EXECUTIVE SUMMARY OF DELIVERABLE D2.1

DOCUMENT NOTE

		YES	NO
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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Intermittent nature of Renewable Energy Sources (RES) is one of the significant technical barriers in increasing RES penetration especially in non-interconneted power systems. Unfortunately demand does not coincide with the RES production creating either significant shortage or significant excess of energy produced by RES. To make matters worse, the thermal units operating to meet the most significant part of the demand cannot always decrease their output beyond a certain technical limit. Even worse, especially for larger island systems, quite often these units cannot be switched off and then switch back on in very short time in favour of increased RES production. Additionally, they cannot always follow the sometimes rapid changes in both demand and RES production. These reasons create limitations to RES penetration especially on island systems.

Matching supply and demand and provide support to the power system either by absorbing energy when it is excess or by injecting energy when there is shortage, is one of the main tasks that energy storage can perform in a power system. Therefore, studying the impact of combining RES and energy storage for islands is essential in order to examine what are the benefits of such an operation for a power system with respect to increasing RES penetration and power system operation. This is the main goal of this deliverable.

More precisely this deliverable provides results from the simulation of 7 different islands from 6 different countries with different sizes and electricity demand patterns, from as small as Corvo in the Azores Archipelago to as large as Cyprus in the Mediterranean for various levels of RES penetration combined with energy storage. More precisely, 3 different storage methods, namely batteries, Pump Hydro Storage and use of Hydrogen, produced by electrolysis driven by RES, for electricity production via a Fuel Cell are considered. Additionally, a demand side management methodology for desalination plants via Reverse Osmosis is also examined since water scarcity is a common characteristic not only for some of the islands studied, but also of other islands targeted by the STORIES action. The provided results have focused on the impact that the combination of RES and storage means can have on the operation of an island power system mainly in terms of system economics and emissions.

The aim of this document is to summarize the results from considering Energy Storage appilcation for co-operation with RES in autonomous power systems. These results have been explicitly described in

- Deliverble D2.1 "Market applications for energy storage methods and RES units". http://www.storiesproject.eu/index.php?secid=2&pid=38&spid=19

Also on the web-site there are available :

1. One document which summarizes the potential applications of energy storage in various islands
2. One document explaining the methodology used for simulating island power systems with storage devices. Some general outline is also provided here.
3. For each of the four technologies considered one document summarizing both simulation results and cost benefit Analysis.

2. INTRODUCTION

2.1. Short description of the Island systems selected to be simulated

2.1.1. La Graciosa case study

La Graciosa is a small island located to the north of Lanzarote (Canary Islands, Spain). It has a small resident population of 658 people. Currently it is being provided of electric power and water from neighbouring Lanzarote through a submarine cable with capacity for 1.3 MW, and a submarine water pipe. La Graciosa, as happens with the rest of the Canary Islands, is exposed to the Trade winds that blow predominantly from the northeast. Strong constant winds throughout the year, although in the summer months the mean average speed is higher than in the winter. Solar radiation is also high most of the year. Wind and solar radiation gives an important potential for renewable energy electricity production.

The island yearly electricity consumption is 3,485,039 kWh which, considering the specific consumption of the Canary Islands thermal plants of 0.25 kg of fuel oil per kWh, represents a yearly consumption of 871,260 kg of fuel oil. Associated to this consumption of fossil fuels there are 3,140 tons of CO_2. Peak electric power demand is 668 kW.

2.1.2. San Pietro case study

San Pietro is a volcanic Island located off the South western Coast of Sardinia. Has a resident population of 6,660 inhabitants which are mostly concentrated in the fishing town of Carloforte, that more than triples in the summer months, growing to 15-20,000 people. The island electricity demand experiences high seasonal variation due to tourist activity. Wind and solar radiation gives an important potential for renewable energy electricity production. Average wind speed is 5,3 m/s, with relatively constant wind velocities during the year (4 m/s in July to 6.2 in February). Solar yearly average radiation is 4.5 kWh/m²-d, with yearly variations from 1.9 kWh/m²-d in December, to 7.2 kWh/m²-d in June. Wind and solar radiation gives an important potential for renewable energy electricity production.

The electrical system is interconnected to Sardinia, through a submarine cable, with a capacity of 5.5 MW (at 15 kV). The island yearly electricity power demand suffers a high seasonal variation from the winter to the summer months, due to the tourist activity. Yearly electricity consumption is 15,620 MWh, and peak power consumption is 2.3 MW.

2.1.3. Cyprus case study

Cyprus is the third largest island in the Mediterranean, after Sicily and Sardinia, with an area of 9.251 sq. kms. in the north-eastern corner of the Mediterranean, Cyprus is an isolated island not interconnected in any way with other countries.The population of Cyprus is estimated (Dec. 2006) at 867.600 of whom 660.600 belong to the Greek Cypriot community, (76,1%), 88.900 (10,2%) to the Turkish Cypriot community and 118.100 (13,7%) are foreigners residing in Cyprus.
Rest economic and demographic data have been provided in Deliverable D2.1.

2.1.3.1 Electricity Data

There are 3 power stations, on the island (Vasilikos, Dekheleia and Moni) operated by the Electricity Authority of Cyprus (EAC). Details on these units are provided in Deliverable D2.1.
The year under study was 2005 during which the peak load was 850MW and the total demand was 4.4TWh.

2.1.3.2 RES Data

The currently installed capacity on the island is rather low. Despite the fact that Cyprus presents the largest per capita installed capacity of solar water heaters on Cyprus, the installed PV capacity only recently started to increase and reaches now 1.7MW producing 1.6GWh during 2008. There are also plants that use biomass/biogas with installed capacity of 3.3MW producing 7.8GWh during 2008. The wind resource is not as favorable as for instance on the Greek islands but there are few areas where wind power casn be installed. During 2005,the year of study the authorized capacity by the Regulatory Authority of Cyprus (CERA) is 289.7MW.

2.1.3.3 Estimation Of Water Needs

Cyprus does not have plenty of potable water from natural resources.The total annual water demand all over Cyprus for the year 2000 is estimated to be 265.9 million m^3. The water demand is met by water dams, springs, Desalination plants, recycling and reuse of water for gardening purposes and imports water from abroad, mainly Greece

The main source for domestic water supply is desalination, which is equivalent to 12.6% of the total annual water demand in Cyprus for the year 2000. More details on water demand and situation on the island has been provided in Deliverable D2.1.

2.1.4. Ios Case study

2.1.4.1 General description

Ios is an island in the Cyclades group in the Aegean Sea as shown below. Ios is a hilly island with cliffs down to the sea on most sides, situated halfway between Naxos and Santorini. Population was 1,838 in 2001 on an area of about 109 km². Ios attracts very large numbers of young tourists.

2.1.4.2 The electrical system

Ios is part of Paro-Naxia autonomous system, which includes Paros, Antiparos, Folegandros, Ios, Irakleia, Koufonisi, Naxos, Sikinos and Sxoinousa. It is located in the central part of the Southern Aegean Sea. This is one of the largest insular power system in Aegean Sea, with high wind potential and several existing water reservoirs which are currently used for irrigation and in parallel can be exploited for a WHPS.

The power station of this system with 10 Internal Combustion (IC) power units of 61.4MW, located on Paros. The interconnections between the islands, all in Medium Voltage (MV) 20/15kV are shown in Fig. 2.1. Details on the characteristics of interconnection cables is available in Deliverable D2.1.

Additionally to the 10 units installed units, one rented unit also produces energy during the summer months July-August of 359MWh. thermal units of the island.

A summary of the demand for this power system for 2005 is shown in Table 2.3. The annual rate of increase is estimated to 12%. The Estimated energy demand in Paros and Ios islands for 2006 is provided in Table 2-2.

Table 2-1 Data from the local power station of Paros (1PPC, 2005)

Population	*Peak demand (kW)*	*Annual electrical energy demand (GWh)*	*Electricity production cost (€/kWh)*	*Fuel cost (€/kWh)*	*Share of FC to the EPC (%)*	*Load factor (%)*
48397	56000	179	0,1306	0,08	63%	37%

Table 2-2 Data from the local power station of Paros (PPC, 2005)

Island	*Annual electrical energy demand (GWh)*	*Peak demand (MW)*
Paros	84,4	26,3
Ios	12,6	3,9

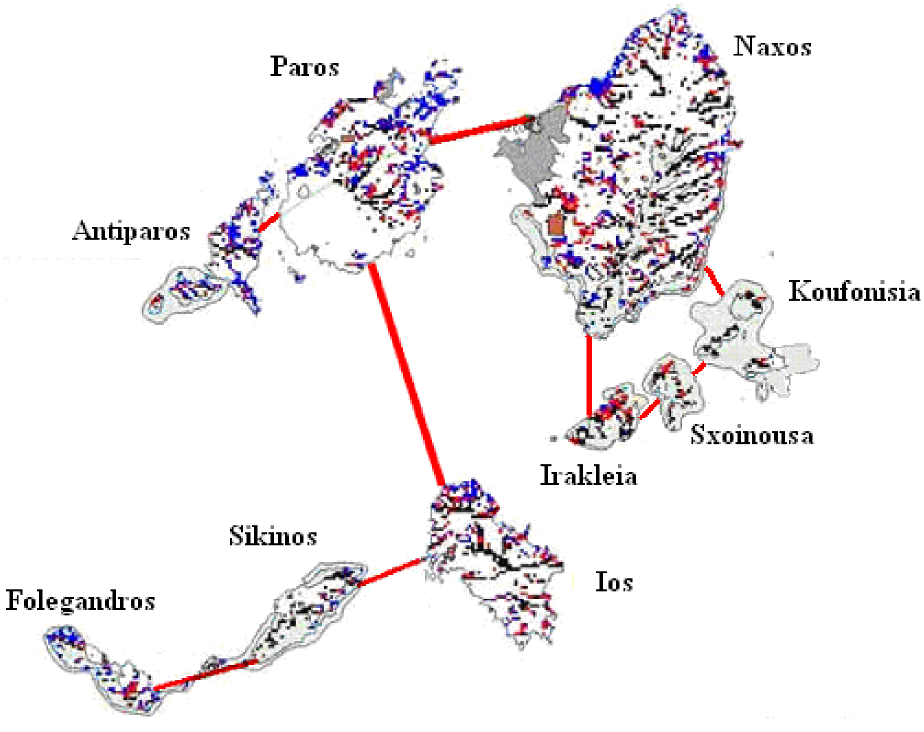


Fig. 2.1 The local power system of Paro-Naxia (interconnections between islands) and wind potential [Σφάλμα! Δεν έχει οριστεί σελιδοδείκτης.] **(CRES 2001).**

Load demand and wind data

Analytical time series of load demand and wind data are used for the simulation (Fig. 2.1and Fig. 2.2). The annual energy demand in power system of Paros is estimated for 2010 to 246.3GWh, the peak demand 74.8MW(61.2MW in 2006) during summer months and the load factor 37.6%. The average wind speed is 9.1 m/s.

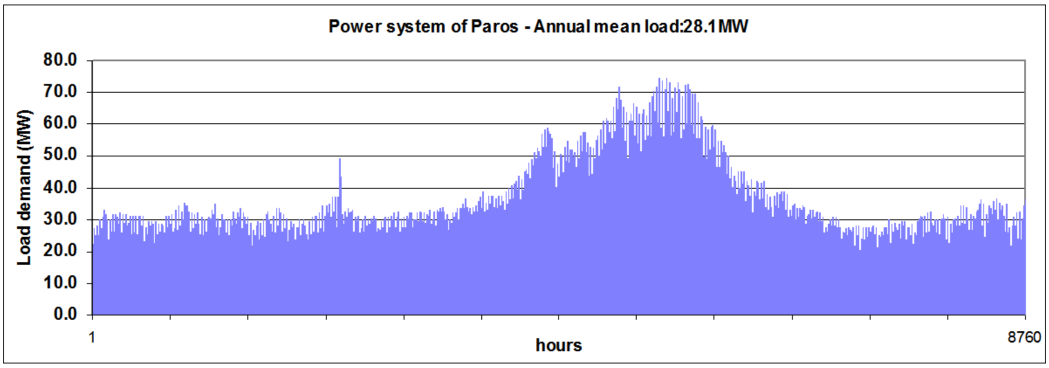


Fig. 2.2 Electricity demand in power system of Paros: a) Hourly time series data,

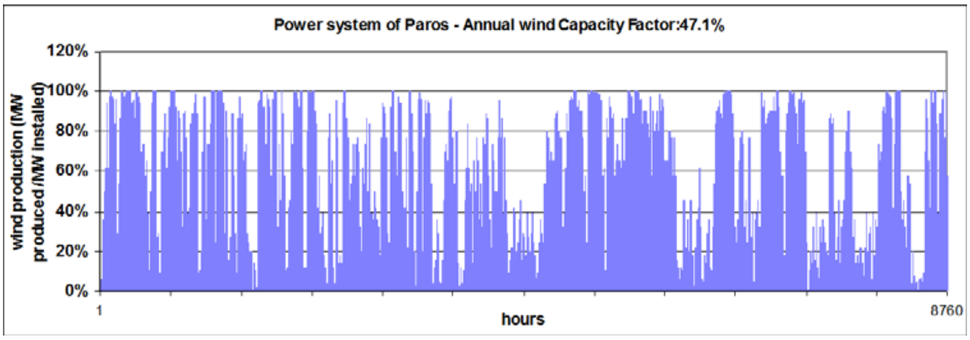


Fig. 2.3 Wind production distribution in Paros: a) Hourly time series data,

2.1.4.3 RES potential - Current development of RES in Paro-Naxia power supply system

The technically exploitable potential is very high.However, the current development is not so high as one would expect. The total installed wind power capacity is 2.46MW, while PPC constructs a new wind park of 3MW. There is also a small PV plant on the roof of an hotel in Paros of 10kW.

Especially on Ios there are two wind turbines in operation (0.6MW – Purgos – with operation license, 0.56MW – Pelekania - with operation license) and the total granted authorization capacity on Ios is 504kW.

2.1.5. Corvo case study

The island of Corvo is one of the 9 islands in the Azores archipelago and together with S. Miguel and Flores form the Western Group. e. The island is an inactive volcano named Monte Grosso and its crater, a lake, is the island highest point, circa 720 m as shown in Fig. 2.4. There is only one settlement, Vila Nova do Corvo, where some 400 people reside.

Fig. 2.4 Corvo island crater

The island's demand of approximately 1086 MWh and peak of 199kW is covered by two sets of 120kW and two of 160kW, i.e. 560kW. Based on these figures, it is evident that the four generators are never operating simultaneously. Thus, the demand is met by two generators one of each group

The fuel cost in Corvo is the highest of the entire archipelago, nearly 5 times more than average in Azores. On Corvo Island, the security of supply is a real and frequent concern, since due to bad weather conditions it is common to have oil shortages in this island. To reduce Corvo's dependency and secure supply, the implementation of an energy system that combines RES and storage is the best solution.

2.1.6. Milos case study

Milos is a Greek island sited on the southwest part of the country and specifically in the group of islands called Cyclades. Its distance from Athens is 86 nautical miles, i.e. 160 km approximately. There are almost 5000 people living in the island, but the population rises about 5 times during the summer period because of tourism. However, significant percentage of the population is employed in the mines of the island and therefore Milos is not only a touristic island. Milos is an autonomous power system interconnected with the nearby small island of Kimolos. On the island, one power station operated on fuel oil exists and belongs to the PPC [2], the operator of the island. In order to meet peak demand during summer without affecting significantly the reliability of the power system, some units are usually rented during the summer period and are placed higher in the priority list than rest diesel-oil units. All these units use diesel oil.

Technical data of all these units and the emission level of the fuel used have been provided in the full version of Deliverable D2.1.Table 2-3 summarizes the data on Milos

Table 2-3 General Data on Milos

Population	4771
Interconnected or non	Non Interconnected
Minimum active power consumption	1750 kW
Maximum active power consumption	9880 kW
Mean power factor of the global consumption	42.1%
Yearly Consumption	36457MWh
Installed Thermal power	11.250kW (8 units)+ 5728kW (5 rented units)
Wind Park Capacity	2050kW
Wind power production	4980MWh

Meteorological data height and place if different than the location of the park. Kythnos island. For each type of wind turbine, the machine's characteristic curve that gives the power output as a function of wind speed is necessary.

2.1.6.1 Estimation of water needs

On Milos, the annual average rainfall is not high, resulting in lack of water in the island. The problem becomes even bigger through summer that is the dryer period of the year and the population increases.. One solution to the problem was given by transferring water from the mainland of Greece at 8 €/m^3. The estimated water consumption,as described in detail in Deliverable D2.1 is 406,000 m^3

2.1.7. Mljet case study

The Island of Mljet (Fig. 2.5)is situated in the southern Dalmatian archipelago, 30 km west from Dubrovnik and south of the Peljesac Peninsula, separated from it by the Mljet channel. Mljet island is an interconnected island to the Mainland Croatia via two sub-sea cables. There is not a power station on the island.

Details on the electrical characteristics of the undersea lines, overhead lines and power capacity at each substation have been explicitly described in Deliveable D2.1

Fig. 2.5 The southern Dalmatian archipelago.

Hotel Odisej is the major consumer on the island, especially during the summer months. The hotel consumes about 16% of the island demand while its demand during May-October is 20-23%. Therefore, installation of a desalination plant in a major consumer can be an interesting scenario to be simulated.

Table 2-4 provides the total consumption of the island, the consumption in its eastern part, the western part without the Hotels and the demand of the hotel.

Table 2-4 Distribution of the demand to each part of the island and hotel Odissej

Total Island (MWh)	***Eastern Part (MWh)***	***Western Part (MWh)***	***Hotel Odissej (MWh)***
4401.92	***1992.53***	***1564.26***	***703.91***

Mljet island is quite abundant on RES. The wind power conditions are quite favourable 5.88m/s on the eastern part of the island and located in the southern part of Croatia, the solar potential is higher than the rest of the country.

In order to evaluate the impact of the scenarios studied on the emissions avoidance the critical 24-hour emissions curve from the power system of Croatia has been constructed using the methodology described in [3],as shown in Fig. 2.6.

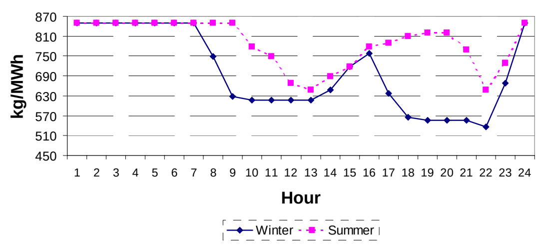


Fig. 2.6 Typical CO_2 emissions curve for the upstream Croatian Network

3. METHODOLOGY FOLLOWED FOR SIMULATIONS

3.1. Batteries

Batteries are the most widespread storage devices all over the world. It is estimated that one third of the world population, non – interconnected with the grid, use batteries to meet some of their needs. The limited life-time period for the batteries, especially in deep discharge mode, is balanced by their low capital cost, especially for lead-acid batteries. However, the battery manufacturers are constantly searching ways of lengthening their life time. The most widespread type is Lead Acid batteries. Other types of batteries are under the stage of development or demonstration applications for hedging demand and RES production. Advance on these technologies is rapid and soon will start been installed in many locations including islands. A summary of batteries usual applications on energy and power are provided in Deliverable D2.1.

3.1.1. Simulation approach

Most Autonomous power systems for providing electricity to very remote applications running on significant percentage on RES, e.g. telecommunication applications are based on lead-acid batteries. On the island of Kythnos, a battery bank of lead-acid can provide significant aid for running for short time the power system under 100% RES [4].

For both island case studies the following diagram of Fig. 3.1 describes the control concept. Both islands are considered isolated grid, neglecting the interconnection cable.

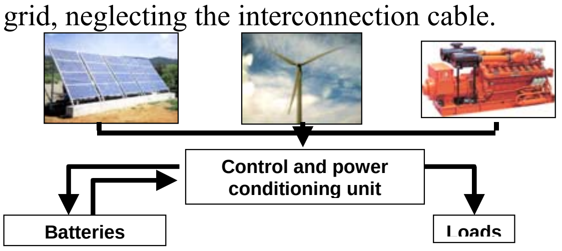


Fig. 3.1 Control concept for the components to be installed on the simulated islands

The necessary installed power of the wind-PV hybrid system, the power of the diesel back-up, the needed battery storage capacity, and the power of rectifiers and inverters connecting the DC and AC bus are calculated using HOMER "Hybrid Optimization Model for Electric Renewables" developed by NREL (National Renewable Energies Laboratory, USA).

3.2. Pump hydro storage

3.2.1. Description of the system

Pumped Storage is considered as the most suitable storage technology for achieving high wind penetration levels in medium or large autonomous power systems. In autonomous power systems wind farms owners face curtailment by the system operator of surplus wind-generated power during periods of low demand. The ability to balance demand with wind power, defines the wind capacity to be installed A hybrid Wind Hydro Pumped Storage (WHPS) - always comprised by new wind farms, two reservoirs for the recycling of water, hydro turbines, pumps and penstocks - is proposed as a mean to increase the wind installed capacity, substitute expensive fuel oil and reduce the required conventional installed capacity (**Fig. 3.2**).The later is possible because the variable output of wind power is managed and transformed into a guaranteed power supply. and the wind power to be absorbed by the grid.

The wind farm and the hydro pumped storage system are not necessarily installed at the same location. The topography should permit the construction of the two reservoirs, in a small distance and with sufficient hydraulic head as Fig. 3.3 shows.

