRO process is indeed a fascinating renewable energy application, with the potential to generate renewable electricity in an emission-free and sustainable manner. Current investment costs estimated for PRO based power, and the resulting energy, rank the technology above the existing alternatives such as wind and hydro. Yet, with assessed levelized costs of electricity (LCoE) in the area of 200 €/MWh, the PRO technology should be able to compete with solar power right from the beginning of commercial projects.

Statkraft is expecting LCoE to reach of 50 – 100 €/MWh by 2020, although several factors challenge this optimistic view:

- No membrane for PRO is commercially available in early 2010;
- Existing prototypes achieve about ¼ of the target specific power of 5W/m²;
- A 25 MW power plant will require four times the annual amount of comparable membranes currently produced for the desalination industry (based on 2 W/m²);
- Many steps in the PRO process are currently optimized for the conditions found in Norway; other sites will find different water compositions and environmental influences;

But there are also strong supporting factors for leveraging the PRO technology:

- A steep learning curve is expected, once commercial membrane production is scaling up;
- A strong interest is visible from various stakeholders, including research & development, manufacturing, utilities and politics;

- A European policy framework that fosters the RES development and enables countries to define supporting rules, including for Ocean Energy;
- The need for capitalizing on all alternative sources for electrical energy, in preparation for a future with scarce and expensive fossil – and nuclear - resources;
- An obvious commitment from Statkraft to further pursue the PRO technology towards market maturity.

Project development will require stakeholders with stable structures and procedures and a deep involvement of multiple regulatory bodies with expertise similar to but extending the hydropower application. Hence, early PRO projects are expected to stay within the influence and portfolio of incumbent and strong utility companies with the financial strengths required to start and carry out such long-term investments in a risky environment.

For the growing Croatian electricity demand, osmotic power will be a future alternative energy source. Once matured, the PRO technology can become a niche market player and provide a base load capacity of more than 100 MW. Project developers will meet good environmental conditions, especially from a fresh and sea water perspective; and they will be able to utilize a marine and hydropower engineering experience of, by then, probably more than 135 years![155]

[155] Nicola Tesla built the first hydropower plant at the Krka waterfalls in 1885; see also chapter 1.

11. References

Aaberg (2004)	Dr Rolf Jarle Aaberg, Statkraft Energi AS, Norway **Ocean energy proposal *Salinity Power 2,*** Brussels, 19.October 2004 http://ec.europa.eu/research/energy/pdf/other_res05_aaberg.pdf (archived: http://www.webcitation.org/5qYHDAHmo on June 17, 2010)
AMTA (2006)	American Membrane Technology Association **Membrane Desalination Costs** (Feb. 2006), http://www.amtaorg.com/amta_media/pdfs/6_MembraneDesalinationCosts.pdf (archived http://www.webcitation.org/5qYHLaHb7 on June 17, 2010)
Applied Overstock Prices	Applied Membranes **Membranes Overstock Price List** http://www.appliedmembranes.com/Excess_Inventory.pdf (archived http://www.webcitation.org/5qYbOWHv4 June 17,2010)
Applied SW30	Applied Membranes **Product Sheet Filmtech SW30HR LE-4040** http://www.appliedmembranes.com/FilmTec%20Specs/SW30HR%20LE-4040.pdf (archived http://www.webcitation.org/5qYakVgEY, 2010)
Applied SW30 HR LE 400i	Applied Membranes **Product Sheet Filmtech SW30HR LE-400i** http://www.appliedmembranes.com/FilmTec%20Specs/SW30HR%20LE-400i.pdf (archived http://www.webcitation.org/5qYbe0CFvJune 17,2010)
Applied SWC5	Applied Membranes **Product Sheet Hydronautics SWC5** http://www.appliedmembranes.com/Hydranautics%20Elements/SWC5.pdf (archived http://www.webcitation.org/5qYaWu238 June 17, 2010)
Bonacci and Andrić (2008)	Ognjen BONACCI, Ognjen, ANDRIĆ, Ivo **SINKING KARST RIVERS HYDROLOGY: CASE OF THE LIKA AND GACKA (CROATIA)** *ACTA CARSOLOGICA 37/2-3 – 2008, pages* 185-196, http://carsologica.zrc-sazu.si/downloads/372/2Bonacci.pdf (archived http://www.webcitation.org/5qbdYaPTm June 19, 2010)
Botany	Botany Online - Osmosis http://www.biologie.uni-hamburg.de/b-online/e22/22c.htm (archived http://www.webcitation.org/5rpwqZ9e0 Aug. 8, 2010)
Car (2006)	Car, Stjepan: Nikola Tesla and Konèar Group: Symposium "**Tesla in Croatia**", UNESCO house, Paris, Sep. 13, 2006 : *Editor: Zlatko Kniewald – Zagreb, Croatian Academy of Engineering;* http://www.hatz.hr/hrv/skupovi/tesla_unesco_proceedings.pdf (archived http://www.webcitation.org/5qYHQxr76 on June 17, 2010)
Childress et.al. (2009)	Achilli, A., Cath T.Y,, Childress A.E.: **Power generation with pressure retarded osmosis: An experimental and theoretical investigation** (Nov. 1, 2009) *Journal of Membrane Science* Volume 343, Issues 1-2, , Pages 42-52
Damelin (2007)	Damelin, Dan (Lincoln Sudbury Regional Highschool) **Chemical Potential** http://chemsite.lsrhs.net/chemKinetics/PotentialEnergy.html (archived http://www.webcitation.org/5qYU1Ugre June 17, 2010)