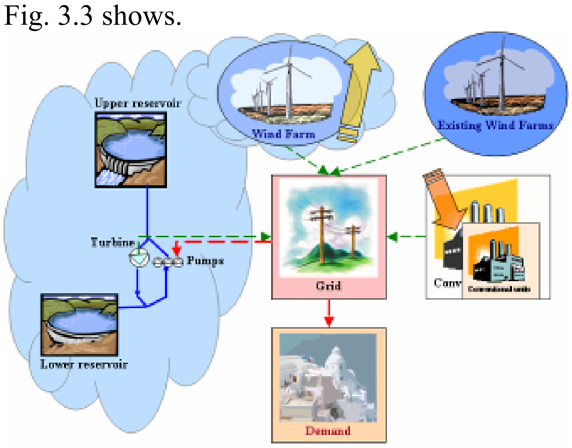


Fig. 3.2 **General concept of the WPS in autonomous power systems [5]**

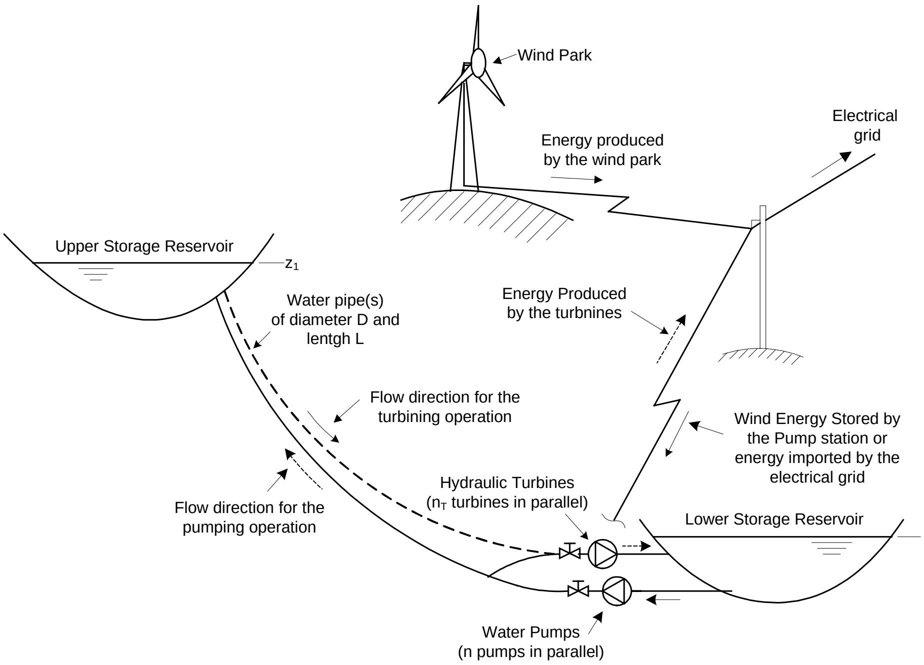


Fig. 3.3 General concept of energy and water flows in the WPS [6]

3.2.2. Operation of the system

The components of the WHPS are directly connected to the grid. Wind power may be given directly to the demand or may be used for pumping through the grid. The priority is dependent on the legislative framework.
The operation of the WHPS should not affect the operation and the wind power absorption from the wind farms outside of the hybrid system. The wind power from the wind farms is absorbed in priority, according to the absorption capability of the power system and the contracts between wind farm investor and system operator.

3.2.3. Regulatory framework – Tariffs

The operational policy and the design of the WHPS is dependent on the regulatory framework and the tariffs for the different energy or guaranteed power components. There are three components of income:

- Wind energy directly given to the grid.
- Hydro turbine's energy production..
- The provided "guaranteed power", which is typically the rated capacity of the hydro-turbines.

Finally, the pricing of the power which is derived by thermal power plants and is used for pumping, should be defined.

The methodology and basic mathematical equations required for Cost benefit Analysis have been explicitly described in Deliverable D2.3 as well as the specialized document on methodologies uploaded in the web-site.

3.2.4. Methodology for simulating Pump Hydro

3.2.4.1 <u>Introduction</u>

The analysis is consisted on the following main steps:

- Definition of the wind installed capacity outside the WPS
- Pre-feasibility study of WPS
- Evaluation of existing reservoirs
- Feasibility study of WPS (Dimensioning / Cost estimation / Benefits)

3.2.4.2 <u>Definition of the Wind installed capacity outside the WPS</u>

Wind farms operating in such autonomous systems are subject to output power limitations, related to technical constraints of the conventional generating units, namely the minimum loading levels of the thermal units (technical minimum) and a dynamic penetration limit, applied for stability purposes [7,8].

The level of the allowed wind penetration is different for each island and it depends on the following technical and economical factors:

- the wind potential
- the duration curve of the demand
- the correlation between wind data series and demand
- the order of commitment of conventional units,
- the type of conventional units and their technical minimums
- the allowed instantaneous wind penetration (δ)
- the current electricity production cost of the system, which is always dependent on the oil price.
- the tariffs for the wind energy produced
- the subsidy or grants provided for such investments
- the current cost of the wind investments

In deliverable D2.1 general charts which have been reproduced by the systematic application in various case studies [9], are presented for the definition of this capacity
The main inputs for the use of these charts are:

- the wind potential (average wind speed)
- the allowed instantaneous wind penetration .
- The minimum real wind capacity factor which provides the feasibility of the wind investments.

The outputs of these charts are:

- the wind capacity to be installed in a system, ensuring the safe operation of the system,
- the percentage of wind energy absorbed / curtailed.
- the wind energy contribution

3.2.4.3 Operation and architecture of the WHPS

Different options related with the design and the operation of the WHPS have been analysed, compared and evaluated [5]. As a result the features that are used for the study of the islands include:

1. connection of the Wind farms with the pumping station through the central grid,
2. peak demand supply of the hydro turbine,
3. consideration of the hydro-turbine as a spinning reserve to increase the direct wind power absorption,
4. double penstock and
5. complementary pumping using the available conventional power (the amount of conventional units' spinning reserve is taking into consideration).

3.2.4.4 Connection of the WHPS with the electrical system

The connection of the wind farms with the Pumped Storage unit (PSU) is proposed through the central grid, under the condition that the pumping loads are considered as deferrable loads. This means that in case of wind loss or other stability problem, pumps are disconnected.
Additionally, wind power from the WHPS can be directly absorbed by the electrical system, according to the technical constraints imposed by the Electrical System Operator (ESO). The amount of wind power, which can be absorbed directly by the grid, is dependent on the wind installed capacity outside of the WHPS, and on the allowed instantaneous wind power penetration "δ". As a result, the wind installed capacity outside of the WHPS should be defined, before going on with the analysis of the WHPS. The wind power absorbed in priority from these wind farms is defined by the technical constraints described by the Regulatory Authority for Energy [10] and the WHPS integration will not effect their operation.
The pumping station should be also directly connected to the main grid, in order to use surplus wind power in priority and sometimes conventional power for complementary pumping.
In Fig. 3.4, the proposed structure and the interconnections of the whole electrical system after the WHPS integration is presented. Details on how to evaluate points 2-5 are provided in the corresponding deliverable D2.1

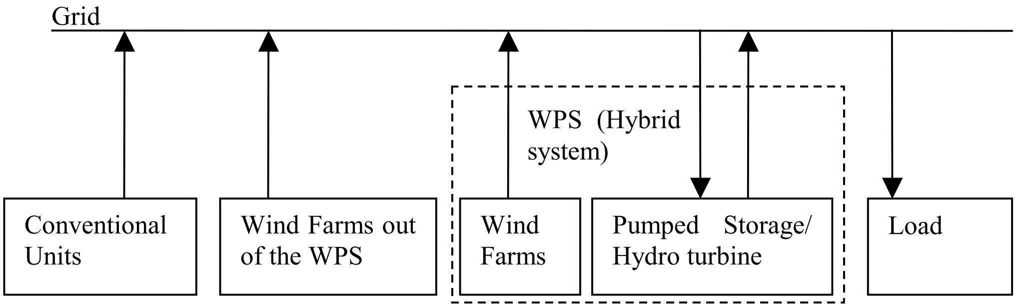


Fig. 3.4 Structure of the electrical system after the WPS integration

3.2.4.5 Simulation of the hydro subsystems (pumps, penstocks, hydro turbine)

The problem of the simulation of the pumping station can be described as "Which is the required power to commit *i* pumps and which is the flow of the water", and in the case of the hydro-turbine's simulation as "Which is the required volume of the water to produce the required power"

The pump and turbine characteristics (Head-flow curve and efficiency-flow curve) are introduced dimensionless.

The mathematical formulas and some useful charts have been indtroduced in Deliverable D2.1. In the same document the methodology for definition of the Penstock's Diameter is provided.

3.2.5. Pre-feasibility study

In fact, given the wind potential, the wind installed capacity is the parameter which defines the available for exploitation energy. The part of this energy which can be directly absorbed by the grid, depends on the technical constraints of the electrical system. The part of the surplus wind energy which can be finally exploited, depends on the architecture the design and the size of the WHPS. For a given wind installed capacity, there is a direct relation between the size of the reservoirs, and the maximum operational target that can be covered by the hydro-turbine with reliability reaching the 100%. The capacity of the hydro-turbine is then defined by this target.

The aim of the proposed approach is to take comparable results for the case-studies islands, so the basic parameters in issue are introduced dimensionless. Details and examples from the application of the flow chart of Fig. 3.5

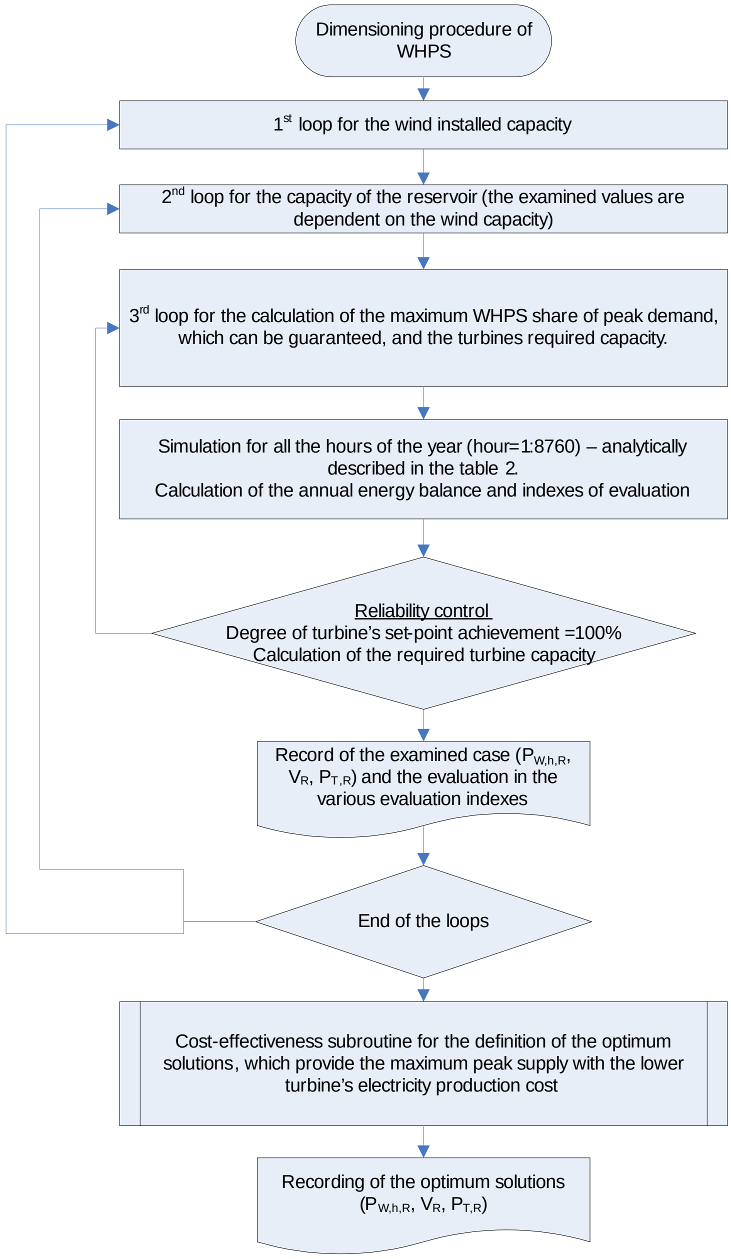


Fig. 3.5. Simplified algorithm for the dimensioning procedure of the WHPS

3.2.5.1 Required Data and assumptions

The required data and assumptions followed for the case studies have been described in Deliverable D2.1. In the same document Assumptions on the thermal power data and required data for wind potential are provided An overview of the formulas and data is provided in Table 3-1.

Table 3-1 Overview of the formulas and assumptions for the WPS cost estimation

Equipment – Cost symbol	***Data/Formula for Cost Estimation (€)***
Wind Farms (C_W)	1200 /kW
Pumps (C_P)	$C_P = N_P \cdot C_{0,P} \cdot \left(\frac{P_{P,rated}}{H_P^{\ 0,3}} \right)^{0,82}$, $C_{0,P} = 1814$
Hydro-turbine (C_T)	$C_T = C_{0,T} \cdot \left(\frac{P_{T,rated}}{H_T^{\ 0,3}} \right)^{0,82}$, $C_{0,T} = 4687$
Reservoir (C_R)	$C_R = 420 \cdot V^{0,7}$
Penstock ($C_{Penstock}$)	$1.25 \cdot \sum_I \left\{ \left[\underbrace{(W_M \cdot \pi D_I \cdot e \cdot L) \cdot C_M}_{Material\ Cost} + \underbrace{(\pi \pi_I \cdot L) \cdot C_I}_{Insulation\ Cost} + \underbrace{\left(1.5 \cdot \frac{\pi D_I^{\ 2}}{4} \cdot L\right) \cdot C_E}_{Excavation\ Cost} \right] \right.$
Grid connection (C_{GC})	4%*(C_P+C_T+C_R+$C_{Penstock}$)
Control system (C_{CS})	1,6%*(C_P+C_T+C_R+$C_{Penstock}$)
Transportation of equipment (C_T)	2,4%*(C_P+C_T+C_R+$C_{Penstock}$)
Personal (C_P)	30%*(C_P+C_T+C_R+$C_{Penstock}$)
Others (C_O)	2%*(C_P+C_T+C_R+$C_{Penstock}$)
Operation and Maintenance (OMC_{WPS})	2%*(C_P+C_T+C_R+$C_{Penstock}$+ C_W)

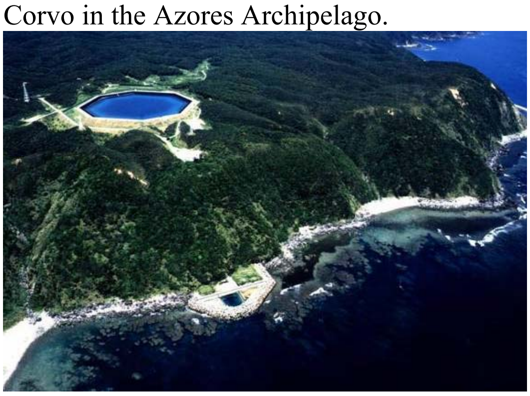
3.2.6. Matching Technologies and islands

Having the description of storage technologies and details on the islands to be simulated, a matrix of assigning storage technologies to islands has been created. Especially for pump hydro, which is quite site specific technology, the criteria of Table 3-2 were used for the islands selection.

Table 3-2 Criteria for the selection of islands for pumped hydro

Criteria	***Ideal case***
Interconnection	Autonomous island with local power station (not interconnected with the mainland)
Current electricity production cost	High current cost of the energy production
RES potential	High wind potential (always wind with pumped hydro) or the existence of other renewable source economically feasible to explore.
Terrain morphology	Not flat (maybe the existence of one reservoir in a suitable site).

The selected islands for this technology namely are Ios, from Greece, Cyprus and Corvo in the Azores Archipelago.



3.3. Desalination

For Milos and Mljet, the methodology followed is described here shortly.

The desalination plant acts as a consumer for the power company with the exception that its operation program is known to the power company. The time programming is made in 20-minute steps but the check of the water level in the reservoir is on hourly base. This schedule is updated frequently, e.g. once per hour, to converge to the water demand and if applied to the wind power production.

Two modes of operation have been studied :

- The desalination plant operates independently from the wind turbine (business as usual)
- The desalination plant takes into account the energy production of the wind-turbine and try to minimize on hourly basis the impact on the power system, by minimizing the exchange of power with it.

The water level, $level_i$ will be checked every hour, so:

$$\min\_level < level_i < \max\_level \qquad \textbf{(1)}$$

Where *min_level* is the low limit, *max_level* is the high limit and level is the water level every hour.

The general flow chart of the algorithm is shown in Fig. 3.6.The approach for Cyprus is provided in the corresponding chapter.

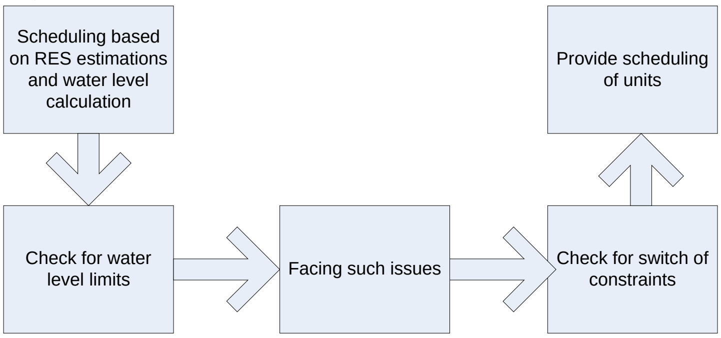


Fig. 3.6 Flow chart of the algorithm followed

4. SIMULATION WITH BATTERY STORAGE

4.1. Case study 1 results-La Graciosa

A microgrid for supplying electric power to the island system is proposed. The system would include a photovoltaic system, a wind farm, a diesel engine and batteries for energy storage. For the analysis and design of the microgrid it has been assumed that it is an isolated grid, where the submarine cable connecting La Graciosa to the neighbouring island of Lanzarote does not exist.The energy flow among the components is shown in **Fig. 4.1**.

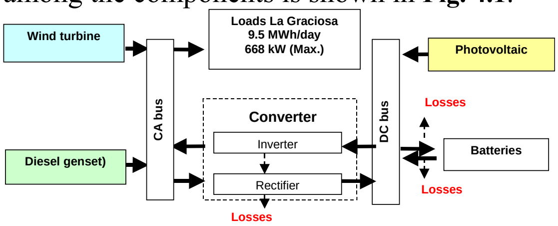


Fig. 4.1 Proposed flow chart between the components to be installed on La Graciosa

Two scenarios for RES penetration have been considered. The first scenario (SCE A) considers the optimum maximum penetration is terms of investment cost, and a 76 % penetration was estimated. The second (SCE B) scenario looks at a 50 % RES penetration.
The installed capacity of the various scenarios is summarized in Table 4-1,while more details on the batteries are provided in Table 4-2.

Table 4-1 Summary of the components penetration-La Graciosa

	SCE A	*SCE B*
PV Installed power	140 kWp	200 kWp
Wind power	900 kW	1800kW
Batteries Capacity	2160kWh	4320kWh
Inverter Capacity	400kW	400kW
Diesel Gen set	400 kW	400kW

Table 4-2 Batteries Results Summary

Batteries	*SCE A*	*SCE B*
Number (Trojan L16P)	1,000	2,000
Battery throughput	316,217 kWh/yr	395,559 kWh/yr
Battery life time	3.40 yr	5.44 yr
Battery autonomy	3.80 hours	7.60 hours

4.1.1. Impact on Power System Operation

Table 4-3 summarizes the energy balance of the island for the two scenarios simulated,
The fuel consumption when comparing business as usual scenario and the proposed two scenarios is provided in Table 4-4,while Table 4-5 presents the associated emissions avoided.

Table 4-3 Summary of the Energy Balance Impact

Power Production Equipment	*Electricity balance (kWh/Year)*		*Share*	
	SCE A	*SCE B*	*SCE A*	*SCE B*
PV	*234,695*	*335,430*	*6%*	*7%*
Wind Power	*1,713,097*	*3,426,194*	*45 %*	*69%*
Diesel Gen set	*1,879,266*	*1,190,835*	*49%*	*24%*
TOTAL				
Yearly production	*3,827,165*	*4,952,459*	*100 %*	*100 %*
Electric demand	*3,485,007*	*3,485,007*		
Excess electricity	*209,764*	*1,311,431*	*5.5%*	*26.5 %*

Table 4-4 Summary of Fuel Consumption for La Graciosa (L/yr)

Business as Usual	1,167,477
SCE A	642,072
SCE B	398,605

Table 4-5 Summary of Emissions Avoided for La Graciosa (kg/yr)

	SCE A	*SCE B*
Carbon dioxide	1,049,657	1,690,788
Carbon monoxide	2,591	4,173
Unburned hydrocarbons	287	462
Particulate matter	195.3	315
Sulphur dioxide	2,108	3,395
Nitrogen oxides	23,119	37,240

4.1.2. Excess electricity Utilization

Given the variability in the energy demand curve (on daily and yearly bases), the high level of RES penetration in the microgrid proposed for La Graciosa, and the limited battery energy storage capacity (due to battery investment cost restrictions), there will be moments when excess electricity from the photovoltaic system and the wind farm will be produced. This will reduce the value of the investment substantially.

This excess power would have to go to dissipating loads that would consume this electricity and produce heat, or a curtailment policy would have to be implemented to cut production from the wind farm and photovoltaic system when supply exceeds demand. Both are inefficient energy solution indeed. A possible solution could be to make use of the excess energy on reverse osmosis desalination plants or hydrogen production for transport fuel.

Assuming specific energy consumption 2.4 kWh/m^3 for water production, util;ized by 10 modules of 30kW each and 4,5 kWh/ Nm^{3}H$_2$ for hydrogen production, the results for either solution is provided in Table 4-6.

Table 4-6 Summary of the excess electricity utilization

	SCE A	*SCE B*
Excess electricity	209,764kWh/yr	1,395,872 kWh/yr
Water production	87,402m^3/year	546,430m^3/year
Hydrogen production Volume	46,614Nm^{3}H$_2$/year	310,194 Nm^{3}H$_2$/year
Hydrogen production Weight	4,162 kg H$_2$/year	27,695 kg H$_2$/year

4.2. *Case study 2 San Pietro*

The optimization simulation lead to 82% of RES penetration under the configuration of Table 4-7. More details on the operating conditions of each component have been explicitly described in Deliverable D2.1. Table 4-8 summarizes the production of each type of component on the island, while a summary on batteries operation is provided in **Table 4-9**.

Table 4-7 Summary of the proposed system for San Pietro

PV Array:	*900 kW*
Wind power:	*4 ENERCON E-70 2.3 MW*
Diesel capacity:	*2,000 kW*
Battery:	*8,000Trojan L16P*
Inverter:	*1,000 kW*
Rectifier:	*1,000 kW*

Table 4-8 Summary of the production for the San Pietro Case study

Component	Production	Fraction
PV array	1,484,555 kWh/yr	5%
Wind turbines	21,651,706 kWh/yr	77%
Generator 1	4,939,221 kWh/yr	18%
Total	***28,075,482 kWh/yr***	***100%***

Table 4-9 Details for the Battery Characteristic

Number (Trojan L16P)	8,000
Battery throughput	316,217 kWh/yr
Battery life time	8.12 yr
Battery autonomy	6.78 hours

Table 4-10 shows the energy balance on the island.

Table 4-10 Excess energy and RES fraction on San Pietro

Variable	*Value*
Total production	28,075,482 kWh
Primary load	15,620,034 kWh/yr
Renewable fraction:	0.82
Excess electricity:	12,002,370 kWh/yr

The estimated fuel consumption for meeting San Pietro demand is 5784klt while with the proposed system this will be 1720klt. This leads to 70.3% reduction in fuel consumption with associated reduction in emissions as described in Table 4-11.