DHMZ	Meteorological and Hydrological Institute of Croatia (DHMZ - Državni hidrometeorološki zavod) **Home Page** http://meteo.hr/index_en.php (June 11, 2010) (no webcitation possible)
Edwards - Freshwater	Edwards Aquifier Glossary **Freshwater** http://www.edwardsaquifer.net/glossary.html#fresh (archived http://www.webcitation.org/5qYXtKrr7 May 2nd, 2010)
Edwards (1984)	D. Edwards, Consultant to the FAO **Status and Prospects for brackish and sea water cage culture of finfish in Yugoslavia with special emphasis on salmonid species** FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO) Rome 1984, FI:DP/YUG/83/011 Table of Content: http://www.fao.org/docrep/field/003/R2733E/R2733E00.htm#TOC Conclusions: http://www.fao.org/docrep/field/003/R2733E/R2733E02.htm#ch7. (archived http://www.webcitation.org/5qYHy9zlh June 17, 2010)
EIA Consultants (2010)	MINISTRY OF ENVIRONMENTAL PROTECTION, PHYSICAL PLANNING AND CONSTRUCTION **PROFESSIONAL PREPARATION of environmental impact assessments projects** (POSLOVI STRUČNE PRIPREME I IZRADE STUDIJA O UTJECAJU ZAHVATA NA OKOLIŠ) http://puo.mzopu.hr/UserDocsImages/Popis_ovlastenika.pdf (archived http://www.webcitation.org/5qYHmsau8 June 17, 2010)
EIA Regulation (2008)	THE GOVERNMENT OF THE REPUBLIC OF CROATIA **REGULATION ON ENVIRONMENTAL IMPACT ASSESSMENT (2008)** http://www.mzopu.hr/doc/Regulation_on_information_and_participation_of_the_public..._OG_64-08.pdf **(archived** http://www.webcitation.org/5qYI3qlVv **June 17, 2010)**
EIHP Mission	Energy Institute Hrvoje Pozar **Home page -> Institute -> Mission** http://eihp.hr/english/institut_m.htm#d (archived http://www.webcitation.org/5qYKGboHM June 17, 2010)
Electricity Market (2004)	The Government of the Republic of Croatia **Electricity Market Act *Official Gazette 177/04* - Provisional Translation** http://www.hep.hr/opskrba/en/laws/zoiidzoe_ENG_NN_177_04.pdf (archived http://www.webcitation.org/5qYI8IEL5 June 17, 2010)
Energetika (2008)	Croatian Chamber of Economy Industry and Technology Department **Energy 2008** http://www2.hgk.hr/en/depts/industry/Energetika_2008.pdf (archived http://www.webcitation.org/5qYIEHpjJ June 11, 2010)
Energy Strategy (2008)	MINISTRY OF ECONOMY, LABOR AND ENTREPRENEURSHIP AND UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) **UPDATE/UPGRADE OF THE ENERGY STRATEGY AND OF THE IMPLEMENTATION PROGRAMME OF THE REPUBLIC OF CROATIA** Green Book – DRAFT – Translated version: http://www.undp.hr/upload/file/201/100871/FILENAME/GreenPaperDraft_EN.pdf (archived http://www.webcitation.org/5qYILVPXg June 17, 2010)
EOP (2007)	The Government of the Republic of Croatia **ENVIRONMENTAL OPERATIONAL PROGRAMME** http://ec.europa.eu/enlargement/pdf/croatia/ipa/3_croatia_environmental_operational_programme_2007-2009_en.pdf (archived http://www.webcitation.org/5rpyfhTUX Aug 8, 2010)