Table 4-11 Emissions due to the proposed solution-San Pietro

Pollutant	**Emissions (kg/yr)**
Carbon dioxide	4,531,237
Carbon monoxide	11,185
Unburned hydrocarbons	1,239
Particulate matter	843
Sulphur dioxide	9,100
Nitrogen oxides	99,802

4.2.1. Excess electricity Utilization

12 GWh of excess electric energy is high, that if not used, would have to go to dissipating loads, or a curtailment policy would have to be implemented to cut production from the wind farm and photovoltaic system when supply exceeds demand. Possible applications for this excess electricity include reverse osmosis water desalination or electrolysis hydrogen production for transport fuel. 10 modules of 200kW can be used to produce 5,000,000 m^3 of water annually.
If excess RES electricity was to be used to run electrolysers for hydrogen production, and estimating a specific consumption of 4,5 kWh/ Nm^3 hydrogen (11,2 Nm^3H_2 in a kg of H_2), the hydrogen production that could be obtained is provided in Table 4-12.

Table 4-12 Summary of the Hydrogen production when excess electricity is utilized

Variable	*Value*
Hydrogen production (Volume)	2,667,193 Nm^3H_2/year
Hydrogen production(Weight)	238,142 kg H_2/year

4.3. Conclusions of the case studies analysed

The provided results have focused on the impact that the combination of RES and batteries can have on the operation of an island power system mainly in terms of system economics and emissions and how batteries can increase RES penetration on RES islands

For both islands simulated, La Graciosa and San Pietro, scenarios that lead to 80% RES penetration were simulated.. For levels of penetration above this percent, the excess electricity is geometrically increased as well as the installation cost. Two alternatives for the excess electricity are proposed: Reverse Osmosis desalination plants that could be connected at moments when electricity supply from RES is higher than demand from the conventional electric loads; Hydrogen production, with electrolysers operating also as can consume excess electricity when supply is higher than demand. The H_2 could be used as transport fuel for the small road vehicle fleet of the island, and even for the fishing boats transport fuel. RO desalination plants and electrolysers could operate as programmable loads that can consume excess electricity when supply is higher than demand

Unless such methods of exploiting excess energy are exploited, RES penetration cannot be further economically increased for the cases studied. A scenario with lower RES penetration target, e.g. 50% for La Graciosa will provide lower benefits for the grid in the emissions levels and fuel consumption, but with significantly lower excess energy. Such a configuration can be used a first step in introducing RES on this Spanish island and during the construction phase to consider ways of exploiting additional excess electricity and apply demand side measures for smoothening the peak of the island. Then the additional works than can lead to much higher penetration, always considering storage, can be constructed increasing the expected benefits.

5. SIMULATION WITH PUMP HYDRO STORAGE

5.1. Case study 1 results-Ios

5.1.1. Scenario 1. Adding wind without Pump Hydro Storage

According to the methodology briefly described in Chapter 3, the maximum allowed wind installed capacity without storage is estimated to 12.2MW. The energy supply of this wind installed capacity is 16.4% and the wind energy curtailment is 27.6%.

5.1.2. Scenario 2. Pump Hydro Installation

5.1.2.1 Results of the pre-feasibility study

In Fig. 5.1 the results of the pre-feasibility study of WPS in the power system of Paro-Naxia are presented. Pre-feasibility study aims to examine the effect of the WPS integration into the autonomous power supply system. Then, in these charts the electricity production cost of the power system without pumped storage considering a Brent price of the order of 100$/b is presented in straight red line. This price is considered as a long term reference price.

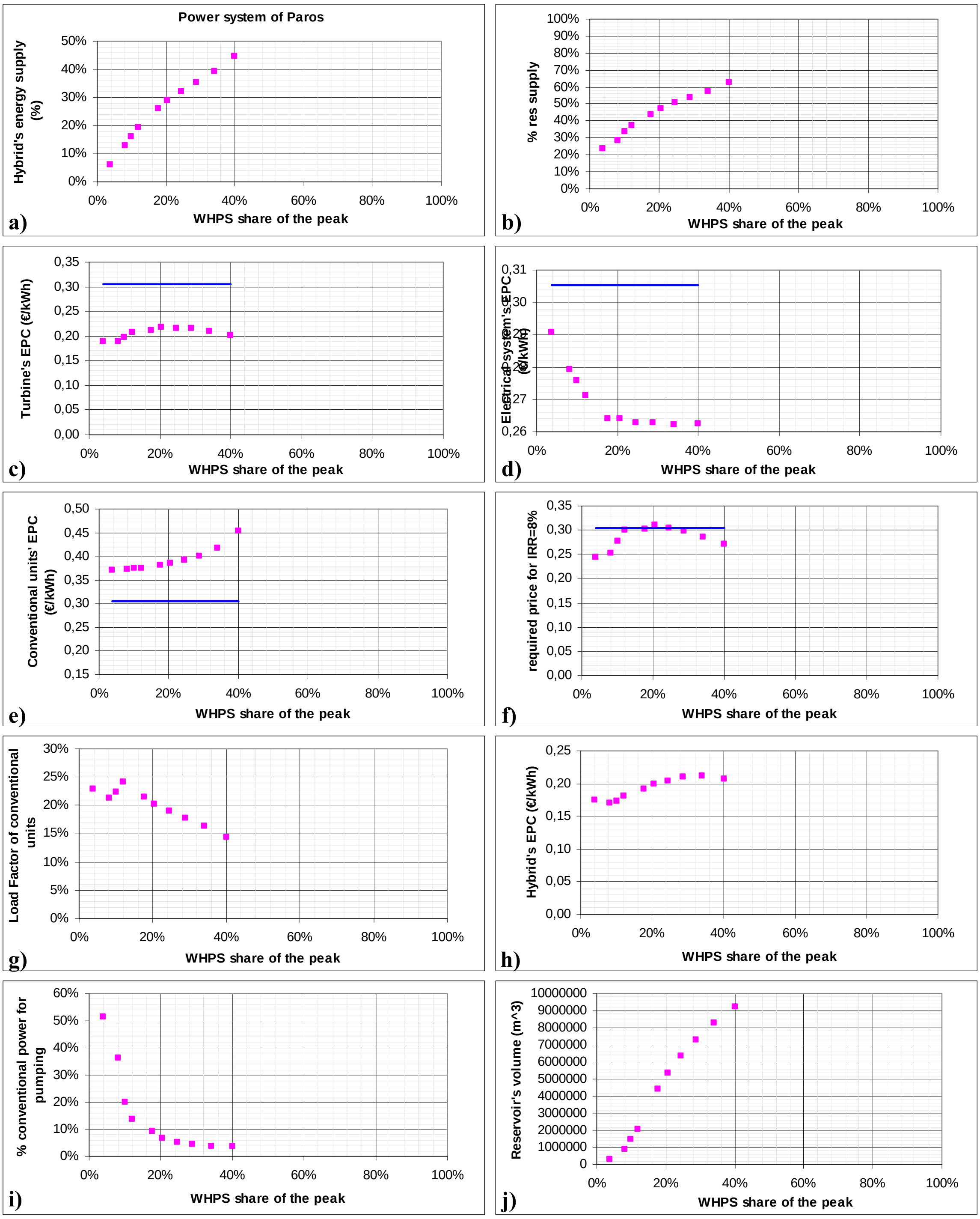
The Market price for the conventional electricity used for pumping p_m is 0.12€/kWh (much more expensive than the regular tariff of the consumer 0.09€/kWh), taking into consideration the higher marginal electricity production cost. Fixed price for the wind production p_w is 0.085€/kWh in Greece.

The Market price for the conventional electricity used for pumping p_m is 0.12€/kWh (much more expensive than the regular tariff of the consumer 0.09€/kWh), taking into consideration the higher marginal electricity production cost. Fixed price for the wind production p_w is 0.085€/kWh in Greece.

The main conclusions of this approach in the power system of Paro-Naxia are:

- For the large scale RES integration i.e. peak demand supply up to 50% or hybrid's electricity supply up to 55% (Fig. 5.1.a), and cumulative RES supply in the island up to 70% (Fig. 5.1.b), the required reservoirs volume is up to 13 million m^3 (Fig. 5.1.i) and the required wind installed capacity is up to 100MW (Fig. 5.1.j).
- The electrical system's EPC could be reduced (Fig. 5.1.d) as a result of the WPS integration (from the level considered with Brent price 100$/b).
- The conventional units EPC is increased (Fig. 5.1.e) as soon as the same units operate less after the WPS integration and their low load factor is further decreased (Fig. 5.1.g).
- As regards, the turbine's and hybrid's EPC, the former varies around 0.18-0.22€/kWh and the latter around 0.17-0.21€/kWh (Fig. 5.1.c). This cost is comparable to the peak supply cost, even a lower Brent price is considered. The turbine's electricity production cost is independent to the Brent price. Then, the profitability of this investment is strongly depends on the tariffs for the turbine's electricity production.
- The investment cost of the WPS is estimated to 1800-2700€/kW installed (cumulative wind and hydro turbine capacity) or 6000-9000€/kW of turbine capacity (Fig. 5.1.m, Fig. 5.1.n). Lower cost is estimated for larger WPS systems.
- The efficiency of the WPS plant is estimated to 55-67% (Fig. 5.1.h).
- The RES supply in the Paro-Naxia can be significantly increased thanks to the WPS integration. Around 20% RES supply could be achieved if wind installed capacity is introduced without any storage devices. For further RES supply, the WPS integration could contribute up to an additional 50% (or up to 70% cumulative RES supply), for the examined cases of this study (Fig. 5.1.b).
- For this achievement the wind installed capacity in the WPS should be increased. Unfortunately, only the 45-60% of the wind energy is exploited (Fig. 5.1.l). There are several cases where the wind energy is not exploited due to the fulfillment of the upper reservoir.

On the other hand the conventional power which is used for pumping is always lower than 20% (Fig. 5.1.k).


Power system of Paros
Hybrid's energy supply (%)
WHPS share of the peak
a)
% res supply
b)
Turbine's EPC (€/kWh)
c)
Electrical system's EPC (€/kWh)
d)
Conventional units' EPC (€/kWh)
e)
required price for IRR=8%
f)
Load Factor of conventional units
g)
Hybrid's EPC (€/kWh)
h)
% conventional power for pumping
i)
Reservoir's volume (m^3)
j)

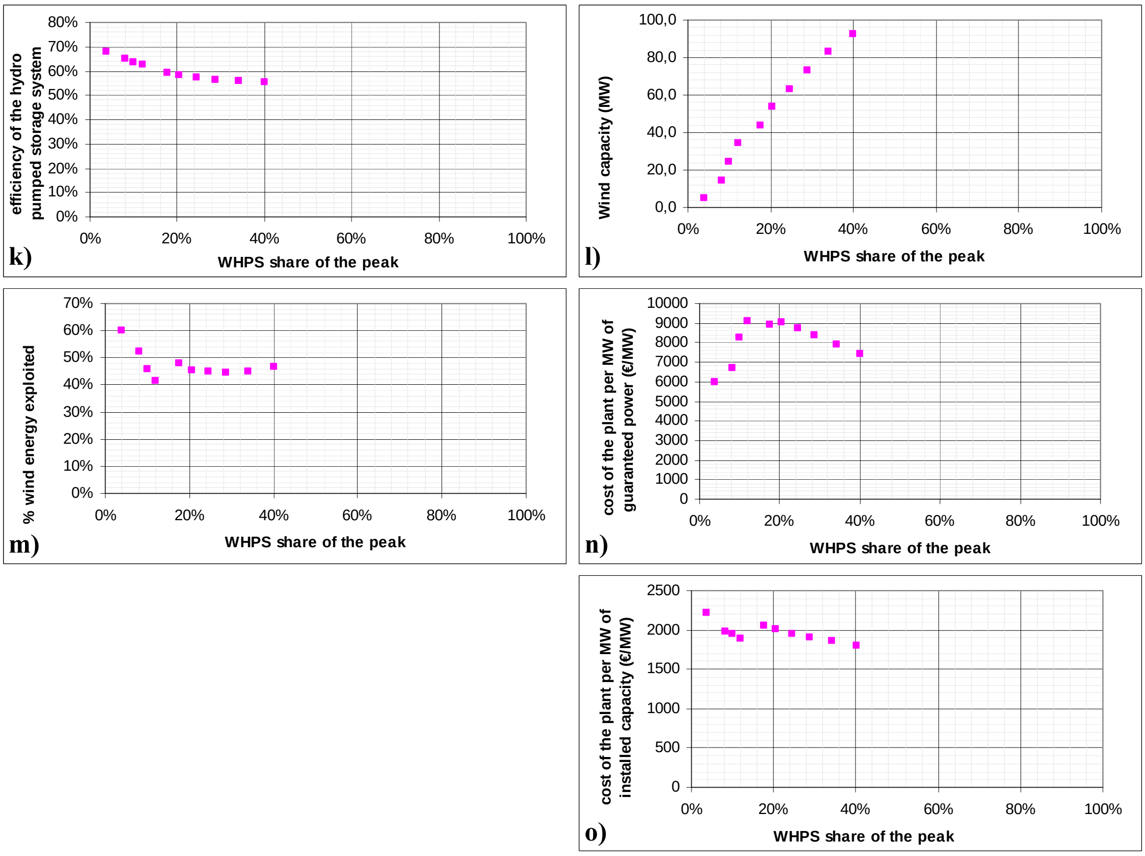


Fig. 5.1 Results of the pre-feasibility study in Paro-Naxia complex: a) hybrid's energy supply, b) total RES electricity supply in the island, c) Turbine's EPC, d) Electrical system's EPC, e) Conventional units' EPC, f) Required price for the turbines electricity production to provide IRR=16%, g) Load factor of conventional units, h) Hybrid's EPC, i) Conventional power for pumping, j) Reservoir's volume, k) efficiency of the pumped storage system, l) wind capacity (MW), m) wind energy exploited (%), n) cost of the plant per MW of guaranteed power, o) cost of the plant per MW of installed capacity

5.1.2.2 Evaluation of existing reservoirs

In the complex of Paro-Naxia there are several existing reservoirs. Two of them are considered as more suitable for the parallel exploitation towards a WPS integration:

- Reservoir of Eggaron in Naxos
- Dam of Milopotamos in Ios

The reservoir in Naxos, is in an altitude of 118m, while in a distance of 3160m, there is possible site of a second upper reservoir in an altitude of 910m. Then the available hydraulic head will be 790m.

The reservoir in Ios, is in an altitude of 70m, while in a distance of 2300m, there is possible site of a second upper reservoir in an altitude of 690m. Then the available hydraulic head will be 620m.

Although a higher hydraulic head is provided in Naxos, the development of the first WPS of Paro-Naxia is proposed to be realized in Ios. This is also justified due to the high rates of development in Ios, the distance between Ios and Paros (high losses) and the distance between the upper and lower reservoir in the case of Naxos.

5.1.2.3 Feasibility study

The system of Paro-Naxia has a special interest, because it is consisted of five main islands (Paros, Naxos, Ios, Sikinos, Folegandros) and some smaller and the only local power station is located in Paros, which is the first in order island. As a result this system is considered as a weak and centralized system with high energy transportation losses and problems of stability.

Additional constraints are imposed on the design and the dimensioning of WPS in Ios due to the capacity of the existing underwater cables between the islands.

The dimensioning in this case, starts from the existing reservoir. Taking into consideration that the existing reservoir is also used for irrigation, then only a part of the reservoir's capacity can be used for energy use. The topography of the site of the upper reservoir imposes an additional constrain. Then, the useful capacity of the reservoirs has been considered 120.000m^3, to start with the simulation and the dimensioning procedure. The hydraulic head is 620m and the distance between the two reservoirs is 2300m.

The rest components of the WPS has been then estimated:

- Hydro turbine: 8MW,
- Wind Farms' capacity: 8MW
- Upper reservoir: 120.000m^3 - Lower reservoir (existing): 260.000m^3
- Pumping station: 6,5MW (10 pumps)

The general design of the WPS is compromised:

- double penstock
- use of the turbine as a spinning reserve to increase the direct wind absorption
- hydro-turbine's supply of the daily demand peaks (stable daily energy production, distribution according to the needs)

The main effect on the contribution to 2010 of this plant is estimated to 7.9% of the electricity demand. A small part is derived by direct wind absorption (1.9%) and an other 6% is derived by the hydro turbine supply. The "Guaranteed power" is 8MW or the 7% of the annual peak demand.

The tariffs for the hydro turbine production, the pricing of guaranteed power and the price for the conventional power for pumping are objectives of negotiation between investor, system operator and regulatory authority (RAE).

The proposed WPS is in accordance with the current grid infrastructure and the underwater cables. The maximum aggregated production (wind and turbine) is 13.1MW (and it occurs in peak demand load). Only 77 hours annually the aggregated production exceeds 10MW, which is lower than the demand, and the ability of the two underwater cables between Ios-Paros (~10MW) and Ios-Sikinos (~5MW).

WPS integration in Ios contributes to the decentralization of the electrical system, with positive effect on the stability, reduction of transportation losses and better quality of power.

The results from the simulation of the power system of Paro-Naxia are presented in Table 5-1. The results are comparably presented for the case with and without WPS.

With the introduction of the WPS in the power system of Paro-Naxia, the wind penetration is increased from 16.6%, which can be achieved with wind integration without storage, to 23.9%. Simultaneously the system's EPC remains almost the same. As a consequence the operation of conventional units and their required installed capacity are reduced. The large power system of Paro-Naxia needs a rather progressive renewable energy integration to preserve the reliability of the system. Today the system is rather centralized, with all the local conventional power generated in Paros and transported to the other islands through several underwater cables. With the current infrastructure the proposed WPS, is considered as a good solution to make the first step towards a larger renewable penetration. In parallel, the Hellenic Transmission System Operator plans the interconnection of the Cyclades complex (Paro-Naxia is included) with the mainland, which will permit a larger wind power integration. In this case, clean wind power will be transferred to the mainland and local conventional units will be set to cool reserve. In such a perspective, WPS could be used to ensure the stability and the power quality of a rather weak power system characterized by large wind integration without local conventional production.

Table 5-1 Summary of results for IOS

	Current situation (2005)	***Current infrastructure (2010)***	***Adding RES without storage devices (2010)***	***Proposed operation (2010)***
Demand (MWh)	179000	246260	246260	251540
Peak demand (MW)	56	74.8	74.8	74.8
Annual mean load (MW)	20.4	28.1	28.1	28.1
Wind installed capacity	~1.3MW	1.8MW	18.3MW	18.3 (outside the WPS) 8 (inside the WPS)
Conventional capacity(MW)	61.4	82	82	72.2
RES Production (MWh)	~4000	5540	40890	40890 (wind outside WPS) 4670 (wind in WPS) 14600 (hydro turbine) 60160
RES supply (%)	2.2%	2.2%	16.6%	16.3% (wind outside WPS) 1.9% (wind in WPS) 6% (turbine) **23.9%**
RES curtailment (MWh)	-	-	24150 (36%)	24150 (wind outside WPS) 23800 (wind in WPS)
Thermal units (MWh)	175000	240720 (97.8%)	205370 (83.4%)	191380 (76.1%)
Diesel (MWh or tn)	524tn	720tn	615tn	573tn
HFO (MWh or tn)	38127tn	52445tn	44744tn	41696tn
CO_2 Avoided (tn)	3388	4692	34634	50955
SO_2 Avoided (tn)	14.32	19.8	146.4	215.4
NO_x Avoided (tn)	6.16	8.5	63	92.6
PM10 Avoided (tn)	1.36	1.88	13.9	20.5
Estimated O&M cost (€)	15,76	21,65	19,09	18,21
Estimated O&M Cost of Energy (COE)- €ct/kWh	0,088	0,088	0,078	0,072
Estimated change in Installation cost pay -back(€)			2,15	2,90
Total Cost of Energy (COE)- €ct/kWh	0,127	0,126	0,124	0,121
Scenario 100$/B				
Estimated O&M Cost of Energy (COE)- €ct/kWh	0,153	0,153	0,133	0,123
Total Cost of Energy (COE)- €ct/kWh	0,192	0,191	0,179	0,171

5.2. Case study 2 results-Cyprus

5.2.1. Scenario 1 – Adding wind power without Storage in Cyprus

According to the methodology briefly described in Chapter 3, the maximum allowed wind capacity to be installed without storage is estimated to 310MW. The energy supply of this wind installed capacity is 12.5% and the wind energy curtailment is 10.3%.

If the target is to ensure 0% curtailment, then the maximum allowed wind capacity to be installed without storage is restrained only to 127MW (25% of the annual mean load) and the wind energy supply to 5.5%).

5.2.2. Scenario 2 - Pump Hydro Installation

5.2.2.1 Results of the pre-feasibility study

In the following figure the results of the pre-feasibility study of WPS in the power system of Cyprus are presented. Pre-feasibility study aims to examine the effect of the WPS integration into the autonomous power supply system. Then, in these charts the electricity production cost of the power system without pumped storage considering a Brent price of the order of 100$/b is presented in straight red line. This price is considered as a long term reference price.

The Market price for the conventional electricity used for pumping p_m has been received 0.10€/kWh (around the existing consumer's price) and the fixed price for the wind production p_w was considered 0.125€/kWh.