EP1315554	Patent EP1315554 **SEMI-PERMEABLE MEMBRANE, METHOD FOR PROVIDING ELECTRIC POWER AND A DEVICE** http://www.wipo.int/pctdb/en/wo.jsp?WO=2002/013955 (June 8, 2010)
EP1971420	Patent EP1971420 **A METHOD AND A SYSTEM FOR PERFORMING MAINTENANCE ON A MEMBRANE USED FOR PRESSURE RETARDED OSMOSIS** https://data.epo.org/publication-server/document?PN=EP1971420%20EP%201971420&iDocId=6985091&iPosition=0&iFormat=3 (June 8, 2010)
ERI Overview	EnergyRecoveryInc. **Technology Overview** http://www.energyrecovery.com/index.cfm/0/0/33-Overview.html (no archive possible; last access June 17, 2010)
ERI PX 300	EnergyRecoveryInc. **Pressure Exchanger PX 300 Brochure** http://www.energyrecovery.com/UserFiles/file/PX300_brochure_1109.pdf (archived http://www.webcitation.org/5qYaETqHV June 17, 2010)
ERI PX Manual	EnergyRecoveryInc. **Pressure Exchanger Manual** http://www.energyrecovery.com/UserFiles/file/80019-01-8%2065%20Series%20Manual.pdf (archived http://www.webcitation.org/5qYZwnWmP June 17, 2010)
EU – 2020 (2009)	European Parliament **DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC** http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF (archived http://www.webcitation.org/5qYITB6pY June 17, 2010)
EU Enlargement (2010)	EU Enlargement Croatia **Status in the accession negotiations EU - Croatia** http://ec.europa.eu/enlargement/pdf/enlargement_process/accession_process/how_does_a_country_join_the_eu/negotiations_croatia_turkey/overview_negotiations_hr_en.pdf (archived http://www.webcitation.org/5qYIWDi2x June 17, 2010)
EU Project Brochure (2004)	European Comission **The Salinity Power project- Power production from the osmotic pressure difference between fresh water and sea water (2001-2004)** ENK6-CT-2001-00504, http://cordis.europa.eu/documents/documentlibrary/82766661EN6.pdf (archived http://www.webcitation.org/5qYJBOTL9 June 17, 2010)
EU WFD (2000)	European Parliament Water Framework Directive 2000/L327: **Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy** http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0001:EN:PDF (archived http://www.webcitation.org/5qYJSrhvi June17, 2010)
Eurostat (2007)	Eurostat **Gas and electricity market statistics (2007),** (Electricity prod. 2005 from Hydropower in EU-27) http://www.energy.eu/publications/KSGB07001ENC_002.pdf (archived http://www.webcitation.org/5qYJYvajM June 17, 2010)

Fairbridge (1980)	Fairbridge, R.W., **The estuary: its definition and geodynamic cycle.** In Olaussen, E., and Cato, I., (Editors): *Chemistry and Geochemistrv of Estuaries.* John Wiley & Sons, New York 1980.: pp. 1-35.
FZOEU	Environmental Protection and Energy Efficiency Fund (FZEOU) **Home page** http://www.fzoeu.hr/hrv/index.asp?s=sredstva (archived http://www.webcitation.org/5qYJf79It June 17, 2010)
GNOO	Istituto Nazionale di Geofisica e Vulcanologia - Gruppo Nazionale di Oceanografia Operativa (GNOO) **Homepage** http://gnoo.bo.ingv.it/afs/
Grid Code (2006)	MINISTRY OF ECONOMY, LABOR AND ENTREPRENEURSHIP **Grid Code, Official Gazette 36/06 (inofficial translation)** http://www.hrote.hr/hrote/en/Documents/Grid_Code.pdf (archived http://www.webcitation.org/5qYKVyT6s June 17, 2010)
GWI (2010)	Global Water Intelligence **RO Membrane Supplier Marketshare 2008/9** Chart of the Month (online) Global Water Intelligence, Volume 11, Issue 2 (Feb. 2010) http://www.globalwaterintel.com/archive/11/2/analysis/chart-month-reverse-osmosis-membrane-suppliers-market-share-2008-9.html (archived http://www.webcitation.org/5qYaqh7Wm June 17, 2010)
HE Dubrovnik	HEP Dubrovnik Operation **Homepage** http://www.hep.hr/proizvodnja/en/basicdata/hydro/dubrovnik/default.aspx (archived http://www.webcitation.org/5qYLGmNUX June 17, 2010)
HE Senj	HEP Senj Operation **Homepage** http://www.hep.hr/proizvodnja/en/basicdata/hydro/west/senj.aspx (archived http://www.webcitation.org/5qYLIuiBu June 17, 2010)
HEP	HEP – Hrvatska Elektroprivredna Group **Home page** http://www.hep.hr/hep/en/group/default.aspx (June 11, 2010)
HEP - Croatia - Powerplants	Elektroprojekt Consulting Engineers **(**Zvonimir Sever) **Hydroelectric Power Plants in Croatia** Published by HEP – Hrvatska Elektroprivredna d.d., 199?
HEP Hydro	HEP Prozvodnja d.o.o. **Homepage – Hydropower Plants** http://www.hep.hr/proizvodnja/en/basicdata/hydro/default.aspx (archived http://www.webcitation.org/5qu6q0J3Q July 1st 2010)
HEP-OPS Laws	HEP Operator prijenosnog sustava d.o.o (OPS) **Home page** – List of Legislation concerning electricity market http://www.hep.hr/ops/en/documents/default.aspx **(archived** http://www.webcitation.org/5qYLB0fW2 **June 17, 2010)**
HERA (2008)	Croatian Energy Regulatory Agency (HERA) **Annual Report 2008** http://www.hera.hr/english/html/annual_reports.html (archived http://www.webcitation.org/5qYL5F7sB June 17, 2010)
Heritage (2010)	Heritage Center for International Trade & Economics Contacts **2010 Index of Economic Freedom - Croatia** http://www.heritage.org/index/country/croatia (archived http://www.webcitation.org/5qYLEHdwB June 17, 2010)