The main conclusions of this approach in the power system of Cyprus are:

- There is a general remark that the results are less attractive. The reason is the low wind potential in Cyprus. It should be clarified that WPS is not a fuel, but only a power storage system. Then in areas without reach and cheap renewable source, the main problem is to identify the original source for exploitation. If this is not possible, then, we should expect higher costs and prices. But this is essential, towards the larger renewable contribution.
- Only a moderated RES integration (i.e. peak demand supply up to 16% or hybrid's electricity supply up to 14% - Fig. 5.2a) can be achieved. Then the cumulative RES supply with wind (outside the WPS) and WPS may reach only up to 20% (Fig. 5.2 b) of the annual electrical demand. In this direction, the required reservoirs volume is up to 31 million m^3 (Fig. 5.2.i) and the required wind installed capacity is up to 470MW (Fig. 5.2.j). Even the estimation of 6.3m/s average wind speed, sounds optimistic for such a massive wind integration. Cyprus has a very limited spatial and qualitative wind potential.
- The electrical system's EPC seems to get reduced (Fig. 5.2.d) up to a 10% peak supply as a result of the WPS integration (from the level considered with Brent price 100$/b). In fact, this is a thoughtless conclusion as soon as the high consumption of conventional power for pumping (fig. 4.23.k) in a relatively low price strongly affects the results.
- The conventional units EPC is increased (Fig. 5.2 e) as soon as the same units operate less after the WPS integration and their low load factor is further decreased (Fig. 5.2.g).
- As regards, the turbine's and hybrid's EPC, the former varies around 0.25-0.32€/kWh and the latter around 0.29-0.42€/kWh (Fig. 5.2.c). This values represents a large cost, more expensive than the current peak supply cost, even a higher Brent price is considered. The only advantage is that the turbine's electricity production cost is independent to the Brent price, providing less risk as regards the future costs and the fuel feed. Then, the profitability of this investment is strongly depends on the feed-in tariffs for the turbine's electricity production. The cost could be reduced if the existing dams of Cyprus are used for energy purposes.
- The investment cost of the WPS is estimated to 1360-1520€/kW installed (cumulative wind and hydro turbine capacity) or 3800-7000€/kW of turbine

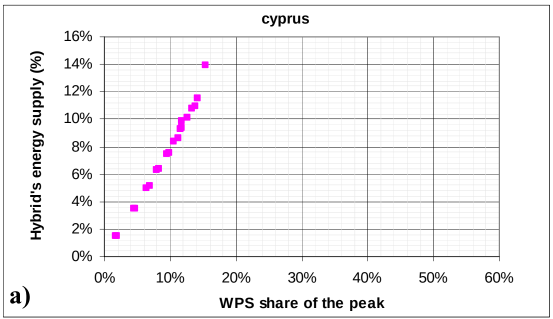
capacity (Fig. 5.2.m, Fig. 5.2.n). Lower cost is estimated for larger WPS systems. It is relatively lower than in the previous examined case of Paro-Naxia due to the economy of scale.

- The efficiency of the WPS plant is estimated to 37-52% (Fig. 5.2.h).

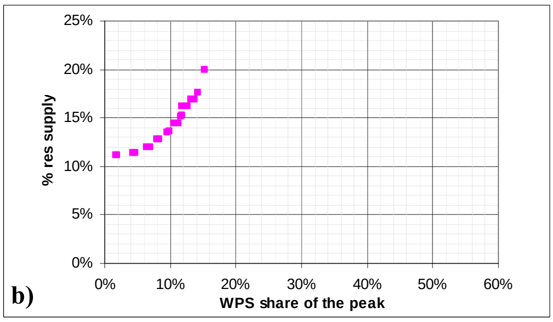
- The RES supply in Cyprus can be increased thanks to the WPS integration. Only a share of 11% RES supply could be achieved if wind installed capacity is introduced without any storage devices. Further RES supply up to 9% could be achieved via the WPS integration, for the examined cases of this study (Fig. 5.2.b).

- For this achievement the wind installed capacity in the WPS should be significantly increased. In the case of Cyprus a relatively higher share of wind energy exploited (78-88%) is provided thanks to the uniform annual curve of power demand and the low wind potential (Fig. 5.2.l).

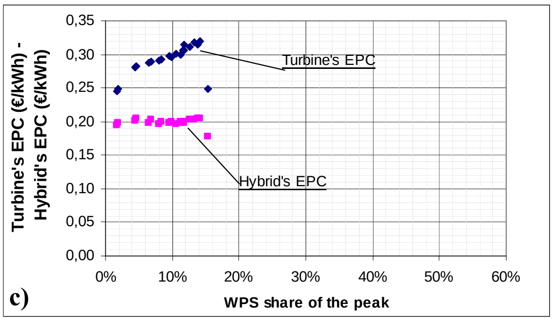
- On the other hand, the conventional power which is used for pumping is high, introducing the need for a rational design of the whole system (Fig. 5.2.k).


cyprus
Hybrid's energy supply (%)
WPS share of the peak

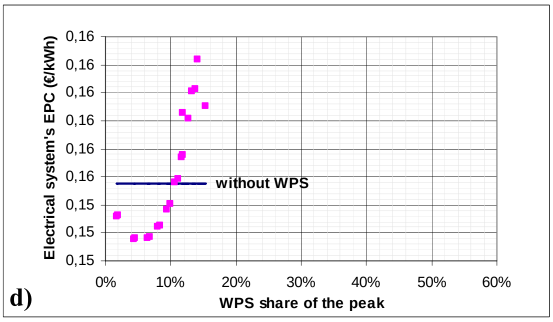
a)


% res supply
WPS share of the peak

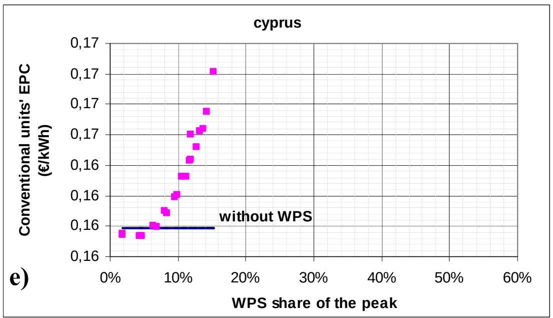
b)


Turbine's EPC (€/kWh) -
Hybrid's EPC (€/kWh)
Turbine's EPC
Hybrid's EPC
WPS share of the peak

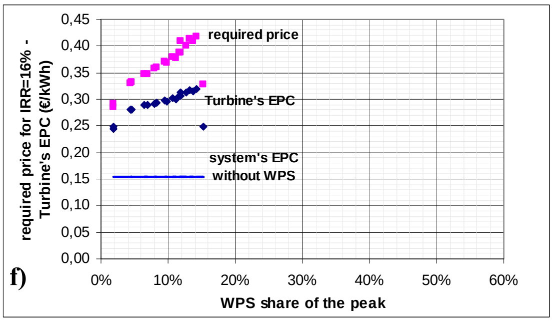
c)


Electrical system's EPC (€/kWh)
without WPS
WPS share of the peak

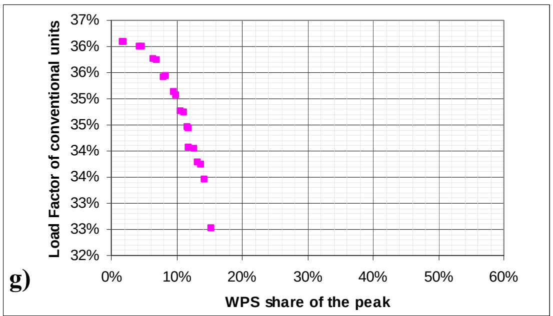
d)


cyprus
Conventional units' EPC
(€/kWh)
without WPS
WPS share of the peak

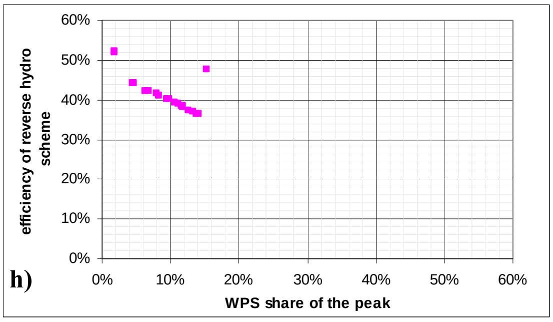
e)


required price for IRR=16% -
Turbine's EPC (€/kWh)
required price
Turbine's EPC
system's EPC
without WPS
WPS share of the peak

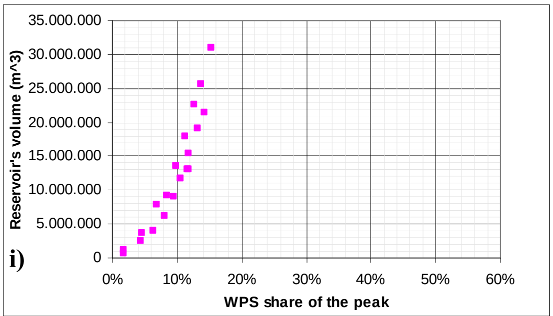
f)


Load Factor of conventional units
WPS share of the peak

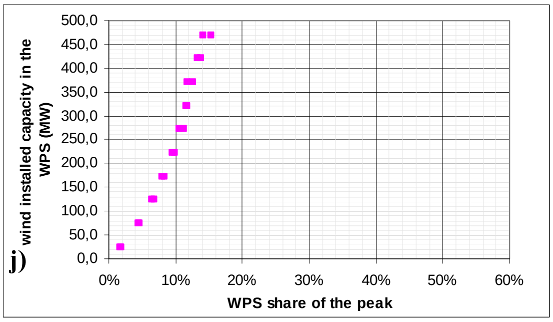
g)


efficiency of reverse hydro
scheme
WPS share of the peak

h)


Reservoir's volume (m^3)
WPS share of the peak

i)


wind installed capacity in the
WPS (MW)
WPS share of the peak

j)

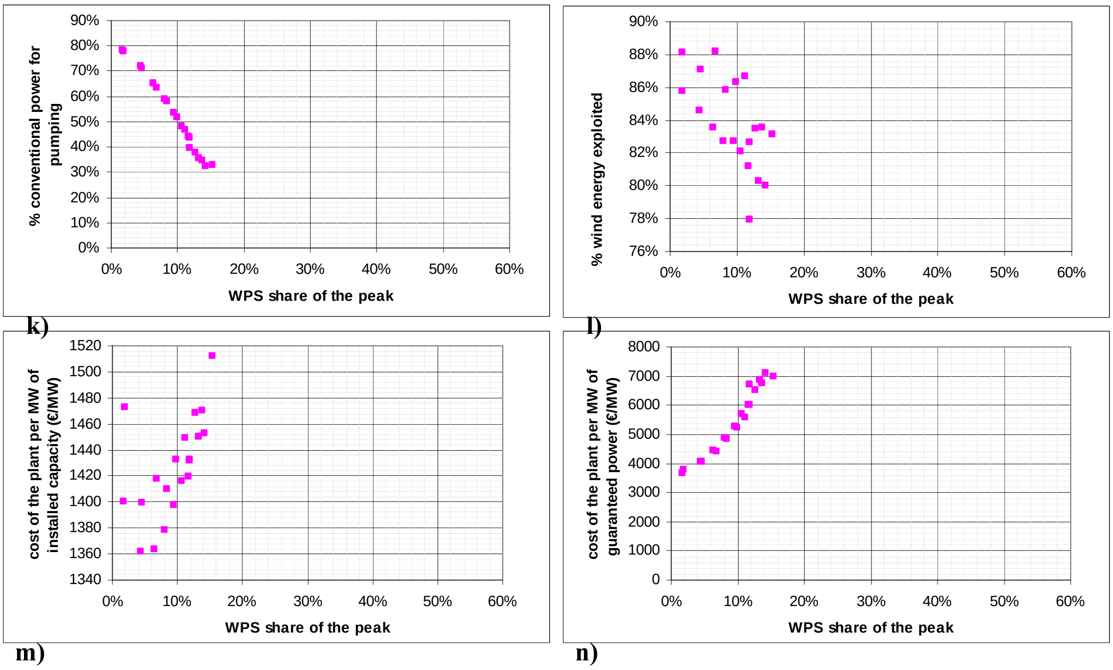


Fig. 5.2 Results of the pre-feasibility study in Cyprus: a) hybrid's energy supply, b) RES supply, c) Turbine's and hybrid's, d) Electrical system's EPC, e) Conventional units' EPC, f) Required price for the turbines electricity production to provide IRR=16%, g) Load factor of conventional units, h) efficiency of the pumped storage system, i) Reservoir's volume, j) wind installed capacity, k) % Conventional power for pumping, l) wind energy exploited (%), m) cost of the plant per MW of installed capacity, n) cost of the plant per MW of guaranteed power.

5.2.2.2 <u>Evaluation of existing reservoirs</u>

In this paragraph the existing reservoirs for irrigation are evaluated by the point of view of energy exploitation in the framework of a WPS integration.

There are several reservoirs in Cyprus most of them constructed in fifties and sixties for irrigation and watering. Due to the low wind potential, and the discouraging results of the pre-feasibility study of the WPS in Cyprus, the exploitation of the existing reservoirs seems to be the only way.

As regards the possibility to use the existing reservoirs for energy purposes, the topography in Cyprus always provide the opportunity for the construction of an upper reservoir. The main question is to provide the highest possible hydraulic head in the relatively lowest distance.

The initial overview of the existing reservoirs, together with the pre-feasibility study in Cyprus, shows that that there are several potential cases.

In Fig. 5.3 all the existing reservoirs are presented.

It is obvious that both the wind installed capacity and the hydro storage systems should be geographically distributed in the island for several reasons.

The wind installed capacity should be distributed for three main reasons:

- First of all such a big installed capacity needs a big area to be installed. There is not a specific site in the island which could seat such a huge wind installed capacity.
- The second reason introduces the advantages of the geographical distribution of wind installed capacity in the decrease of the wind power output variability
- Finally, from the electrical point of view it is preferable to widely distribute the wind

farms. By this way the electrical losses due to the transmission of wind power to the demand are decreased, and additionally, if a part of the grid is lost for any reason, it is preferable to lose only a part of the wind production.

The Pumped Storage System should be also divided in a couple of pumped storage systems for various reasons:

- First of all due to the geographical distribution of wind installed capacity, aiming at the reduction of losses, the pumped storage units should be distributed in the island. Ideally, a pumped storage, with a pumping ability of the same order should be installed closely to the wind installed capacity.
- Secondly, the centralized production of the hydro turbines should be also avoided for electrical stability reasons and reduction of the Transmission and distribution losses.
- Thirdly, topographical reasons and restrictions impose the splitting of the plants. In general, it may be easier to find more sites which can host smaller reservoirs, than one site for a huge reservoir.
- Finally, due to the size of the investment, and the significant risk – since it is an innovative application with few real examples worldwide – it is difficult to be realized by one individual investor. It would be easier to announce 5 to 10 plants which can be undertaken by different investors.

The sitting of a suitable site for the construction of the reservoirs seems to be more difficult than the sitting of the wind farms. A suitable site should fulfill the following criteria:

- Suitable topography where two reservoirs can be constructed,
- providing a high hydraulic head between the two reservoirs,
- with small distance between them and
- a neighbored stream should be available for the filling of the reservoir in the beginning of the operation, and the complement of water losses due to evaporation.

So, it is preferable to construct a couple (3-6) of smaller WPS distributed in the island.

In the framework of this study and after the initial identification of order of the reservoirs' capacity, only the large dams are examined as probable cases for WPS installation. Theoretically, the small dams, could also provide a hydro storage solution, but scale reduction cost does not occur.

Then after an initial evaluation of the topography around the existing reservoirs, four of them are considered as initially suitable and subject for further investigation.

According to the initial estimations, there are possible sites which provide a relatively significant hydraulic head in a relatively low distance (Table 5-2). This is an acceptable reservoirs capacity considering both the hydro and wind potential.

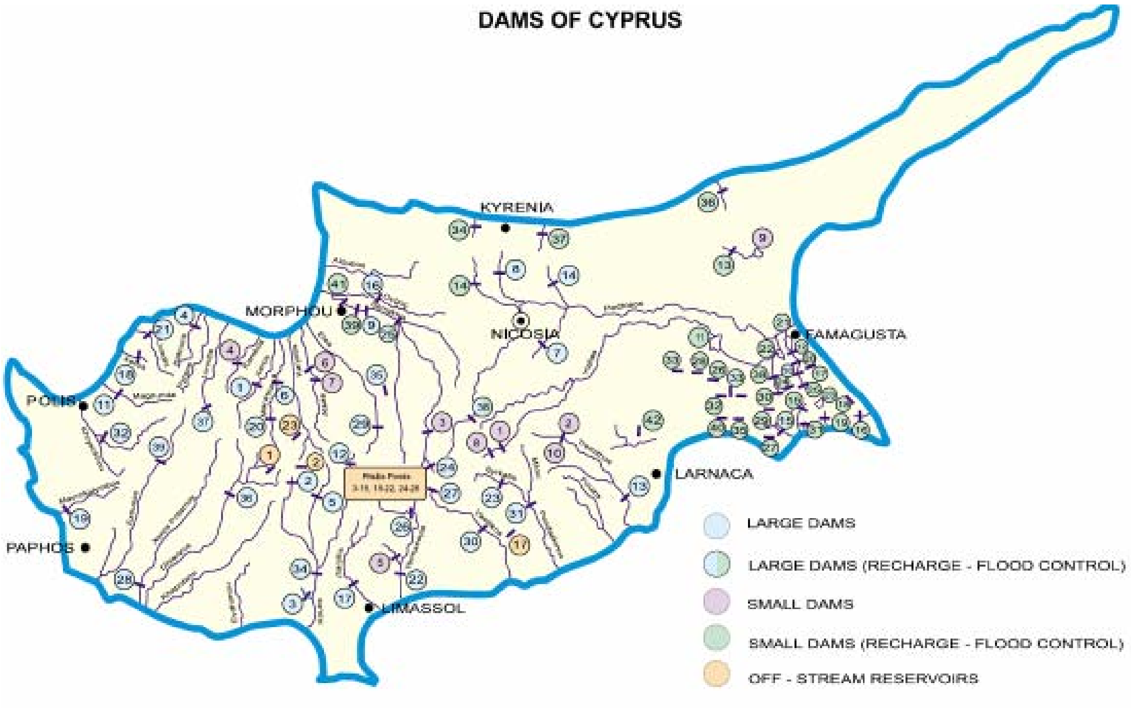


Fig. 5.3 Siting of the existing reservoirs in Cyprus

Table 5-2 Evaluation of existing dams with potential for a WPS exploitation in Cyprus

Index in Fig. 5.3	*Dam Name*	*Volume of the existing (lower) reservoir (10^6 m^3)*	*Estimated Hydraulic head H (m)*	*Distance from the probable site of the upper reservoir L (km)*
34	*Kouris*	115	350	7.5
28	*Asprokeramos*	52	250	5
32	*Evretou*	24	400	6.8
31	*Dhypotamos*	15.5	220	5.5

5.2.2.3 Feasibility study

The system of Cyprus has a special interest. Due to the lack of local energy sources, Cyprus is totally dependent on the fuel oil imports. Additionally, Cyprus is not a typical windy island and suffers from water scarcity. Then any propose of sustainable development of the electrical system which will be based on wind with hydro, is expected to be more expensive than in other case-studies islands.

The dimensioning in this case, starts from the existing dams and the pre-feasibility study. Taking into consideration that the existing reservoirs are also used for irrigation, then only a part of the reservoir's capacity can be used for energy use. Additionally, the topography of the site of the upper reservoir imposes an additional constrain. Then, useful capacity of the reservoirs has been estimated initially around to 30-40*$10^6$$m^3$, to start with the simulation and the dimensioning procedure. The hydraulic head was received 350m and the distance between the two reservoirs 5km.

The rest components of the WPS has been then estimated:

- Hydro turbine: 250MW,
- Wind Farms' capacity: 450MW
- Upper reservoir: ~30,000,000m^3 - Lower reservoir (existing): ~76,000,000m^3
- Pumping station: 360MW

- Number of plants: 2

The general design of the WPS is compromised:

- double penstock
- use of the turbine as a spinning reserve to increase the direct wind absorption
- hydro-turbine's supply of the daily demand peaks (stable daily energy production, distribution according to the needs)

The main effect on the contribution to 2010 of this plant is estimated to 11.3% of the electricity demand. A small part is derived by direct wind absorption (5.9%) and an other 5.4% is derived by the hydro turbine supply. The "Guaranteed power" is 250MW or the 25.4% of the annual peak demand.
In Cyprus, there is no legislation about hybrid systems. Then the tariffs for the hydro turbine production, the pricing of guaranteed power and the price for the conventional power for pumping are objectives of negotiation between investor, system operator and regulatory authority (CERA).

The results from the simulation of the power system of Cyprus are presented in Table 5-3. The results are comparably presented for the case with and without WPS.

With the introduction of the WPS in the power system of Cyprus, the wind penetration is increased from 10%, which can be achieved with wind integration without storage, to 25%. Simultaneously the system's EPC remains almost the same. The power system of Cyprus is entirely depended on oil, while it is characterized by a rather moderate wind potential. Then the wind power production or the proposed solution of WPS integration is a rather expensive solution, but it has to compete with a current high electricity production cost. Fortunately, the existing reservoirs constructed during the last three decades to collect water for irrigation and the Cyprus topography, permits the parallel exploitation of the existing infrastructure for energy purposes. The possible lack of water can be faced by the integration of desalination units which could operate with the wind surplus. Although Cyprus is not the ideal place for wind or hydro plans, there are several reasons -such as the existing feed-in tariffs, the lack of other renewable sources (hydro or geothermal) and the lack of any prospects for interconnections- which show that the WPS integration is a suitable solution, until the costs of solar thermal for electricity and photovoltaics drop.

Table 5-4 Summary of results for Cyprus

	Current infrastructure (2010)	***Adding RES without storage devices (2010)***	***Proposed operation (2010)***
Demand (MWh)	5016960	5016960	5305276
Peak demand (MW)	984	984	984
Annual mean load (MW)	573	573	573-606
Wind installed capacity	0,00	310	310 (outside the WPS) 450 (inside the WPS)
Conventional capacity	1171,00	1171	921
RES Production (MWh)		506310	506310 (wind outside WPS) 295540 (wind in WPS) 456250 (hydro turbine)
RES supply (%)		10%	10% wind outside WPS 5,9% wind in WPS 9,1% turbine **25%**
RES curtailment (MWh)		77280	77280 (wind outside WPS) 551600 (wind in WPS)
Thermal units (MWh)	5016960	4510650	4047176
Diesel (tn)	277187	249214	223607
HFO (tn)	831561	747640	670819
CO_2 Avoided (tn)		428845	821407
SO_2 Avoided (tn)		1812,59	3471,83
NO_x Avoided (tn)		779,72	1493,47
PM10 Avoided (tn)		172,15	329,73
Results for 54$/b			
Estimated O&M cost (10^6 €) 54$/b	513,54	472,12	441,11
Estimated O&M Cost of Energy (COE)- €/kWh 54$/b	0,102	0,094	0,083
Installation cost pay -back (10^6 €)	129,59	170,04	219,63
Estimated change in Installation cost pay -back(€)		40,46	90,05
Total Cost of Energy (COE)- €/kWh - 54$/b	0,128	0,128	0,125
Results for 100$/b			
Estimated O&M Cost of Energy (COE)- €/kWh 100$/b	0,176	0,160	0,139
Total Cost of Energy (COE)- €/kWh - 100$/b	0,201	0,194	0,180

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5.3. Case study 3 results- Corvo

The island of Corvo represents a very small autonomous system, with currently extremely high electricity production cost. The choice of a hybrid system comprised by wind and pumped storage, may not be the best solution for the increase of RES penetration. Additionally, these solutions are rather complex for a small island without the required technical know-how for its operation and maintenance. The battery storage may be a more consistent technology for such small islands

5.3.1. Scenario 1- Wind power in Corvo without storage

In this small case study-island, the identification of the wind power capacity, which could be permitted without any storage devices, has only a theoretical importance, since the wind capacity will be very small and without attractiveness for any investor. With similar methodology as in other cases, the maximum allowed wind capacity to be installed without storage is estimated to 74.4kW. The energy supply of this wind installed capacity could be 18% and the wind energy curtailment is 33.3%.

As a result, this is a very small wind capacity, and possibly it could be achieved with one wind turbine of the order of 70-80kW or with several small wind turbines of the order of 5-10kW integrated in buildings or rural areas in the island. In such cases the power supply system-market is always consisted of only one player. Then, if there is a political will for a significant RES penetration, the overall system (WHPS, local power station, grid and system operation) will be owned by one player. As a result no wind installed capacity outside of the hybrid is expected.

5.3.2. Scenario 2 - Pump Hydro Installation

5.3.2.1 pre-feasibility study

The peak demand in this island is only 0.205MW. Then, the pre-feasibility study is realized only for comparative reason. Pre-feasibility studies always provide an initial investigation on the dimensioning and on the different degrees of penetration that could be achieved.

Pre-feasibility study aims to examine the effect of the WPS integration into the autonomous power supply system. Then, in these charts the electricity production cost of the power system without pumped storage considering a Brent price of the order of 100$/b is presented in straight red line. This price is considered as a long term reference price.

Since the target for such a small case study island is a large WPS integration, then the philosophy of the operation which is considered has several differences from the previous case studies:

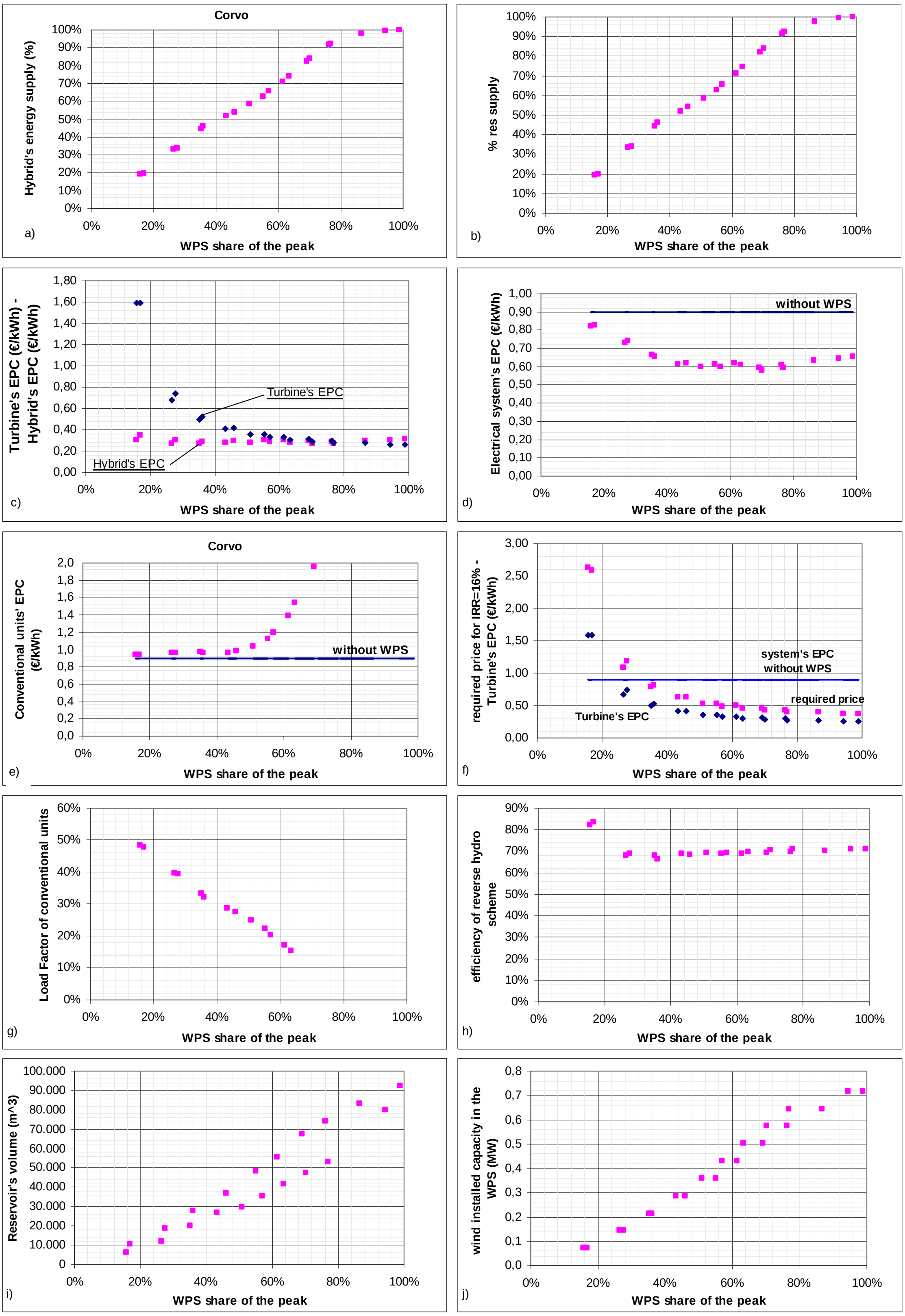
- First of all, conventional power for pumping is not considered here. The high wind potential and the order of capacity of the reservoir, permits a different design.
- Additionally, as soon as the WPS will play a primary role in the whole system, the stable daily turbine supply is not possible. The target here for the WPS is to provide the required power according to the needs of the demand. Then, the hydro-turbine's energy output is modulated taking into consideration the daily energy demand.
- No wind installed capacity outside of the WPS has been considered.
- A fixed price for the wind production p_w was considered 0.10€/kWh.

The main conclusions of this approach in the Corvo island are:

- For the large scale RES integration i.e. WPS electricity supply up to 100% (Fig. 5.4.a and b), the required reservoirs volume is up to 90,000 m3 (Fig. 5.4.i) and the required wind installed capacity is up to 0.7MW (Fig. 5.4.j).
- The electrical system's EPC could be reduced (Fig. 5.4d) as a result of the WPS integration (from the level considered with Brent price 100$/b).
- The conventional units EPC is increased (Fig. 5.4.e) as soon as the same units operate less after the WPS integration and their low

load factor is further decreased (Fig. 5.4.g). In case of high WPS penetration, extremely high conventional units EPS occur, as soon as very limited operation is required.

- As regards, the turbine's and hybrid's EPC, the former varies around 0.25-0.45€/kWh and the latter around 0.30-0.40€/kWh (Fig. 5.4.c). This cost is very competitive against the peak current cost, even a lower Brent price is considered. The turbine's electricity production cost is independent to the Brent price. Then, the profitability of this investment is strongly depends on the tariffs for the turbine's electricity production. Additionally, the WPS cost is decreased as soon as its penetration is increased, clearly justifying the different target-approach in this case.
- Although, in terms of EPC, this hybrid solution seems to be attractive, requires a high investment cost. Actually, the estimated investment cost of the WPS is 4,000-6,000€/kW installed (cumulative wind and hydro turbine capacity) or 17,000-20,000€/kW of turbine capacity (Fig. 5.4.m, Fig. 5.4.n). Lower cost is estimated for larger WPS systems.
- The efficiency of the WPS plant is estimated to 70% (Fig. 5.4.h).
- The RES supply in Corvo can be significantly increased thanks to the WPS integration.
- For this achievement the wind installed capacity in the WPS should be increased. More than 60% of the wind energy is exploited (Fig. 5.4.l).
- No conventional power is used for pumping as explained previously (Fig. 5.4.k).


Corvo
Hybrid's energy supply (%)
WPS share of the peak
a)
% res supply
WPS share of the peak
b)
Turbine's EPC (€/kWh) - Hybrid's EPC (€/kWh)
Turbine's EPC
Hybrid's EPC
WPS share of the peak
c)
Electrical system's EPC (€/kWh)
without WPS
WPS share of the peak
d)
Corvo
Conventional units' EPC (€/kWh)
without WPS
WPS share of the peak
e)
required price for IRR=16% - Turbine's EPC (€/kWh)
system's EPC without WPS
required price
Turbine's EPC
WPS share of the peak
f)
Load Factor of conventional units
WPS share of the peak
g)
efficiency of reverse hydro scheme
WPS share of the peak
h)
Reservoir's volume (m^3)
WPS share of the peak
i)
wind installed capacity in the WPS (MW)
WPS share of the peak
j)

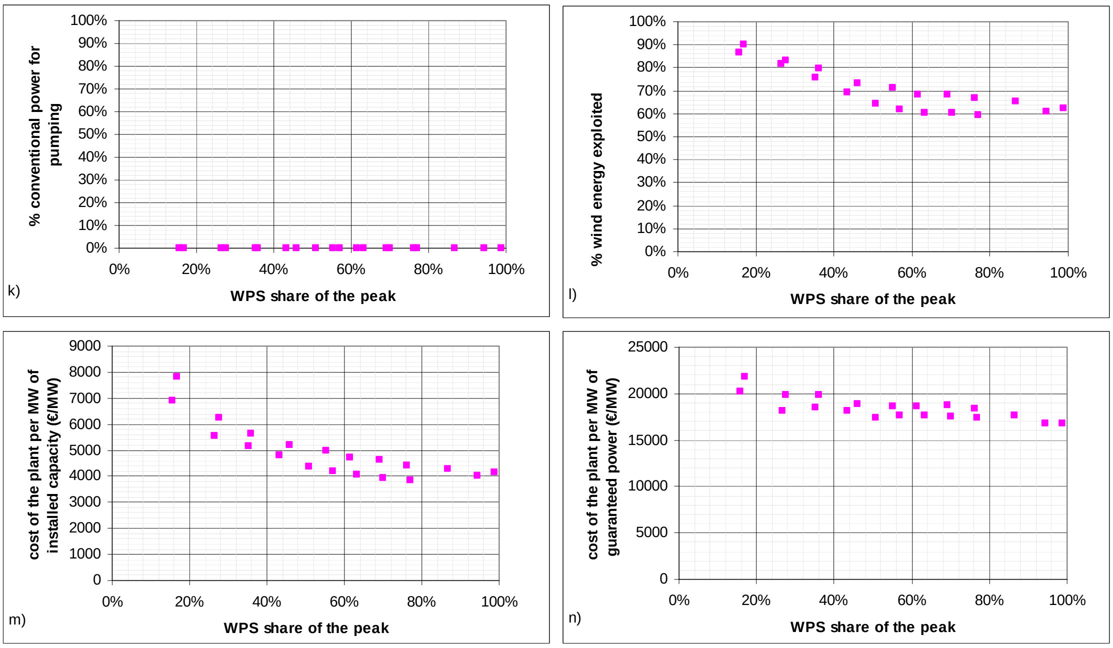


Fig. 5.4 Results of the pre-feasibility study in Corvo: a) hybrid's energy supply, b) RES supply, c) Turbine's and hybrid's, d) Electrical system's EPC, e) Conventional units' EPC, f) Required price for the turbines electricity production to provide IRR=16%, g) Load factor of conventional units, h) efficiency of the pumped storage system, i) Reservoir's volume, j) wind installed capacity, k) % Conventional power for pumping, l) wind energy exploited (%), m) cost of the plant per MW of installed capacity, n) cost of the plant per MW of guaranteed power.

5.3.2.2 Evaluation of morphology

Corvo's main feature is the extinct Monte Gordo volcano, whose crater (the Caldeirão) is the predominant feature, with a 3.7 km perimeter and 300 meter depth. The highest point on the island is the "Morro dos Homens" on the southern flank of the Caldeirão, at 718 m above sea level. One road leads to the top of the volcano.

Some small streams in the south-east part of the island may provide the root towards the definition of a suitable site for the installation of a WPS. In this case a hydraulic head of the order of 250-300m could be easily provided in a distance of 600-800m between the two reservoirs.

The other case is construct a Seawater Pumped Storage Power Plant (like in Okinawa-Japan). In Corvo island, there are several places suitable for this plant, which provide a significant hydraulic head. There are areas in the west side and the north east side of the island very close to the sea (distance of the order of 400-500m) with an altitude of 300-350m. The north part of the island provides also suitable sites with even higher hydraulic head, but these areas are considered as a natural beauty due to the volcano.

5.3.2.3 Feasibility study

The system of Corvo represents a totally different case study and has special interest, because it is a very small island. It is obvious, that in such a small system with high potential and small energy needs, the achievement of a higher penetration directly could be the target. Corvo is the most isolated island in Europe, and then a solution which will provide energy independence is desirable.

According to the pre-feasibility study and the concept of the previous paragraph, a system which could provide the 100% of the energy needs is examined. To start with the dimensioning and the feasibility study of the Corvo's WPS, a hydraulic head H=280m in a distance of 700m, is assumed

The rest components of the WPS has been then estimated:

- Hydro turbine: 0.24MW,
- Wind Farms' capacity: 0.9MW
- Upper reservoir: 90,000m^3 - Lower reservoir (existing): 90,000m^3
- Pumping station: 0.9MW (10 pumps)

The general design of the WPS is a little bit different than in the previous case studies. Again a double penstock is required to provide operational flexibility. Due to the small size of the power system of Corvo, and the small wind installed capacity, wind power is only used for pumping and the whole power demand is supplied by the hydro turbine.

The assumption that the wind power is only given for pumping is a safe-side assumption, which ensures the safe operation of this small isolated power system. In such cases, total loss of wind power may occur due to sudden fall of wind or due to a sudden storm over the one or two wind turbines of the island with wind speeds that exceed the operational limits of the turbines. Additionally, the variation of the wind power production may be significant and cause frequency or voltage fluctuation.

The hydro turbine supply is then estimated to 100% of the electricity demand in 2010. The "Guaranteed power" is 0.24MW or the 100% of the annual peak demand. Then, all the diesel power units of the system are set in cool reserve.

It is obvious that despite the high cost of installation of a WPS (15575 €/kW of guaranteed power or 9893 €/kW of cumulative installed capacity), the replacement of the current power supply system with the WPS is feasible. The electricity production cost of the system could be reduced to 0.3€/kWh from the current cost of 0.9€/kWh. Then, a definition of a tariff for the hydro production around 0.4€/kWh could provide the required incentive for the undertaken of this investment. It is a relatively small investment of the order of 3.7 million €, then a relatively higher IRR is essential.

Another important issue which should be taken into consideration is the operational complexity and the reliability of the whole system. In such isolated areas, the lack of know-how and of experts for the operation and maintenance of the energy systems, determines in a high degree the final decisions making.

Always the local power utility prefers technical solutions which are more reliable and less complicated. The integration of a hybrid system additionally to the current conventional system may increase the need for control and management of the whole system. On the other hand, the integration of a hybrid system, which will provide the total electricity supply maybe feasible and preferable in terms of operational complexity and energy independence

The results from the simulation of the power system of Corvo are presented in Table 5-5. The results are comparably presented for the case with and without the integration of WPS.

With the introduction of the WPS in the power system of Corvo, the wind penetration is increased from 0% today up to 100%. Simultaneously the system's EPC is significantly reduced (from the current 0.656 to 0.358€/kWh), providing in parallel fully independence from the oil price. Today, the power system of Corvo is entirely depended on oil, while Corvo is an isolated power system without any prospect of interconnection. The oil is even more expensive due to the distance and transportation expenses. On the other hand, abundant wind potential remains the cheapest, local and unexploited source. The morphology of Corvo, permits the construction of the required infrastructure for the operation of a WPS which could supply the entire electricity demand. If the target is to make Corvo one of the first 100% RES islands in Europe, then the WPS seems to be an ideal solution. For more conservative targets, other solutions (for example PV with batteries) should be examined and may be proved more suitable or cheaper for such very small island-cases.

Table 5-6 Summary of results for Corvo

	Current infrastructure (2010)	*Proposed operation (2010)*	
Demand (MWh)	1256	1256	
Peak demand (MW)	0.24	0.24	
Annual mean load (MW)	0.14	0.14	
Wind installed capacity (MW)y	-	-	(outside the WPS)
		0.9	(inside the WPS)
Conventional capacity(MW)	0.56	0,24	
RES Production (MWh)	0	-	(wind outside WPS)
		0	(wind in WPS)
		1256	(hydro turbine)
RES supply (%)	0%	0% wind outside WPS 0% wind in WPS 100% turbine	**100%**
RES curtailment (MWh)	-	- (wind outside WPS) 3550 (wind in WPS)	
Thermal units (MWh)	1256	0	
Diesel (tn)	707	0	
HFO (tn)	0	0	
CO_2 Avoided (tn)	-	1064	
SO_2 Avoided (tn)	-	4.50	
NO_x Avoided (tn)	-	1.93	
PM10 Avoided (tn)	-	0.43	
Results for 54$/b			
Estimated O&M cost (M€)	0.74	0.08	
Estimated O&M Cost of Energy (COE)- €/kWh	0.587	0.059	
Installation cost pay -back (M€)	0.09	0.36	
Estimated change in Installation cost pay -back(M€)		0.27	
Total Cost of Energy (COE)- €/kWh	0.656	0.348	
Results for 100$/b			
Estimated O&M Cost of Energy (COE)- €/kWh	0.852	0.059	
Total Cost of Energy (COE)- €/kWh	0.922	0.348	

5.4. Conclusions of the case studies analysed

In autonomous islands, the wind penetration is restricted due to technical reasons related with the safe operation of the electrical systems. The combined use of wind power with pumped storage systems (WPS) is a mature solution to exploit the wind potential, increase the wind installed capacity and substitute conventional units operation and installed capacity. The simulation is based on the non-dynamic analysis of the electrical system, in order to calculate the energy contribution of the different power units. The aim is to analyse the prospects of Wind and Pumped Storage systems to increase the renewable energy penetration levels. Three islands with totally different features has been analysed as representative case studies:

- The island of Ios, which is part of autonomous system of ParoNaxia complex, Cyclades, Greece
- The island of Corvo, Portugal
- The island-country of Cyprus

Several differences are imposed in the design and operational strategy of the WPS due to the different features of each case study. The main features and the conclusions for the three case studies are comparably presented in the following table.

With the introduction of the WPS the wind penetration in autonomous systems can be increased, simultaneously in most cases decreasing the system's EPC. As a consequence, the operation of conventional units and their required installed capacity can be significantly reduced.

The probable financial benefit from the introduction of the WPS should be shared between the ESO and the investor, by the definition of a suitable price. The main parameters which should be taken into consideration for the definition of the suitable price are the size of the plant, the size of the island, the current cost of the system and the duration curve of the demand.

Even in cases, where the system's EPC is not decreased thanks to the integration of the WPS, an important advantage is that the production cost is to a large extent known in advance, contrary to the current cost which depends strongly on the oil price. Thus, the installation of WPS can provide both financial and environmental benefits and is strongly recommended for all the examined cases.

	Ios	***Corvo***	***Cyprus***
Short description of the case study	part of a medium size autonomous grid comprised by several islands	Very small and isolated island	Large country-island autonomous system
Prospects of interconnection	prospects of interconnection with the mainland	no prospects of interconnection	no prospects of interconnection in medium term
Why to introduce a WPS system in this system?	-Rather medium current electricity production cost -centralized system -existing reservoir -suitable topography for the construction of the upper reservoir	Very high current electricity production cost - suitable topography for the construction of the WPS - possibility of sea-water pumped storage	- Lack of other renewable sources (except of high solar potential, but expensive technologies) - Existing reservoirs and dams constructed for irrigation
Drawbacks of WPS or main technical obstacles to be considered	- transport capacity of underwater cables	-operational complexity is increased with the integration of the WPS	- rather moderate wind potential - lack of water
Operational design	- wind power supplies the power demand with respect to the technical constraints of the autonomous system and the wind power surplus is used for pumping.	- wind power is used only for pumping	- wind power supplies the power demand with respect to the technical constraints of the autonomous system and the wind power surplus is used for pumping.
Target	- a rather medium contribution	- even 100% electricity supply is possible	- a rather medium contribution
Other options	-	- use of batteries or hydrogen storage	- use of solar thermal or photovoltaics, when their costs are decreased.
Prospects of WPS to reduce the current electricity production cost	Neutral. The EPC will be slightly decreased thanks to the WPS integration	Positive. The EPC will be substantially decreased thanks to the WPS integration	Negative. The EPC will be increased due to the WPS integration.
Priority for the implementation	High	High	High

6. SIMULATION RESULTS WITH HYDROGEN

The introduction of hydrogen (H_2) as an energy storage means in power systems was examined in the case of the Greek island Milos and the Portuguese island Corvo. In both cases, a proposed RES & Hydrogen-based power system was studied that used wind energy as an additional source of electricity production replacing part of conventional electricity and hydrogen as an energy storage method.
The proposed systems were optimized and simulated using HOMER "Hybrid Optimization Model for Electric Renewables" developed by the National Renewable Energies Laboratory (NREL), USA and then they were compared to the existing power systems in terms of the cost of power generation, RES penetration and emissions produced locally. In both islands, it was considered that hydrogen is produced locally through a water electrolysis unit, which uses excess energy produced by wind turbines. Hydrogen is then stored in gaseous form and is used as a feedstock for a fuel cell aiming to produce electricity when wind is not available

6.1. Milos Case study

According to the results of the simulation, the power generation cost of the existing power system is relatively high around 113 €/MWh, while the wind energy penetration does not exceed 13%. The resulted cost of energy is derived using a price of 0.68 €/L for diesel fuel and 0.34 €/L for heavy oil fuel. The island is heavily dependent on imported fuels as it consumes 8,833,264 L/yr of heavy oil and diesel fuel that results in 26,961,874 kg/yr of CO_2 emissions produced.

The proposed RES & hydrogen storage system for the power system of Milos consists of:

- 28 vestas V-52 wind turbines of 850 kW nominal capacity each;
- 2 vestas V-44 wind turbines of 600 kW nominal capacity each;
- 4 thermal generator sets running on heavy oil with 4.9 MW nominal capacity in total;
- 1 rental thermal generator set with 1032 kW nominal capacity;
- 1 fuel cell of 1 MW nominal capacity;
- 1 alkaline water electrolysis of 2 MW nominal capacity;
- 1 hydrogen storage tank with total capacity of 4000 kg of hydrogen.