HR Identity	Government of the Republic of Croatia **Homepage -> about Croatia -> identity** http://www.vlada.hr/en/about_croatia/information/identity_card (archived http://www.webcitation.org/5qYLRxt4U June 17th, 2010)
HROTE	Croatian Energy Market Operator (HROTE) **Homepage -> About us** http://www.hrote.hr/hrote/en/about/default.aspx (archived http://www.webcitation.org/5qYLOS064 June 17, 2010)
IEA/OECD (2008)	International Energy Agency/OECD **Deploying Renewables Principles for Effective Policies** In support of the G8 Plan of Action; 2008, ISBN 978-92-64-04220-9 http://www.iea.org/textbase/nppdf/free/2008/DeployingRenewables2008.pdf (archived http://www.webcitation.org/5qYLX4gdZ June 17, 2010)
IRENA	International Renewable Energy Agency (IRENA) **Homepage -> News** http://www.irena.org/index.php?option=com_content&view=article&id=436:irena-welcomes-the-republic-of-croatia-as-145th-signatory&catid=57:news-2009-2010&Itemid=129 (archived http://www.webcitation.org/5qYLaDPgf June 17, 2010)
Jadran	Agency for Adriatic Sea Watershed, BiH (Jadran) **Home Page** http://www.jadran.ba/ **(July 24, 2010)**
Jones and Finley (2003)	A.T. Jones, W. Finley: **Recent Developments in Salinity Gradient Power**; *The proceedings of the Marine Technology Society OCEANS 2003,* Online access at: http://waderllc.com/2284-2287.pdf (archived http://www.webcitation.org/5qYLhWXCh June 17, 2010)
Koch MegaRO	**Koch Membrane** Product Sheet MegaMagnum http://www.kochmembrane.com/pdf/Brochures/665.36%20KMS_BRO%20MegaRO%20US.pdf (archived http://www.webcitation.org/5qYYzUMZE June 17, 2010)
Kuližić (2010)	Biljana Kuližić, Energy Institute Hrvoje Požar **Trends and Tendencies in Electric Energy Production and Utilization** *MSc Program „RenEnergy in CEE“ Lecture Notes*, March 2010
Kupusovic (2010)	Kupusovics, Director, Hydro Engineering Institute, BiH, at UN Economic Comission for Europe - Convention on the Protection and Use of Transboundary Watercourses and International Lakes **Workshop on transboundary water resources management in South- Eastern Europe** *18-20 May 2009, Sarajevo* http://www.unece.org/env/water/meetings/Sarajevo_workshop/presentations/session4/Adriatic_Sea_group/Neretva.pdf (archived http://www.webcitation.org/5qbMsau6h June 19, 2001)
Lachish (1998)	Lachish,Uri - *guma* science, (1998, online) **Osmosis Reverse Osmosis and Osmotic Pressure - what they are** http://urila.tripod.com/ (archived http://www.webcitation.org/5qYWcidwY June 17, 2001)
Lenntech Osmosis Calculator	Lenntech Water Treatment Solutions **Osmotic Pressure Online Calculator** http://www.lenntech.com/calculators/osmotic/osmotic-pressure.htm (archived http://www.webcitation.org/5qYXH88OQ June 17,, 2010)