The simulation results for the optimized RES & hydrogen power system showed that the power system generation cost decreases slightly to 112 €/MWh and there is a huge increase on RES penetration on the island, around 80%. The simulation of the proposed system includes a subsidy of 30% for wind technology and 50% for hydrogen technologies.Table 6-1 presents the main results of the simulations for the existing and proposed power system.
The results of the simulations showed that the introduction of hydrogen as an energy storage method and the increased penetration of wind energy deliver electricity at a lower cost. Apart from the cost of energy that was not drastically changed, the significant increase of renewable energy penetration of the proposed power system results in a substantial reduction in the diesel and heavy oil fuel consumption. The decrease of fossil fuel consumption has the dual effect of reducing the island's dependency on imported fuels and the production of harmful emissions. Contrary to the existing power system, the proposed system produces a considerable amount of excess electricity. However, this amount may be exploited by using it to produce either hydrogen fuel for transport applications or energy for heating purposes. These options make the proposed system even more beneficial for Milos island.

Table 6-1 Summary of the results with and without Hydrogen for Milos

	Existing power system	Proposed RES & H_2 power system
Wind installed capacity (MW)	2.05	25
Conventional capacity (MW)	11.25	5.9
Fuel cell capacity (MW)	0	1
Electric production (kWh/yr)	39,741,108	83,781,928
Electrolyser load (kWh/yr)	0	7,352,470
Electric demand (kWh/yr)	39,728,620	39,552,032
Excess electricity (kWh/yr)	12,544	36,877,792
RES penetration	13.4%	86%
Diesel fuel (L/yr)	704,548	154,906
Heavy oil (L/yr)	8,128,720	3,054,863
CO_2 avoided (tn/yr)	0	17,120,117
CO avoided (tn/yr)	0	35,607
UHCs avoided (tn/yr)	0	3,944
PM10 avoided (tn/yr)	0	2,684
SO_2 avoided (tn/yr)	0	327,536
NOx avoided (tn/yr)	0	317,722
Cost of energy (€/MWh)	113	112

6.2. Corvo Case study

The island of Corvo is the smallest out of the 9 islands in the Azores archipelago. The supply of electricity to an isolated island small island such as Corvo is very limited, while there is a great concern due to the environmental issues related to fossil fuel use like water and land contamination and pollution by oil products and wastes through leakage during shipping handling and storage.

The existing power system of Corvo includes four diesel generators with total capacity of 560 kW. However, the island's annual demand of around 1084 MW is covered by one generator of 120 kW and another of 160 kW. The results of the simulation of the existing power system of the island revealed that the power generation cost is considerably high at 259 €/MWh. The resulted cost of energy is derived using a price of 0.816 €/L for diesel fuel. The expensive cost of energy in conjunction with the environmental impacts of a fossil fuel-based power system and the security of supply of an isolated small island make the need for RES exploitation more imperative.

The introduction of hydrogen as en energy storage medium in the power system of Corvo includes the integration of wind energy. The analysis showed that the optimum RES & hydrogen power system includes the following components:

- 2 fuhrländer, FL100 of 100 kW nominal capacity each;
- 1 diesel generator set running of diesel with nominal capacity of 120 kW;
- 1 diesel generator set running of diesel with nominal capacity of 160 kW;
- 1 PEM fuel cell of 50 kW nominal capacity;
- 1 alkaline water electrolyser of 80 kW nominal capacity;
- 1 hydrogen storage tank with total capacity of 200 kg of hydrogen.

The simulation results for the optimized RES & hydrogen power system showed that the power generation cost on the island decreases to 145 €/MWh, but more than half the electricity is produced from wind energy, making a considerable increase of RE penetration from zero to 80%. Moreover, the introduction of RES and hydrogen as an energy storage medium in the power system results in a significant decrease in emission production on the island. The following table presents a comparison between the existing and the proposed power system for Corvo island. As it can be witnessed, the introduction of wind energy as an energy source and hydrogen as a storage method is a quite attractive proposal for the power system of Corvo island. The proposed system results in a remarkable reduction (43%) in the power generation cost. Moreover, with the proposed system the 80% of the electricity needs of the island would be covered by wind energy, which uses a free feedstock for the production of energy, decreasing the island's heavy dependency on imported fuel and the production of harmful emissions and enhancing security of supply, taking also into account the long distance of this island from larger islands and Continental Portugal

Table 6-2 Summary of the results with and without Hydrogen for Milos

	Existing power system	Proposed RES & H_2 power system
Wind installed capacity (kW)	0	200
Conventional capacity (kW)	560	280
Fuel cell capacity (kW)	0	50
Electric production (kWh/yr)	1,084,413	1,557,893
Electrolyser load (kWh/yr)	0	320,005
Electric demand (kWh/yr)	1,084,411	1,084,411
Excess electricity (kWh/yr)	0	153,472
RES penetration	0%	80%
Diesel fuel (L/yr)	288,051	89,024
CO_2 avoided (tn/yr)	0	524,209
CO avoided (tn/yr)	0	1,251
UHCs avoided (tn/yr)	0	138
PM10 avoided (tn/yr)	0	94
SO_2 avoided (tn/yr)	0	1,052
NOx avoided (tn/yr)	0	11,170
Cost of energy (€/MWh)	259	145

.

7. SIMULATION RESULTS WITH DESALINATION

The behaviour of the power system of 3 islands, namely Milos, Mljet and Cyprus has been studied. The methodology briefly described in section 3 and in more detail in Deliverable D2.1 was applied to Milos and Mljet.
For Cyprus the approach followed is somewhat different. The scope is to simulate the operation of a desalination system and its impact on the power system of Cyprus when there is effort to reduce wind power curtailment on the island if the foreseen installations of wind power were currently realized.

7.1. Case study 1 results-Milos

The following scenarios have been evaluated for the island system of Milos regarding:

- Addition of one wind turbine -SCEN 1
- Addition of one wind turbine +desalination with independent scheduling-SCEN 2
- Addition of one wind turbine +desalination with co-operation in scheduling SCEN 3
- Addition of desalination plant only.-SCEN 4

In all scenarios, the additional wind turbine is 850kW while the characteristics of each identical desalination module are shown in Table 7-1. The electricity demand of the desalination plant is 68% of the total island demand.

Table 7-1 Characteristics of the desalination plant.

Modules	4
Hourly water production/module	21m^3
Power needed/module	150kW
Tank capacity	3000 m^3
Upper capacity level,(minlevel$_i$)	2800 m^3
Lowest capacity level (maxlevel$_i$)	500 m^3
Estimated Annual Demand	2900MWh

7.1.1. Adding Wind power production without desalination-Scenario 1

The operation of the wind turbine affects mainly the units that consume diesel oil since they are the most expensive. The reduction in the operating cost is higher than the one of energy and reaches 106,637€ or 3.84% of the fuel cost of the island. However, the savings could have been increased if there could have been an energy medium to store the wind power curtailed which reaches 15.88% of the potential production. This is the scope of the rest of the scenarios studied.
The percentage of wind turbine production compared to the total wind power production, around 31%, is taken into account when calculating the wind power curtailment and the final income loss for the owner. The curtailment for the additional wind turbine is 375.7MWh worth of 31785€. For the existing park, the amount of energy sold reduction is 373.2MWh with value of 31,572€. If there had not been the wind power curtailment, the additional income for the owners of the wind turbines would have been 63,357€ higher.

7.1.2. Adding wind power production and desalination plant-Scenario 2

Based on water needs description on the island of Milos, described in subsection 2.1.1, taking into account the excess electricty when adding a wind turbine and the increase of demand of Desalination, Scenario 2 is considerd. Here the schedule of the desalination plant is completely independent from the wind power estimations.

Significant reduction on the wind power curtailment is achieved and more wind power, by 322MWh, is injected to the grid, although wind power penetration is somewhat decreased to 16%. Around 64% of the year energy is bought from the grid while the rest 36% energy is sold. Around 13% of the year the balance is within ±50kW.

7.1.2.1 Impact on the Economics for the owner of the desalination plant& the rest of stakeholders.

Here, an analysis for the economics for the owner of the desalination plant, the owner of the wind power turbine and the power system operator is provided. It is assumed that the desalination plant and the wind turbine have different accounting system.

The owner of the desalination plant is charged according to B1B tariff of the PPC as described in Table 7-2. The wind power curtailment is reduced to 277MWh reducing the income for the owner of the 4th wind turbine by 23437€, 8347€ less than scenario 1.

Table 7-2 Details for B1B Tariff-Milos

Power charge		8.4351€/kW
Energy Charge	***First 400kWh/kW***	0.04990€/kWh
	Rest kWh	0.03310€/kWh

Table 7-3 summarizes the economic balance for the owner of the desalination plant if he is also the owner of the additional wind turbine. The net cost for meeting the load is 5396€. The fuels cost is increased for the PPC, on average by 98.01€/MWh, higher than the average fuel cost for the Island, compared to the operation under scenario 1.

The owner of the existing wind park increases the energy sold by 224 MWh, increasing his income by 18967.32€. However, he still sells less 149MWh to the grid compared to the current situation. This means that he still losses 12605.4€. If the whole park belongs to him, the additional benefit compared to scenario 1 reaches 27241.2€.

Table 7-3 Annual Economics for the owner of the desalination plant-Milos

Energy expenses (€)	***Wind turbine income (€)***	***Final cost (€)***
173,410.91	***168,015.4***	***5,395.56***

7.1.3. Adding wind power production and desalination plant co-operation-Scenario 3

Although wind power curtailment is reduced due to desalination plant in scenario 2, it still remains high. At the same time, wind power is not used simultaneously with the increase in the loading of the power system. Scenario 3 assumes that the installation of a desalination plant is foreseen and the operating schedule is assumed to take into account the wind power estimations under the simple 4-hour persistence model. This means that the wind power forecast tool that the owner uses updates its forecast every 4 hours according to the last value of the previous 4 hours. Then the algorithm described in section 3 is applied. The total wind power requested is somewhat decreased but the peak of the thermal station production and the island remains the same with Scenario 2. The histogram of the power balance is shown in **Fig. 7.1**. As the chart shows, the power balance is negative most of the times. In fact, it is negative at around 54,07%, while at 46,93% of the time is positive. Around 22,40% of the time, the power balance is within ±50kW. Therefore the exchange of the combination with the grid is narrower compared to scenario 2 with all the benefits for the power system operation.

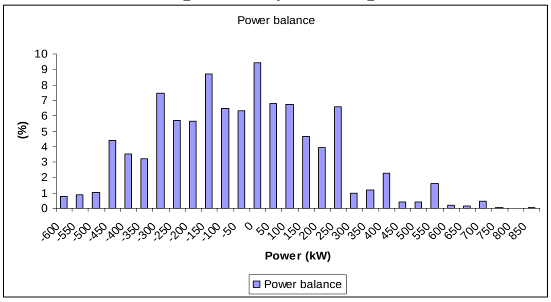


Fig. 7.1 Power balance to the grid under scenario 3 (Positive values selling to the Grid)

However, what changes significantly is the reduction of the wind power curtailment, as. This affects both the operating cost and the fuel consumption provided in Table 7-5.

7.1.3.1 Impact on the Economics for the owner of the desalination plant.

The curtailment for the additional wind turbine is 210MWh providing increased income by 5600€ compared to scenario 2 and 13947.59€ compared to scenario 1. If there had not been wind power curtailment, the income would have been 17837€ higher. The owner of the desalination plant is charged at B1B. However, the peak charge will be increased, since more often 4 desalination modules will operate.

Table 7-4 Economics for the owner of the desalination plant-Milos-Scenario 3

Energy expenses (€)	*Wind turbine income (€)*	*Final cost (€)*
196707.3	*173,615.50*	*23091.74*

7.1.3.2 Comparison with scenarios 1 & 2

If the owner of the desalination is owner of the additional wind turbine as well, he will have to pay 23091,74€ as a balance for the water produced, 17696€ higher than the case of scenario 2. This increase can be faced if one takes into account that three stakeholders on the island are expected to have additional income.

The operator of the power system decrease the fuel cost increase by 42,389€ compared to scenario 2. The additional fuel cost for meeting the additional thermal power station production due to the desalination plant (Compared to scenario 1) is 89.27€/MWh. A comparison of the monthly additional cost for meeting the desalination load for scenarios 2 and 3 is shown in Fig. 7.2. Only for July and August the additional cost is higher due to the increased water demand for this period and the fact that the additional energy requirements are closer in time with relatively high wind power production to maintain the balance. This leads to higher increase in production of the diesel fueled units. In all the other cases, the additional cost is lower and for the months with higher wind power penetration, significantly lower.

The retail seller increases its income compared to scenario 2 by the difference 196707-173410=23297€.

The owner of the existing wind park, if different from the owner of the 4th wind turbine, will sell 150.8 MWh more than in scenario 2 increasing his income by 12757.68€. The final curtailment for the existing wind park will remain the same with the current situation on the island.

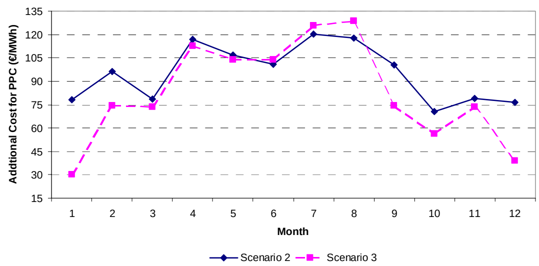


Fig. 7.2 Additional fuel cost for meeting the Desalination load demand compared to scenario 1

If the owner of the 4th wind turbine is not the owner of the desalination plant, then the additional income for him will be 5600 €. The final increase in income of the wind park owners is 18,357.8€,compared to scenario 2. Compared to scenario 1, the additional income for wind park investors will reach, 45,652.42€ due to increasing wind power sales.

If the owner of the desalination plant is the owner of all the wind turbines, then the additional cost for scenario 3 is 4938.5€ higher than the one of scenario 2.

7.1.4. Adding desalination plant co-operation without wind- Scenario 4

This scenario evaluates the potential impact of a desalination plant on the power system of Milos when the wind turbine is not installed. Thus, the impact of combining wind power and a desalination plant can be assessed. The operation of the desalination plant is considered the same with scenario 2. The production of the thermal power plant is significantly increased. The peak demand of the island is the same with scenarios 2 and 3, 10330kW, but the peak demand of the power plant production is slightly increased. Moreover, the fuel consumption, especially diesel and hence O&M cost, are significantly increased as Table 7-5 shows. However, part of the increase of the demand is met by the reduction of the wind power curtailment that now is 5.96%, the lowest of all the scenarios studied. Monthly details are provided in Deliverable D2.1 and in the comparative graphs of sub-section 7.1.5.

It should be noted that the reduction of wind power curtailment is 157.9MWh and the additional income for the owner of the existing wind power park on the island will be annually 13,358€. Therefore, if the owner of the existing park installs the desalination plant the energy cost for him would be 160,052€.

The owner of the desalination plant will be charged at B1B tariff scheme. The energy and the peak of the desalination plant are the same with scenario 2. The corresponding charge is provided in Table 7-3 under economic results column.

However, the additional cost for the operator of the system will be significant under this scenario. The cost would increase by 9.85% due to the fact that the most expensive units, diesel fueled units would be affected and increase their production. The fuel cost for this additional amount of energy required would have been 99.46€/MWh significantly higher than scenario 3 and a bit higher than scenario 2. Scenario 2 which has the same scheduling of the desalination unit but one additional wind turbine is by 126,801€ less expensive. Therefore, this is the value of adding one wind turbine for PPC to meet the additional demand caused by the wind turbine. If the desalination co-operates when determining its schedule with the wind turbine, scenario 3, the cost for PPC will be 169,191€ lower.

The value of the wind turbine production is 84.7€/MWh if the scenario 3 is applied and only 71.4€/MWh if scenario 2 is applied.

A detailed summary and comparison of all scenarios is provided in the following section.

7.1.5. Summary

The following tables and graphs summarize the impact on the fuel consumption, cost, and change in wind power production, curtailment and thermal power plant production for all the scenarios studied. First of all the impact per month in thermal power production and peak compared to the current situation are shown in Fig. 7.3 and Fig. 7.4, respectively. The increase in power plant production is higher in scenario 2 compared to scenario 3 mainly due to the reduced wind power curtailment.

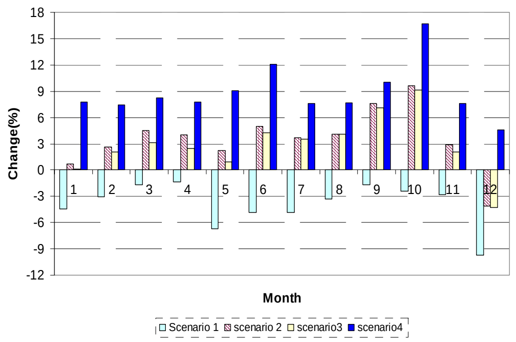


Fig. 7.3 Monthly change in power plant production-Milos

For scenario 1, there is not always reduction of the peak demand because wind power and load are not coincident. For some months, and fortunately for August, the peak demand is reduced. Both operating scenarios 2 and 4 increase monthly peak. Scenario 4 presents always higher peak than scenario 2 due to lack of the additional wind turbine.

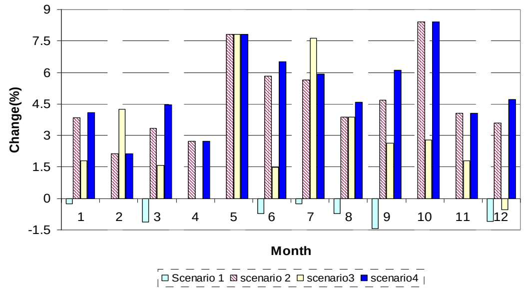


Fig. 7.4 Monthly change in peak of the power plant-Milos

Operation under scenario 3 manages to maintain the same peak demand for April and reduces the peak during December. Compared to scenarios 2 and 4, lower peak is maintained except of February and July

As a result of the change in thermal production, fuel consumption and thus the operating cost will be affected. As already discussed in the previous subsections, impact on units that consume mazout is rather limited as Fig. 7.5 shows. For winter months mazout consumption is reduced for scenario 1. For summer months the increase is due to the re-distribution of energy to the units that consume mazout due to shutting down for some periods one of the units that consume diesel. Very important is the change in diesel consumption shown in Fig. 7.6. For scenario 1, the diesel consumption is reduced for all months because of its cost.

For the rest scenarios, increase in thermal units production is noted for those units that consume diesel because the units that consume mazout, already operate almost at their technical maximum, before the units that consume diesel increase their production. Notable is the change during October when some of the base units are usually under scheduled maintenance and the increased required thermal production is met by units that consume diesel. Especially for Scenario 4, the consumption increase is 120%.

Change in fuel consumption leads to change in cost for fuel as Fig. 7.7 shows. For all months in scenario 4 the cost is decreased. There is strong correlation between diesel consumption change and operating cost as the results for scenario 4 show. Scenario 3 manages to reduce cost for December and January when wind power conditions are rather favorable.

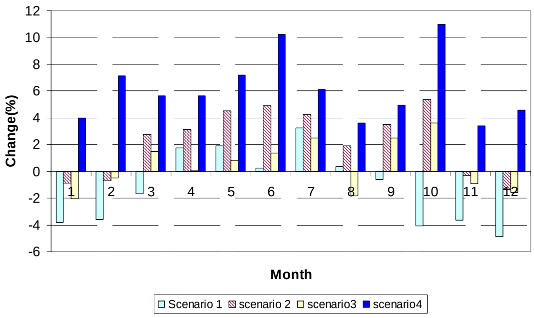


Fig. 7.5 Monthly change in mazout consumption Milos

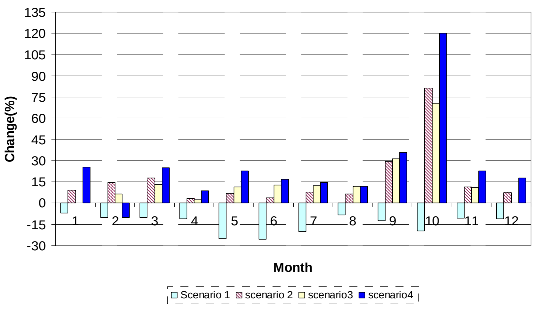


Fig. 7.6 Monthly change in diesel consumption-Milos

A comparison of the Wind power curtailment percentages per month is shown in Fig. 7.8. In all cases scenario 1 presents the highest wind power curtailment. For all months scenario 3 for the desalination plant helps so that the wind power curtailment percentage is lower than all the scenarios with the additional wind turbine. During some months, wind power curtailment percentage is lower than the current situation and especially for March scenario 3 presents the lowest wind power curtailment among the scenarios studied.

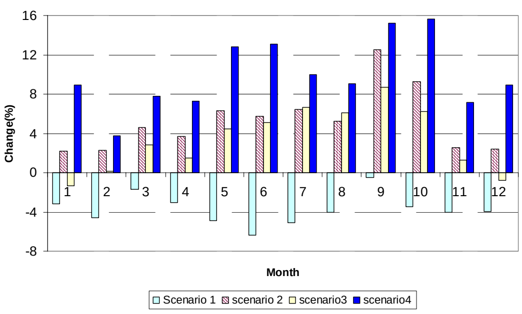


Fig. 7.7 Monthly change in fuels cost-Milos

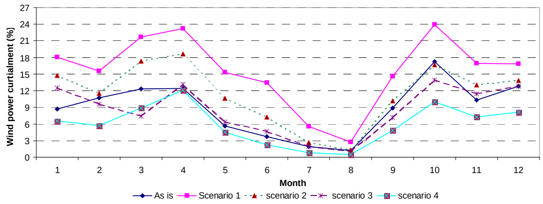


Fig. 7.8 Wind power curtailment per month for each scenario studied-Milos

High wind power curtailment impacts on the wind power penetration percentage especially during spring months as shown in Fig. 7.9.

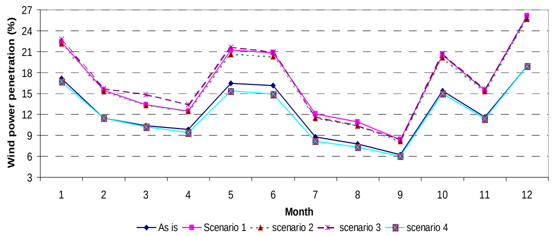


Fig. 7.9 Wind power penetration per month for each scenario studied-Milos

A summary of various indices for the power system of Milos is shown in Table 7-5 for quick evaluation. The percentage change for the various indices is shown in Fig. 7.9-Fig. 7.11. Fig. 7.10 focuses on RES and thermal plant production while Fig. 7.11 focuses on fuel consumption and cost.

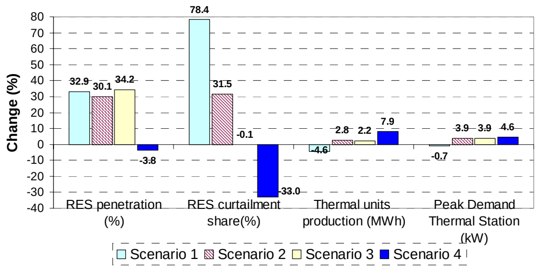


Fig. 7.10 Comparison of the various scenarios with current operation regarding RES and power plant consumption

Fig. 7.12 presents the change in the emission levels. It is notable that for scenario 3, although the thermal production is increased by 2.2%, CO_2 emissions are increased by 1.8%. Taking into account that the desalination plant increases by 6.8% the total demand of the island, wind power helps in mitigating the increased emissions for meeting this demand.

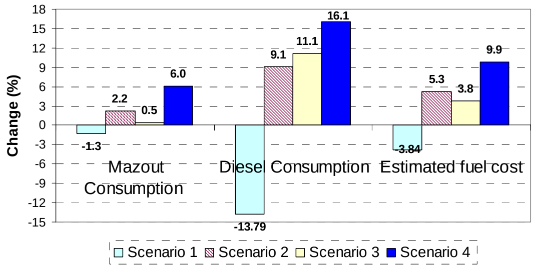


Fig. 7.11 Comparison of the various scenarios with current operation regarding fuel consumption and cost

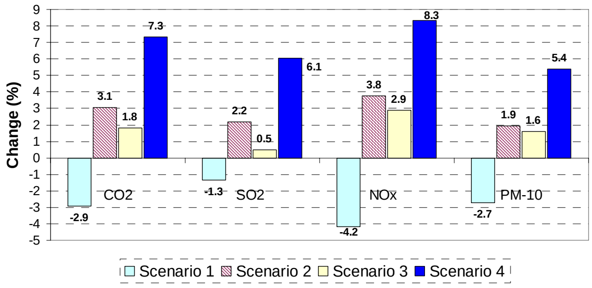


Fig. 7.12 Comparison of the various scenarios with current operation regarding emissions

Table 7-5 Comparative table of all the scenarios studied for Milos

	Current situation	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Demand (MWh)	39737.574	39737.574	42646.574	42641.574	42646.57
Peak Demand (kW)	9880	9880	10330	10330	10330
RES Production (MWh)	4887.6	6498.5	6821.4	7038.1	5045.5
RES penetration (%)	12.3	16.35	16	16.51	11.83
RES curtailment (MWh)	477.7	1226.6	903.7	687	319.8
RES curtailment share(%)	8.9	15.88	11.7	8.89	5.96
Thermal units production (MWh)	34849.974	33239.074	35825.174	35603.474	37601.07
Peak Thermal Station (kW)	9808	9737	10187	10187	10258
Mazout Consumption Tn	7395.2	7299	7556.7	7428.3	7841.5
Diesel Consumption (klt)	1437.2	1239	1567.8	1597.2	1668.9
CO_2 (tn)	27178.59	26386.155	28014.711	27675.714	29173.26
SO_2 (tn)	423.56	417.91	432.89	425.58	449.24
NO_x (tn)	143.31	137.35	148.7	147.45	155.26
Particulate (tn)	15.47	15.05	15.77	15.72	16.3
Estimated Fuel cost (k€)	2778.9	2672.2	2925.7	2883.3	3052.5
Estimated Fuel Cost of Energy (COE)-€ct/kWh	7.974	8.039	8.167	8.098	8.118

7.1.6. Conclusions

For the island of Milos the operation with and without the combination of an additional wind turbine with a desalination plant were studied.

Installation of an additional wind turbine will reduce the fuel consumption and hence both the emissions and the operating cost of the island. However, this will increase significantly the wind power curtailment on the island reducing the value of the investment on wind power compared to investing on wind on another island, with lower potential but without such problems. Especially if the investment on the wind turbine is made by another investor than the one owning the existing wind park, the wind power sales of the current owner of the wind park are significantly reduced.

Adding a load that can be controlled and whose product can be relatively easier stored than electricity, will significantly reduce wind power curtailment. Such a load is the desalination load. Thus the value of wind power on the island can be increased for all the stakeholders on the island. Moreover, in the scenario where the desalination plant schedule takes into account the wind power production estimations, the annual average wind power penetration is increased a bit compared to adding only a wind turbine with significant increase from 10% to 15% during Spring months.

If it assumed that neither the additional wind turbine, nor the desalination plant belong to the owner of the existing park, his income loss compared to adding a wind turbine only is mitigated. There will be zero impact in his income if the wind power estimations are used for providing the schedule of the desalination plant.

Under all circumstances, it is much more profitable for the owner of the thermal power plant to have co-operation of the wind turbine with the desalination plant in terms of scheduling its output according to the proposed algorithm. The value of the wind turbine when a desalination plant is to be added reaches 169,191€ contrary to 106,000€ with just adding a wind turbine without increasing Milos demand. Moreover, the additional emissions for the additional demand of the island are significantly lower compared to just adding a wind turbine and a desalination plant on the island.

A potential new investor on Milos island increases the wind power sales income if he also adds a desalination plant. However, co-operation of wind power and the desalination plant has higher operational cost for him taking into account the current tariff scheme on the island. The other stakeholders, existing wind park owner and the power plant owner have benefits which are higher and can cover this additional cost by simply reducing their benefits. The additional cost for the co-operation between the desalination plant and the wind turbine is the lowest if this potential investor is the owner of the existing wind park.

Adding only a desalination plant, increases by 6.8% the total demand of the island, and addition of wind power helps in mitigating the increased emissions for meeting this demand and reduce the cost of fuel on the island. The owner of the existing park, even if he is not the owner of the desalination plant will increase his sales because the demand will increase during these night hours but the wind power penetration will be generally reduced.

The Municipality of Milos with the addition of a desalination plants avoids transporting water to the island the water cost is well below 2€/m^3 a quarter of the transport price of 8€/m^3. Allowing installation of wind turbine instead of having the desalination plant running would decrease the additional emissions for meeting the water needs of both the locals and the visitors proving some little income from the increased wind power sales. The benefits and costs of the scenarios studied taking into account externalities such as social and environmental costs are explicitly discussed in the deliverable D 2.3.

Suming up

Desalination plant installation provides water at significantly lower prices (1/4th of the current cost) and if installed at the same period with RES under medium –high penetration reduces wind power curtailment with benefits to the owner of the existing wind park even if he does not make any additional investment.

Moreover, such an installation decreases significantly compared to no RES addition, the additional demand for the power system and thus, both the power system fuel cost and the emissions.

Co-operation of RES and desalination during the scheduling, according to the current tariff scheme for loads in MV in Greece may not be favorable but,

- The fuel cost for the operator of the island can be reduced.
- The company of the additional or existing wind park (depending on who invests) increase their profits.
- The operator of the island has more profit compared to the income loss of the desalination plant owner.
- The municipality meets the water demand at lower emission levels.

7.2. Case study 2 results-Mljet

Two main scenarios with various sub scenarios have been considered for Mljet Island

Scenario 1: Each one of the 3 existing desalination plants, installs RES to meet its own energy demand.

Scenario 2 : The Hotel Odisej, major energy and water consumption on the island couples RES with a desalination plant.

If for every desalination plant a RES unit is to be installed in order to meet at least the annual electricity demand, then the electricity demand from the upstream network would change. Two sub-scenarios have been considered one with wind and another with PV.

7.2.1. Scenario 1

The electricity demand for desalination for each of the existing plant is provided in Table 7-6. The total demand represents 2.86% of the island demand. Its maximum penetration reaches 4.2% during June.

Table 7-6 Electricity demand for each desalination plant on Mljet island(MWh)

Kozarica	*Sobra*	*Blato*	*Total*
12.54	*51.14*	*62.27*	*125.96*

7.2.1.1 Impact on energy balance

The wind turbine installed considered is a Fuhrlander 30 of 33kW installed capacity. Using HOMER software, the optimal size of PV plants to meet the demand of each desalination plant is derived as shown in Table 7-7. The total capacity is 95.12kW.

Table 7-7 Characteristics of the PV installations at each Desalination plant

	Blato	*Sobra*	*Kozarica*
Installed Capacity (kW)	44.9	40.8	9.42

The electricity demand for desalination plants after wind power installation is provided in Table 7-8. The net balance for PVs is marginally zero. For all desalination plants there is flow from mainland Croatia during August. The electricity balance for the whole island and the penetration level for the whole island and the eastern part only is provided in Table 7-9.

Table 7-8 Updated energy balance of desalination plants with wind power

	Energy Purchased (kWh)	*Energy Sold (kWh)*	*Net Purchases (kWh)*
Kozarica	5394	77,055	-71,661
Blato	31,941	59,072	-27,131
Sobra	29,657	62,154	-32,497

Table 7-9 RES production and penetration levels for Mljer

	Production(kWh)	*Penetration total island (%)*	*Penetration eastern part (%)*
Wind	262.07	5.95	13.15
PV	128.52	2.92	2.7

7.2.1.2 Impact on the Losses of the Network

Wind power on the island will be on its eastern part and thus the demand will be reduced on the eastern part of the island and thus the power flow, especially on the line Croatia-Zaglavac. The minimum impact on the losses will be if the wind power is installed at the end of the under sea cable, i.e. at Zaglavac busbar since the undersea cable losses will be reduced. Increase on the voltage of Zaglavac busbar will have some slight effect on reducing the losses on the rest of the eastern part of the island.

Assuming that the eastern and western part are running independently, then the only impact on the losses will be on the eastern part of the island. In such a case it was noted that for 0.29% of the year, i.e. 25 hours, there will be flow from Zaglavac to Croatia with maximum flow of 27.6 kW neglecting the losses.

The losses avoided amount to 6656kWh per year or 10.35% of the losses of the eastern part of the island or 7.53% of the total losses for meeting Mljet demand. The value is 67.2kWh/kW installed.

Solar energy

Since PV will be installed in both Eastern and western part of the island the losses in both parts of the island will be reduced. On the eastern part, the losses reduction is 3.4% of the corresponding losses, 2183kWh. The total losses avoidance in both parts of the island reach 3293kWh, 3.72% of the total losses of the island. 1108kWh are avoided on the western part, 4.6% of the total losses of this part of the island. The value of losses avoidance is 34.6kWh/kWp and in terms of produced energy 25.6kWh/MWh a little bit higher than wind.

7.2.2. Scenario 2

The average daily water consumption for this season is 100m^3. The annual water demand is estimated at about 22000m^3. Assuming energy efficiency of the desalination plant similar to the one of the existing desalination plants i.e. 4.4 kWh/m^3. This would increase both the hotel and the island (western part) demand by 96.8MWh and mainly during the summer months.

The assumptions followed for the allocation of water demand, to each hour of the day and for each month, even non working one, has been explicitly described in Deliverable D2.1.

For the scenarios simulated, the water tank has capacity of providing 3 successive days of water during August, i.e. 577m^3. The minimum content is assumed to be the amount of water to supply for one day the average demand of the current month. In this way, if there is a problem with the desalination plant, there is sufficient time to order water and reduce in the meantime the water consumption. In order to meet the water demand 3 identical units with energy consumption 19kW and production capacity 4.32m^3/h have been assumed.

First, the impact of installing desalination plant without RES is examined and then for various scenarios of installing RES to compensate for this increase in the demand.

7.2.2.1 Desalination without RES

Table 7-10 describes the summary of the results of the analysis of desalination without RES. The monthly energy consumption, the peak demand for the desalination plant are provided. The maximum and minimum level of the water within the tank is also provided. One 250m^3 tank would be sufficient for meeting the water demand. The utilization factor of the desalination units is relatively low, 43.7%, but for August reaches one unit operates for the whole month and 2 units for the 2/3 of the month.

The simulation starts with the season when there is not need for much potable water, November, in order to start from a season with low content of the storage tank.

Table 7-10 Summary of the demand and water production due to the desalination plant.

Number of Unit-Hours	*Peak number of units*	*Peak demand (kW)*	*Energy Consumption (kWh)*	*Water produced (m^3)*	*Min Content (m^3)*	*Max Content (m^3)*
5102	3	57	96938	22031.36	24	242.762

This desalination plant is going to have impact on both the energy and the peak demand of both the island and Hotel Odisej node as Table 7-11 shows. The total demand of the island increases by 2.2%. However, the maximum change in peak, is significantly lower than the peak demand of the desalination plant, less than 30kW. Moreover, 48.7% of the additional demand of the island due to desalination is distributed to off-peak hours. During the period October-April the demand is distributed only to hours 00.00-07.00 increasing the demand during valley hours.

Table 7-11 Impact on the Croatian power system due to desalination without RES

Island	
Peak (kW)	*Energy (MWh)*
1610	4499
Hotel Odisej	
Peak (kW)	*Energy (MWh)*
363	800.8

7.2.2.2 Desalination Combined with wind power

One Fuhlander 30 and one Tulippo 2.6kW wind turbine are assumed to be added to the network to compensate for the increase in the demand, providing 95.1MWh annually. The following scenarios of operation have been assumed :

a)There is just addition of a wind park and the desalination plant operates as described in sub-section 7.2.2.1.In this case the wind turbine produces energy provided to the network and the scheduling of the desalination unit is not affected. This is scenario Sce2aW

b)The desalination plant takes into account the estimation of wind power production for determining the number of desalination units to be used. the wind power production estimation is known to the operator of the desalination plant who tries to operate the plant according to the wind power production and the water demand. The scope is to produce water when larger production of RES is apparent, reducing the impact in the power system operation. Sce2bW

The water production for the case of independent operation is as described in Table 7-10. For the case of co-operation SC2bW, the water production summary is provided in Table 7-12.

Table 7-13 summarizes the impact of installing RES to meet the demand of the desalination plant. The annual additional demand is 1847kWh or just 0.04% of the annual demand. The Hotel peak is slightly decreased.

Wind power penetration in this case is 2.11%, while 98% of the desalination plant demand is met by wind power. However, the lack of coincidence between the desalination plant and the wind power production leads to the need of buying electricity from the grid

The water, energy consumption and number of operating units remain the same for the whole year and thus the impact on annual indices of the power system but there are monthly variations between these two scenarios.

During November, month with high wind power capacity and low water consumption, the combination of wind and desalination plant can lead to significantly increased water production which requires double tank capacity compared to the previous scenarios. Since the water consumption is low for the period January-February and the amount of excess water produced during November is significant, it is decided that the desalination plant does not operate for theses months. Thus, less personnel is required for that period. It is characteristic, that during November such an operation leads to positive energy balance, i.e. the demand of the island is always decreased, despite the fact that the total demand of the island is generally higher compared to the previous scenarios.

Moreover, the significant content in the water tank till April, helps so that the demand during May, when the wind power production is lower, is reduced by about 50%.

Details on changes in energy demand have been provided in Deliverable D2.1

Table 7-12 Summary of water and demand when W/T program helps in determining R/O plant schedule.

Number of Unit-Hours	*Peak number of units*	*Peak demand (kW)*	*Energy Consumption (kWh)*	*Water produced (m^3)*	*Max Content (m^3)*	*Min Content (m^3)*
5102	3	57	96938	22015.6	519	32

Table 7-13 Change in peak demand and energy due to Wind power and Desalination combination

Island		*Hotel Odisej*	
Peak (kW)	*Energy (kWh)*	*Peak*	*Energy (kWh)*
1610	4403.52	362	705.76

In Table 7-14 the characteristics of the change in the power imported from Croatia is provided. For around 50% of the time the energy demand from Croatia is reduced with some little differences on how often this happens. If desalination schedule is based on the wind power production, the periods for buying energy from the network are reduced by 5%. More important difference between the scenarios assumed is how often the change in the imported demand is within specific limits or confidence interval. Co-operation of the wind turbines with small desalination units manages the narrowest values of power balance. It is characteristic that for 80.53% of the time, the demand from Croatia mainland will change within the ± 20kW.

Both peak and energy demand are reduced for winter months and are increased for summer months. Wind power helps so that the losses are significantly reduced compared to the base case scenario of desalination without RES.

A summary of the annual change in losses in both actual and percentage form is provided in Table 7-15.

Although in all cases the total island demand is increased, the fact that the demand is increased in the western part and the production is increased on the eastern part, which generally presents higher losses, compensates for this change of island demand reducing losses.

Table 7-14 Statistical values of the balance of the Desalination &Wind combination

	Sc2aW	*Sc2bW*
Negative Values (Buying from network)	36.4%	31.9%
Zero balance	13.7%	16.6%
Positive Value (Selling to the grid)	49.9%	51.5%
Confidence interval 95%, [2.5%, 97.5%]	[-37.9,34.2]	[-36.3,33.7]
Frequency within [-20kW, 20kW]	72.9%	80.53%

Table 7-15 Change in losses for the scenarios studied with wind-Scenario 2

	No RES	*Sc2aW*	*Sc2bW*
Increase in Demand (kWh)	96938	1847	1875
Losses Change(kWh)	2024.83	-739.6	-657.6
Losses Percentage Change(%)	2.29	-0.84	-0.74

7.2.2.3 Desalination combined with PVs

73.9kWp PVs with expected production for the whole year is 99.3MWh are assummed to be intalled. The total demand from Croatia mainland is reduced by 0.06% compared to no desalination plant with RES penetration of 2.21%. The PV meets 12.4% of the total Hotel and desalination plant demand and 102.44% of the desalination plant demand.

The two sub-scenarios simulated follow the same notation with the case of wind power, Sce2aPV and Sce2bPv respectively. The water demand and energy consumption for the desalination plant for Sce2aPV is as described in Table 7-10 Table 7-16 presents the summary of operation for the desalination plant for Sc2bPV.

It should be noted that for SC2bPV, 18,250m^3 water are produced during peak hours of the day and that the peak demand of this operating scenario never exceeds 38kW. Moreover, significant amount of energy is bought during evening hours during which the electricity prices are lower, and no PV production is available.

Table 7-17 describes the impact of PV on the island power system.

Table 7-16 Summary of water and demand when PV estimation helps in determining R/O plant schedule.

Number of Unit-Hours	*Peak number of units*	*Peak demand (kW)*	*Energy Consumption (kWh)*	*Water produced (m^3)*	*Max Content (m^3)*	*Min Content (m^3)*
5169	3	57	98211	22304.2	519	35.8

Table 7-17 Change in peak demand and energy due to Scenario 2 combined with PV

	Island		*Hotel Odisej*	
	Peak (kW)	*Energy (MWh)*	*Peak (kW)*	*Energy (MWh)*
SC2aPV	1610	4399.46	360	701.54
SC2bPV	1590	4400.68	360	702.86

Table 7-18 presents a summary of the values obtained in the previous paragraphs. Combination of PVs and desalination plant can significantly increase the percentage of exchange with Croatia to be within ±20kW. This is due to the higher correlation of PV power and water demand and the more discrete nature of wind power compared to PVs. It should be noted that for 5.9% of the peak hours the power injected to the grid, rest of the hotel, is higher than 20kW, providing significant relief for the system during these hours.

Regarding network losses, Table 7-19 summarizes the change in the demand of the island and the change in the losses. The PV is placed near the load, next to it, actually, but the western part presents significantly lower losses compared to the eastern part. Thus, although the demand requested from the upstream network is generally reduced, the losses, a non-liner magnitude, are increased. Due to the increased water production for the case of co-operation of PV with the desalination plant, the losses are increased.

Table 7-18 Statistical values of the balance of the Desalination &PV combination

	Sc2aPV	*Sc2bPV*
Negative Values (Buying from network)	33.7%	26.1%
Zero balance	30%	42.1%
Positive Value (Selling to the grid)	36.3%	31.8%
Confidence interval 95%, [2.5%, 97.5%]	[-38,51.9]	[-22.7,42.6]
Frequency within [-20, 20]	74.5%	91.17

Table 7-19 Change in losses for the scenarios studied with PV

	No RES	*Sc2aPV*	*Sc2bPV*
Increase in Demand (kWh)	96938	-2480	-1090
Losses Change(kWh)	2024.83	736.09	808.37
Losses Percentage Change(%)	2.29	0.83	0.91

7.2.2.4 Sensitivity Analysis- PV for Scenario 2 on the Eastern Part of Mljet

Due to increased losses and the increased emission values compared to current situation although the flow from Croatia is reduced, an additional study for the PV of Scenario 2, 73.9kW installed on the eastern part of the island was made. Even if the whole capacity is installed at Zaglavac busbar, the one that can provide the lowest decrease on the losses of the undersea cable, the losses are decreased to reach 86.9MWh, the lowest among the configurations of scenario 2. The reduction of the cost for the DNO, even if the average cost for the Croatian power system (49.6€/MWh) is used can reach 193.59€, or 2€/MWh higher compared to installation of PV on the western part at the Hotel bus bar. This significant decrease on the losses, 2.27MWh compared to the scenarios with PV, and the time it takes place, helps in decreasing the emissions for meeting the updated Mljet demand by 1.6tn per year. However, this is not enough to provide finally total reductions on the emissions.

If the PVs are equally distributed to the main buses of the eastern part, the losses are further reduced by 573kWh, further reducing CO_2 emissions by 430kg and reducing cost by 28.42€.

7.2.3. Results Summary

Table 7-20 presents the results from the evaluation of scenario 1 where the current situation is compared with the addition of wind and PV. Fig. 7.14 provides a summary of the results for SCE2. Table 7-21 summarizes the results for the installation of a desalination plant for the Hotel Odissej, with and without RES, either wind or solar. **Fig. 7.13** presents the change in demand due to desalination with and without RES.

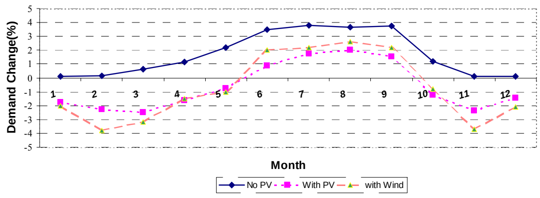


Fig. 7.13 Change in demand of the island from mainland with and without RES

Since, there are some differences in the water production, the CO_2 emissions level for each m^3 of desalinated water was used as an index of comparison as presented in Fig. 7.15. It should be noted that although the demand from the mainland power system is decreased, the emissions are increased. This is due to the fact that the demand for the desalination plant during the summer months, who present higher emission values, as Fig. 2.6 shows, cannot be met by the RES production. Thus, there is increase of the demand during high emission values and higher network losses and decrease of the demand during low emission values. Therefore, reduced demand from the upstream network cannot compensate for the increased emission values. However, the avoided emissions value of produced kWh for Scenario 2 especially when RES co-operate with the desalination schedule, is significantly higher as shown in Fig. 7.16. It should be noted that if no RES is to be installed but only the desalination plant, the increase in emissions will be significantly higher than the one shown in Fig. 7.16, reaching 816.7kg per MWh requested.