Lenntech SWRO	Lenntech Water Treatment Solutions **Energy Recovery Devices for SW-Reverse Osmosis** http://www.lenntech.com/processes/desalination/reverse-osmosis/general/reverse-osmosis-desalination-process.htm#Energy_Recovery_Device_%28ERD%29 (archived http://www.webcitation.org/5qYZclgpu June 17, 2010)
Loeb (2002)	Sidney Loeb: **Large-scale power production by pressure-retarded osmosis, using river water and sea water passing through spiral modules** (Jan. 2002) *Desalination Nr. 143 (2002) pp 115-122*
Loeb et.al (1990)	S. Loeb, T. Honda and M. Reali, **Comparative mechanical efficiency of several plant configurations using a pressure-retarded osmosis energy converter,** *Journal of Membrane Science Volume 51 (3) (1990) 323–335.*
Loeb, Sidney	S. Loeb, **Method and apparatus for generating power utilizing pressure-retarded osmosis,** *Patent US 4,193,267, Assigned to Ben-Gurion University of the Negev, Research and Development Authority, Beersheba, Israel.* http://www.freepatentsonline.com/4193267.pdf (archived http://www.webcitation.org/5qYLnITWR June 17, 2010)
Malnar et.al.	Nada Malnar, B. Sc. Eng., Ivan Landek, B. Sc. Eng., Ivan Grubić, B. Sc. Eng. (State Geodetic Administration) **PROTECTED COASTAL AREA (PCA): WHY? HOW?** http://www.isprs.org/proceedings/XXXVII/congress/8_pdf/13_ThS-19/10.pdf (archived http://www.webcitation.org/5qYLsWAEG June 17th, 2010)
Melbourne (2007)	Melbourne Water Home Page **Seawater Desalination Plant Schema** http://thesource.melbournewater.com.au/content/articles/200706303.asp?From=HotTopic&HotTopicID=2 (archived http://www.webcitation.org/5qo3HtiW2 June 27, 2010)
MFA "Political Structure"	Ministry of Foreign Affairs and European Integration of the Republic of Croatia **About Croatia** (MFA home page) http://www.mfa.hr/MVP.asp?pcpid=970 (archived http://www.webcitation.org/5qYLy1f84 June 17, 2010)
MFA-EI (2009)	Ministry of Foreign Affairs and European Integration of the Republic of Croatia **Croatia on the Road to the European Union (second edition, 2009)** http://www.mvpei.hr/ei/download/2010/04/09/Croatia_on_the_Road_to_the_EU1.pdf (archived http://www.webcitation.org/5qYM3PreG June 17, 2010)
Milanovic (2002)	Petar Milanovic **The environmental impacts of human activities and engineering constructions in karst regions** *Episodes, Vol. 25, no. 1(March 2002)* http://www.episodes.org/backissues/251/13-21%20Mil.pdf (archived http://www.webcitation.org/5qaXlOVfT June 18, 2010)
MZUPO regulations	MINISTRY OF ENVIRONMENTAL PROTECTION, PHYSICAL PLANNING AND CONSTRUCTION **Regulations in the field of environmental protection – home page** http://www.mzopu.hr/default.aspx?id=7257 (archived http://www.webcitation.org/5qYM7OYTr June 17, 2010)
N2000 leaflet	Hrvatska Kockica u Europskoj slagalici **Leaflet on Natura 2000 project** http://www.natura2000.hr/PageTemplates/DocLibPage.aspx?pageId=89&langID=1 (archived http://www.webcitation.org/5qYNcVlwA June 17, 2010)

National Parks	Adriagate.com **List of National and Nature Parks** http://www.adriagate.com/en/croatia/national_parks.aspx?ID=7 (archived http://www.webcitation.org/5qYMrh3gx June 11, 2010)
Natura 2000	European Union **Natura 2000 Network Home page** http://ec.europa.eu/environment/nature/natura2000/index_en.htm (archived http://www.webcitation.org/5qYNMNXju June 17, 2010)
Ocean Energy Council	Ocean Energy Council **Homepage** http://www.oceanenergycouncil.com/ (archived http://www.webcitation.org/5qYNg2nNZ June 17, 2010)
Osmosis	ScienceClarified.com **Osmosis** http://www.scienceclarified.com/everyday/Real-Life-Chemistry-Vol-2/Osmosis-Real-life-applications.html (no webcitation possible; last access June 18, 2010)
Osmotic Pressure	AUS-e-TUTE **Osmotic Pressure** http://www.ausetute.com.au/osmoticp.html (archived http://www.webcitation.org/5qYUaKVzi June 17, 2010)
Pattle (1954)	Pattle, R.E.. **Production of Electric Power by mixing Fresh and Salt Water in the Hydroelectric Pile** (1954) *Nature. 174, p. 660.*
Post (2007)	Post J.W., Veerman J., Hamelers H.V.M., Euverink G.J.W., Metz S.J., Nymeijer K., Buisman C.J.N. **Salinity-gradient power: Evaluation of pressure-retarded osmosis and reverse electrodialysis** (2007) *Journal of Membrane Science, 288 (1-2), pp. 218-230.*
Potential Energy	Georgia State University – Department of Physics and Astronomy **HyperPhysics – Potential Energy** http://hyperphysics.phy-astr.gsu.edu/Hbase/pegrav.html#pe (archived http://www.webcitation.org/5qYSa8ueh June 17, 2010)
Protected areas	Wikipedia **List of Protected areas in Croatia** http://en.wikipedia.org/wiki/Protected_areas_of_Croatia (archived http://www.webcitation.org/5qYN25Fb5 June 17, 2010)
Raicich (1994)	Raicich, Fabio Consiglio Nazional delle Ricerche Instituto Sperimentale Talassografico **“Note on the flow rates of Adriatic Rivers”** *Technical Report RF 02/94*
RELEEL (2007)	EU CARDS Program - Approximation of EU Renewable Energy Legislation and Energy Efficiency Labelling (RELEEL) **Project home page** http://releel.mingorp.hr/default.aspx?id=58 (archived http://www.webcitation.org/5qYMLHf1I June 17, 2010)
RELEEL Guide (2007)	Ministry of Economy, Labour and Entrepreneurship / EU Cards Program “RELEEL project” **Short Guide Through Legislation and Administrative Procedure for Electricity Production from Renewable Energy Sources and Cogeneration** http://releel.mingorp.hr/UserDocsImages/publikacija%20eng.pdf (archived http://www.webcitation.org/5qYKu7GUO June 17, 2010)

RES Tariffs (2010)	Croatian Energy Market Operator (HROTE) **Home page -> Incentives-> Links at the bottom of page** http://www.hrote.hr/hrote/en/Renewables/incentives.aspx (June 12, 2010) http://www.hrote.hr/hrote/en/Renewables/RES_up_to_incl_1_MW.pdf (archived http://www.webcitation.org/5sq9RpdSe Sep 18, 2010) http://www.hrote.hr/hrote/en/Renewables/RES_exceeding_1_MW.pdf (archived http://www.webcitation.org/5sq9bbReZ Sep 18, 2010)
Rhoades et.al. (1992)	Rhoades, J.D, Kandia, A., Mashali A.M. **The use of saline waters for crop production - FAO irrigation and drainage paper 48** FAO Natural Resources and Environment (1992) – Online Document Repository M-56 ISBN 92-5-103237-8 http://www.fao.org/docrep/T0667E/t0667e05.htm#quality%20characteristics%20of%20saline%20waters (archived http://www.webcitation.org/5qYYdGk2p June 17, 2010)
Romic et.al. (2008)	Davor ROMIĆ, Monika ZOVKO, Marija ROMIĆ, Gabrijel ONDRAŠEK, Zoran SALOPEK **Quality aspects of the surface water used for irrigation in the Neretva Delta (Croatia)** *Journal of Water and Land Development No. 12, 2008: pp. 59–70* DOI: 10.2478/v10025-009-0006-9
RZB Croatia (2010)	Raiffeisen Central Bank Research **Strategy Croatia, May 2010** http://www.rzb.at/eBusiness/rzb_template1/1026359884948-1026359885014_1026067974202_1027874455325_1027874650133-1027874650133-NA-NA-EN.html (archived http://www.webcitation.org/5qYNsIVws June 17, 2010)
Sanchez et.al. (2007)	Juan Maria Sanchez Sanchez. Noemi Sanchez Castillo. Rut Sanchez Castillo **Mathematical Model for Isobaric Energy Recovery Devices** *IDA World Congress-Maspalomas, Gran Canaria –Spain October 21-26, 2007* http://www.ecoagua.com/articulosPublicados/MP07_088.pdf (archived http://www.webcitation.org/5qYNx8bEB June 17, 2010)
Sea level	Hrvatski Hidrografski Institut **Direct communication** Monthly mean sea level data for Rovinj, Zadar, Split and Dubrovnik for 1955 – 2007
Seafriends	Floor, Dr. J. Anthoni, Seafriends.org (2006) **Seawater** http://www.seafriends.org.nz/oceano/sea water.htm#Density (archived http://www.webcitation.org/5qYWnfsn3 June 17, 2010)
Skilhagen (2008)	Stein Erik Skilhagen, Statkraft **OSMOTIC POWER - A NEW, RENEWABLE ENERGY SOURCE** WIREC 2008 http://www.statkraft.com/Images/Osmotic%20Power%20presentationIDS%20XI%20december%202009_tcm9-7043.pdf (archived http://www.webcitation.org/5qYO4RpW5 June 17, 2010)
Skilhagen (2009)	Stein Erik Skilhagen, Statkraft **OSMOTIC POWER - Harnessing Europe's rivers (December 2009)** http://www.statkraft.com/Images/Osmotic%20Power%20-%20harnessing%20Europe%27s%20rivers%2009122009_tcm9-7042.pdf (archived http://www.webcitation.org/5qYOA9Cym June 17, 2010)

Skilhagen et.al. (2008)	Stein Erik Skilhagen*, Jon E. Dugstad, Rolf Jarle Aaberg **Osmotic power — power production based on the osmotic pressure difference between waters with varying salt gradients** *Desalination 220 (2008) 476–482*
Statkraft Osmotic	Stakraft **Homepage -> Energy Sources -> Osmotic Power** http://www.statkraft.com/energy-sources/osmotic-power/ (archived http://www.webcitation.org/5qYODIhvN June 17, 2010)
Statkraft press	Statkraft press news, Nov. 24, 2009, http://www.statkraft.com/presscentre/press-releases/2009/the-worlds-first-osmotic-power-prototype-opens-today.aspx (archived http://www.webcitation.org/5qYONbF3r June 17, 2010)
Tariffs (2007)	The Government of the Republic of Croatia **Tariff System for the Production of Electricity from Renewable Energy Resources and Cogeneration** *(Official Gazette 33/2007)* Translated version: **http://www.hrote.hr/hrote/en/Documents/RESCO_Tariff_System.pdf** (archived http://www.webcitation.org/5qYORucgq June 17, 2010)
Tate (2008)	Tate, Jeff (Agape Water Solutions Inc.) **Industrial Reverse Osmosis System Design** *Reprinted from Water Conditioning & Purification Magazine ©2008.* http://agapewater.com/res/Default/wcp_agape_0708.pdf (archived http://www.webcitation.org/5qYR3tcdC June 17, 2010)
Thorsen and Holt (2009)	Thorsen, Thor; Holt, Torleif: **The potential for power production from salinity gradients by pressure retarded osmosis**, *(15 June 2009)* *Journal of Membrane Science, Volume 335, Issues 1-2, Pages 103-110*
Tiložanec (2009)	Tiložanec, Ivan, **LEGAL FRAMEWORK AND ADMINISTRATIVE PROCEDURE FOR RENEWABLE ENERGY SOURCES AND COGENERATION IN THE REPUBLIC OF CROATIA** *RELEEL Seminar (February 2009)* http://releel.mingorp.hr/UserDocsImages/LEGAL_AND_ADMIN_for_RES.pdf (archived http://www.webcitation.org/5qYRA7Co8 June 17, 2010)
Unicredit CEE (2010)	Unicredit Economics and FX Research **CEE Quaterly, April 2010** http://www.bankaustria.at/de/3017.html# (archived http://www.webcitation.org/5qYRJC1dd June 10,2010)
Unit Converter	UnitConverter.org **Online Unit Converter** http://unit-converter.org/UnitConverter/convert?uc_class=1&uc_value=26%2C5&uc_sigdigits=5&uc_unit=6&uc_cat=all&commit=Umrechnen (archived http://www.webcitation.org/5qYXbKTXI June 17, 2010)
Van't Hoff (1901)	Van't Hoff, Jacobus H.: **Osmotic pressure and chemical equilibrium** *Nobel Lecture, December 13, 1901* http://nobelprize.org/nobel_prizes/chemistry/laureates/1901/hoff-lecture.pdf (archived http://www.webcitation.org/5qYRPpMTr June 17, 2010)
Veolia - Ashkelon	Veolia Water - Press Release 2005 **Veolia Water starts up operation of the world's largest reverse osmosis sea water desalination plant in Ashkelon (Israel)** http://www.veoliawater.com/media/news/2005-12-21,1632.htm (archived http://www.webcitation.org/5qYZKpTn6 June 17, 2010)

Visegrad Four (2010)	Energetika.net **15 billion Euros for investments in Croatia's energy sector by 2020** http://www.energetika.net/eu/novice/electricity/15-billion-euros-for-investments-in-croatias-energy-sector-b (March 1st, 2010) (archived http://www.webcitation.org/5sq9vEzeu Sep 18, 2010)
Vrouwenvelder et al. (2010)	J.S. Vrouwenvelder , C. Picioreanu, J.C. Kruithof, M.C.M. van Loosdrecht: **Biofouling in spiral wound membrane systems: Three-dimensional CFD model based evaluation of experimental data** *Journal of Membrane Science 346 (2010) pp 71–85*
Water Management Strategy (2009)	Hrvatske Vode **STRATEGIJA UPRAVLJANJA VODAMA** ISBN 978-953-7672-00-3, March 2009 http://www.voda.hr/fgs.axd?id=1344 (June 12, 2010) (no webcitation possible)
Watersee-Trebišnjica	The Global Environment Facility (GEF) International Waters Learning Exchange and Resource Network **Home page – SEE water bodies – Inventory of surface Waters - Access** http://www.watersee.net/trebisnjica-river.html (archived http://www.webcitation.org/5qYRlAawr June 17. 2010)
WFD-Croatia Maps	EU – Croatia Twinning Project - Water Framework Implementation **Home page –> Downloads -> Maps** http://www.wfd-croatia.eu/templates/radnaEng.asp?sifraStranica=622 (archived http://www.webcitation.org/5qYRoGHWN June 17, 2010)
Worldbank Country Brief	Worldbank homepage **Country Brief Croatia 2010** http://www.worldbank.hr/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/CROATIAEXTN/0,,contentMDK:20150212~menuPK:301252~pagePK:141137~piPK:141127~theSitePK:301245,00.html (archived http://www.webcitation.org/5qYRsQ6d5 June 10, 2010)

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12. Appendix

12.1 Potentials and Development Scenario

POTENTIALS / Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Theoretical Potential [GWh]	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844	8,844
Technical Potential [GWh]	4,333	4,337	4,341	4,346	4,350	4,355	4,359	4,364	4,368	4,372	4,377	4,381	4,386	4,390	4,394	4,399	4,403	4,408	4,412	4,417	4,421
Reasonable Potential [GWh]	866	878	891	903	915	928	940	952	965	977	990	1,002	1,014	1,027	1,039	1,051	1,064	1,076	1,088	1,101	1,113
Capacity increase p.a. [MW]	0	0	0	2	5	5	5	5	5	5	10	10	10	10	15	15	15	10	10	10	5
Capacity installed [MW]	0	0	0	2	7	12	17	22	27	32	42	52	62	72	87	102	117	127	137	147	152
Increase p.a. [GWh]	0	0	0	12	30	30	30	30	30	30	60	60	55	55	83	75	75	50	50	50	25
Realised Potential [GWh]	0	0	0	12	42	72	102	132	162	192	252	312	367	422	505	580	655	705	755	805	830
Achievable FLH	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	5,500	5,500	5,500	5,000	5,000	5,000	5,000	5,000	5,000
Projected electricity consumption [GWh]	20,570	21,475	22,379	23,284	24,188	25,093	25,997	26,902	27,806	28,711	29,615	30,520	31,424	32,329	33,233	34,138	35,042	35,947	36,851	37,756	38,660
Reasonable potential as % of consumption	4.2%	4.1%	4.0%	3.9%	3.8%	3.7%	3.6%	3.5%	3.5%	3.4%	3.3%	3.3%	3.2%	3.2%	3.1%	3.1%	3.0%	3.0%	3.0%	2.9%	2.9%
Realisable potential as % of reasonable pot.	0.0%	0.0%	0.0%	1.3%	4.6%	7.8%	10.8%	13.9%	16.8%	19.6%	25.5%	31.1%	36.2%	41.1%	48.6%	55.1%	61.5%	65.5%	69.3%	73.1%	74.5%
Realisable potential as % of consumption	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.9%	1.0%	1.2%	1.3%	1.5%	1.7%	1.9%	2.0%	2.0%	2.1%	2.1%
Realisable potential as % of theoretical potential	0.0%	0.0%	0.0%	0.1%	0.5%	0.8%	1.2%	1.5%	1.8%	2.2%	2.8%	3.5%	4.1%	4.8%	5.7%	6.6%	7.4%	8.0%	8.5%	9.1%	9.4%
Realisable potential as % of technical	0.0%	0.0%	0.0%	0.3%	1.0%	1.7%	2.3%	3.0%	3.7%	4.4%	5.8%	7.1%	8.4%	9.6%	11.5%	13.2%	14.9%	16.0%	17.1%	18.2%	18.8%
Plant FLH of Turbine FLH	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	7,333	7,333	7,333	6,667	6,667	6,667	6,667	6,667	6,667