Table 7-20 Summary of the scenario 1 results

	Current situation	*Scenario 1-Wind*	*Scenario 1 PV*
Total Island Demand (MWh)	4401.92	4401.92	4401.92
RES Production (MWh)	0	262.07	128.52
RES penetration (%)	0	5.95	2.92
Imported energy to the island (kWh)	4401.92	4139.85	4273.4
Peak Imported (kW)	1580	1574	1576
Exported energy from the island (MWh)	0	357.3	0
Peak Exported	0	27.6	0
Losses (MWh)	88.44	81.78	85.14
CO_2 Avoided (tn)		200.8	99.6
NOx Avoided (kg)		365.41	176.9
SO_2 Avoided (kg)		1212.59	600.32
Particulate Avoided (kg)		97.64	48.8
Estimated O&M cost Avoidance (€)		11824.1	5800.08

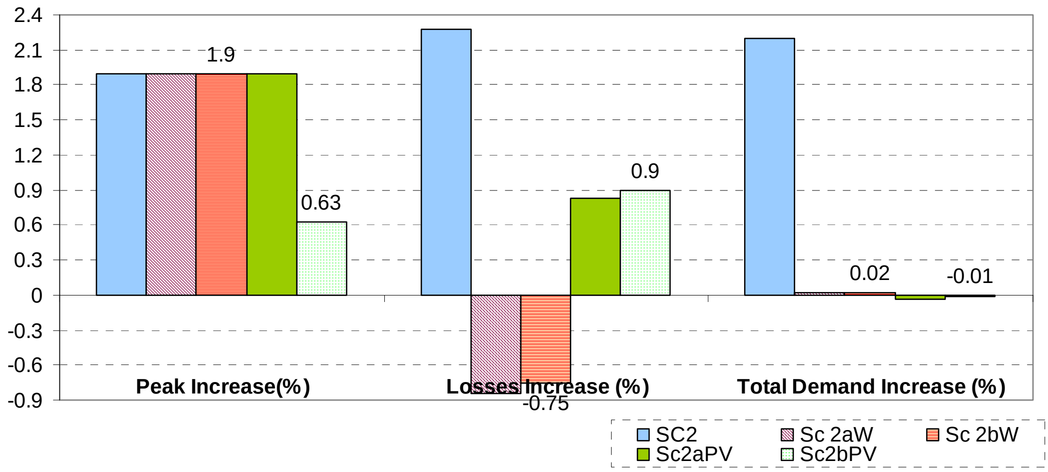


Fig. 7.14 Summary of the results for Scenario 2.

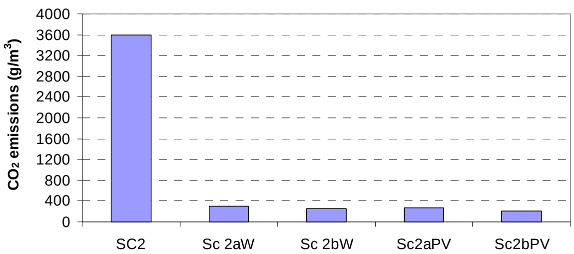


Fig. 7.15 Emissions comparison for the various configurations of Scenario 2-Croatia.

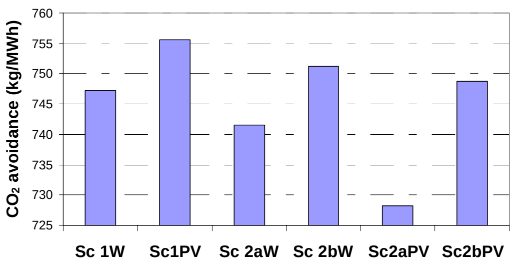


Fig. 7.16 CO_2 avoidance comparison due to RES production Both scenarios

Table 7-21 Summary of the scenario 2 results

	Current situation	*Scenario 2-NO RES*	*Wind*		*PV*	
			Scenario 2a	*Scenario 2b*	*Scenario 2a*	*Scenario 2b*
Total Island Demand (MWh)	4401.92	4498.858	4498.858	4498.858	4498.858	4500.131
RES Production (MWh)	0	0	95.1	95.1	99.3	99.3
RES penetration (%)	0	0	2.11	2.11	2.21	2.21
Imported energy to the island (MWh)	4401.92	4498.695	4403.518	4403.509	4399.46	4400.679
Peak Imported (kW)	1580	1610	1610	1610	1610	1590
Exported energy from the island (kWh)	0					
Losses (MWh)	88.44	90.46	87.7	87.78	89.17	89.24
CO_2 Avoided (tn)		-79.166	-6.544	-5.642	-5.958	-4.86
SO_2 Avoided (kg)		-140.956	-9.557	-5.837	-10.5	-5.209
NO_x Avoided (kg)		-550.116	-115.208	-105.921	-121.226	-102.065
Particulate Avoided (kg)		-44.161	-9.039	-8.533	-9.251	-8.133
Estimated O&M cost Avoidance (€)		-4900.23	-42.5568	-46.0784	85.808	21.8736

7.2.4. Conclusions

Addition of RES on the current configuration of the Mljet power system-Scenario 1 can help reducing both losses and emissions. For similar capacity however, 99kW of wind and 95kW of PV, the value of wind for the power system is significantly higher. This is due to much higher capacity ratio of the wind compared to the PV and the fact that wind must be installed on the eastern part that presents significantly higher losses. Generally, it is desirable for the Distribution Network Operator (DNO) of the mainland to have installations of RES on the eastern part of the island, as the sensitivity analysis for PVs has shown. Therefore, the pricing or the subsidies should be slightly higher on the eastern part due to this fact.

If the major consumer on the island, Hotel Odissej, is going to install a Desalination plant to meet their own water needs and no RES is foreseen, then the cost will increase but most importantly both network losses and emissions will be increased. Increase in emissions will be 816.7g/kWh due to increase of the demand during summer months.

Installation of RES will decrease both emissions and losses of the network. Especially for the wind power the losses will be lower than the losses of the grid currently, due to its installation on the eastern part of the island which presents much higher losses. In terms of network it is more desirable to install RES to compensate the increase in the demand on the eastern part and not on the consumption bus.

The highest benefit for the DNO comes if PV is installed without co-operation with the desalination plant in the scheduling of the module (Sc2aPV). The demand in such a case is increased during hours with rather low load and the production is increased during hours with high load, reducing in this way the emissions avoided. The decrease in the energy cost of producing water will reach 0.5€ct/m^{3}.

The lowest emission increase is for the co-operation of PV large desalination units-(Sc2bPV). In this case the CO_2 emissions is as low as 217.8g/m^3 of produced water, much lower than the 3.6kg/m^3 if no RES is to be installed.

Generally co-operation of RES with desalination plant decreases the emissions for each m^3 of produced water, compared to no co-operation. PV presents lower emissions than using wind power for each m^3 of produced water.

7.3. Case study 3 results- Cyprus

Here a different approach for the analysis of the impact of desalination is followed. It is examined what can be the impact of a Desalination plant on the island of Cyprus when it is partly utilized to reduce the wind power curtailment. It is assumed that for year 2005 the authorized wind power capacity of that period, 289MW is in operation. The fact that wind power should co-operate with steam turbine units leads, especially the periods of low demand, to significant wind power curtailment. The estimated amount of wind power curtailment is shown in Table 7-22. This amount of wind power curtailment, if it was possible to be utilized, would produce significant amount of water, as presented in the same table. However, wind power curtailment cannot be fully exploited because this necessity will exist for no more than 900 hours, and significant amount of power would be required to exploit the amount of wind. This would lead to extremely low utilization factor of a costly device like the Desalination RO plant. Therefore, a compromise should be made so that the same amount of water is produced by reasonable number of units with satisfactory utilization factor.

Table 7-22 Estimated wind power curtailment, water to be produced and constant number of units to operate

Months	*Estimated wind power curtailment(MWh)*	*Estimated water to be produced (m^3)*	*Desalination units operating for the whole month*
January	2007.4	446,088.9	2
February	2358.6	524,133.3	2
March	4402.2	978,266.7	5
April	5459.6	1,213,244.4	6
May	5233.4	1,162,977.8	6
June	2155.3	478,955.6	3
July	234.8	52,177.8	1
August	438.3	97,400	1
September	1444.8	321,066.7	2
October	3024.4	672,088.9	4
November	3680	817,777.8	5
December	3626.1	805,800	4
Total	34604	7,569,978	

The following scenarios have been simulated and compared for the whole year

Scenario 1: Business as usual (no addition of desalination)

Scenario 2: Use of 14 desalination units of 1 MW. These units would be able to produce water, using amount of energy equal to the expected wind power curtailment. For each month the number of units that could produce 75% of the monthly water demand was identified and decided to operate for the whole month while the rest would operate when wind power curtailment would be expected. The amount of units that could operate for the whole month for this scenario is shown in Table 7-22. For instance during March 5 units would operate during the whole month and the rest 9 for the hours when wind power is expected to be curtailed.

Scenario 3: Production of the annual quantity of water of Table 7-22 using 4 units all the time irrespective of the month.

Scenario 4: Production of water of Table 7-23 using constant number of units, updating the scheduling of the units every about 120 hours without increasing the number of operating units when curtailment takes place.

Scenario 5: Production of water of Table 7-23 using constant number of units, updating the scheduling of the units every about 120 hours but increasing the number of operating units to 7 when wind power curtailment is foreseen. Further explanation for scenarios 4 and 5 is provided in the following paragraphs.

7.3.1. Explanation of scenarios 4 & 5.

The reason for testing and analyzing scenarios 4 and 5 is the fact that significant amount of units are required for scenario 2 with low utilization. More specifically, 8 out of 14 units will operate only during the hours when wind power curtailment occur, about 900 hours. 6 units will operate continuously for additional 3 months.

Moreover, during summer period, when more potable water is required, the amount of water produced according to Table 7-22 is very low. To face these both disadvantages of scenario 2, it assumed that half of the annually water demand is distributed equally to all months and the rest is distributed proportionally to wind power curtailment as provided in Table 7-22. Thus, the amount of water to be produced and the number of desalination units required to produce it is provided in Table 7-23. Due to the fact that the units of Table 7-23 are not an integer number and the ability of increasing the number of operating units when curtailment is foreseen-Scenario 5, it is assumed that the water demand of Table 7-23 should be met with in one month and the schedule for the operating desalination units for each month is updated at the following time steps: [0 120 240 360 480 600 660] and submitted to the system operator. The initial number of operating desalination units is sufficient to meet 75% of the water demand to account for the expected wind power curtailment for the month that is considered a priori unknown for the simulation program developed. Then at each of the above time-steps, the number of the desalination units is calculated by (2), where *month_demand* is the monthly water demand according to Table 7-23, *curr_produced* is the water produced till the time of update, while the denominator expresses the number of hours remaining till the end of month.

Table 7-23 Suggested number of desalination units & water production per month

Months	*Number of units*	*Water produced (m^3)*
January	3.4	555,434
February	4	594,456
March	5	821,523
April	5.9	939,012
May	5.5	913,879
June	3.6	571,868
July	2.2	358,479
August	2.3	381,090
September	3.1	492,923
October	4.2	672,089
November	5.1	817,778
December	4.4	805,800
Total	***3.9***	***7,570,000***

Practically an average level of production is suggested for the best period. If there is any deviation, then in the next update this will be settled. For the last update, hour 660, formula (3) is used to ensure that the monthly water demand will be met. Any surplus of water produced is transferred to the next month at 50% till the end of the summer, and 75% for the rest of the months.

$$Des\_units = round\left(\frac{month\_demand - curr\_produced}{month\_hrs - hrs - passed}\right) \cdot 4.5 \cdot 1000 \qquad \textbf{(2)}$$

$$Des\_units = \left\lceil\left(\frac{month\_demand - curr\_produced}{month\_hrs - hrs - passed}\right) \cdot 4.5 \cdot 1000\right\rceil \qquad \textbf{(3)}$$

7.3.2. Results

In this section details on the wind power curtailment, the additional cost for EAC and the water produced are provided. Monthly details have been provided in Deliverable D2.1 while here a summary is provided.

Fig. 7.17 presents a comparison of the wind power curtailment for the various scenarios studied. The lowest wind power curtailment is achieved for scenario 2 and then for scenario 5. Constant operation of the desalination plant helps the least in avoiding wind power curtailment mainly in Spring. Inverse is the analogy for the RES share in meeting desalination load as Fig. 7.18 shows. Scenario 2 manages to maintain significant RES share for meeting the desalination load significantly higher than the average penetration of wind power on the island. In all scenarios RES share is decreased during summer months and is increased especially during November-December. Scenario 5 manages to maintain significantly higher RES share than scenarios 3 and 4. RES share in scenarios 3 and 4 however, is a benefit from increasing the demand since part of the otherwise curtailed wind power is now exploited.

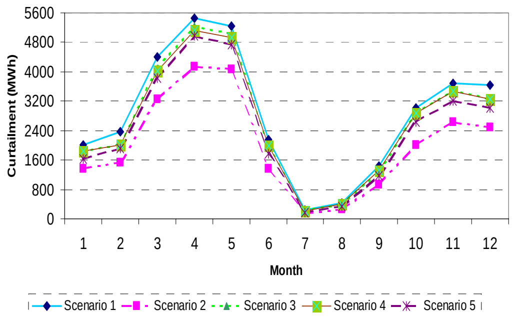


Fig. 7.17 Expected wind power curtailment for the scenarios studied-Cyprus

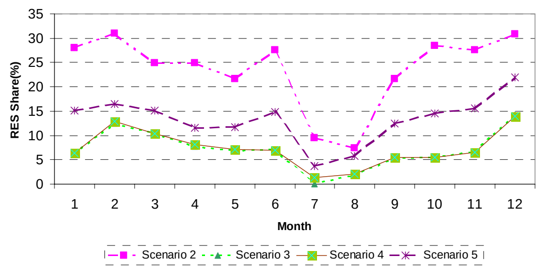


Fig. 7.18 RES share for Desalination under scenarios 2-5-Cyprus.

This affects the additional cost for EAC to meet the additional desalination load as Fig. 7.19 shows. Higher values of RES share reduce the additional cost since lower quantities of energy are required from the oil-fired units. Especially for scenario 2, there are months with lower than 10€/MWh for the additional production from EAC's units. The additional cost is in all the cases apart from July lower than 40€/MWh. Scenario 5 manages to maintain lower additional cost but always above 40€/MWh and below 56€/MWh. Generally, the additional fuel cost for all scenarios is lower than the average fuel cost, 60.42€/MWh for EAC without wind power, leading to slightly lower average cost of fuel compared to scenario 1

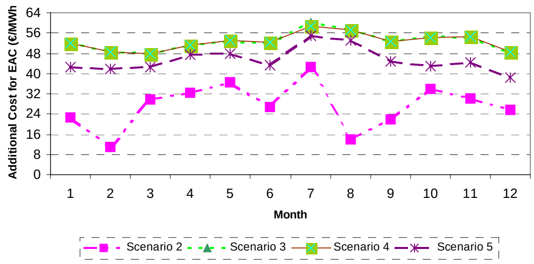


Fig. 7.19 Additional cost for EAC to meet the additional load-Cyprus.

Fig. 7.20 presents the monthly water production. Scenarios 4 and 5 present much smoother water production compared to scenario 2 reducing the need for size of the storage tank.

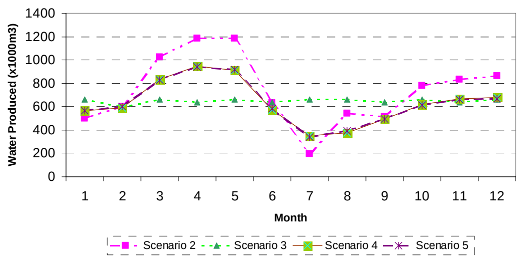


Fig. 7.20 Monthly water produced scenarios 2-5.

The duration curve of operation for the desalination plants is provided in Fig. 7.21. 4 units will operate for more than 50% of the year. The operating hours for the rest 3 units are drastically decreased and 6th or 7th unit is required for less than 20% of the time. Scenario 5 presents better utilization of units 6 and 7 compared to scenario 4, which requires for few periods of February-May 6 units operating, and only during April, the month with the highest wind power curtailment, the operation of the 7th units is required for 180 hours only.

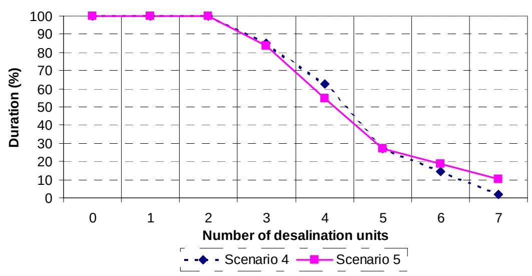


Fig. 7.21 Duration curve for the operation of the desalination units for scenarios 4 and 5.

A summary of the numerical results for the whole year is provided in Table 7-24
The change in the production of each type of the units and the impact in the fuels cost is provided in Fig. 7.23. The more expensive units are mostly influenced by the introduction of wind power on the island of Cyprus. Gas turbines and more expensive Moni power station units reduce their output significantly. Fig. 7.24 presents the increase in emissions due to the operation of the desalination plant. When wind power curtailment is exploited, the percentage increase is lower

Table 7-24 Summary for the scenarios studied for the whole year-Cyprus

	Shedding (MWh)	*Water produced (m^3)*	*Desalination load met by RES (%)*	*Wind power shedding reduction (MWh)*	*EAC additional cost (€/MWh)*	*Max Units Number*
Scenario 1	34066					
Scenario 2	24233	8,854,000	24.81	9,883	27.951	14
Scenario 3	31658	7,786,666	7.02	2,459	52.714	4
Scenario 4	31448	7,608,000	7.8	2,670	52.088	7
Scenario 5	29396	7,613,333	13.78	4,721	44.9	7

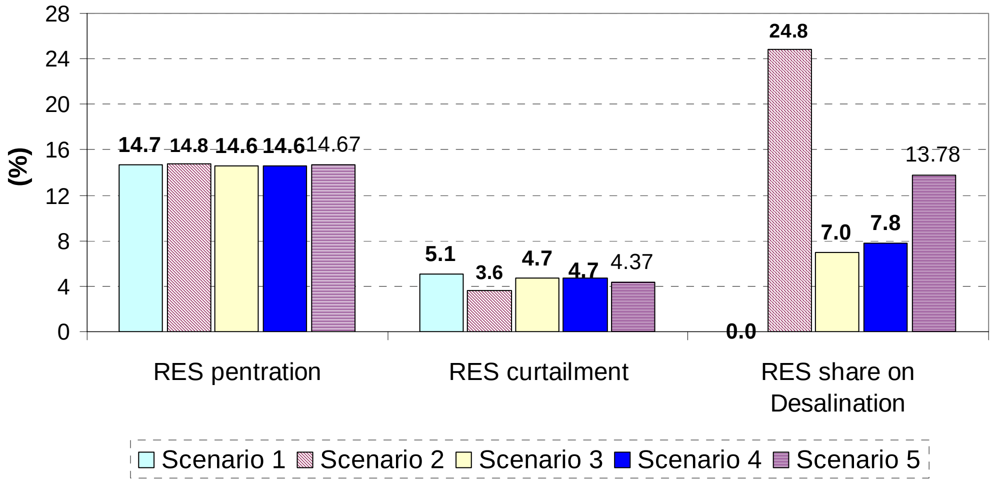


Fig. 7.22 Comparison of various scenarios regarding RES indices-Cyprus

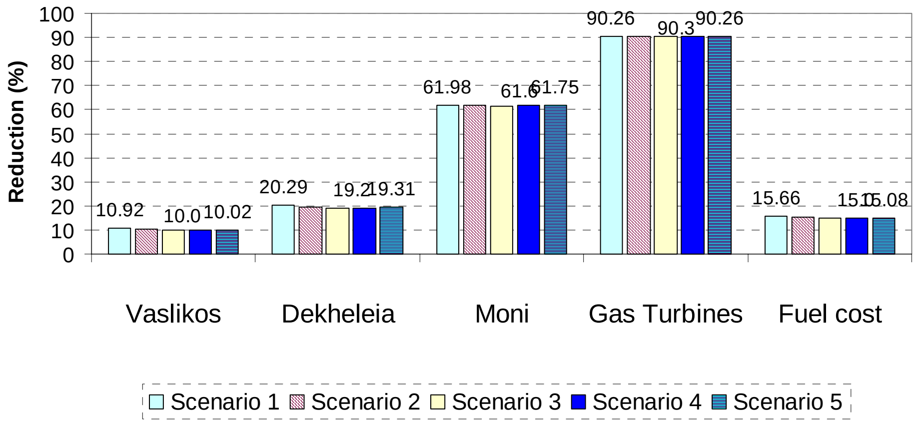


Fig. 7.23 Comparison of the various scenarios with current operation regarding change in production and cost-Cyprus

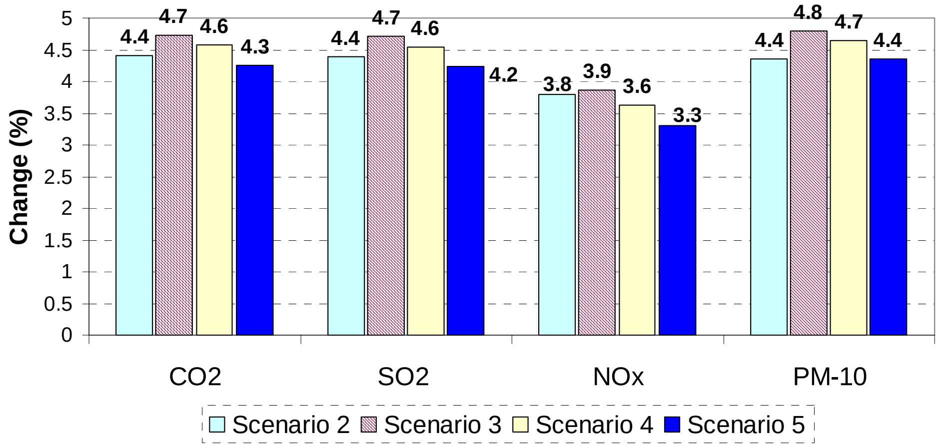


Fig. 7.24 Increase of emissions for the various scenarios compared to Scenario 1

The annual costs and benefits for various stakeholders regarding addition of the desalination system are provided in Table 7-25. The investors on wind parks would prefer the scenarios with least wind power curtailment to reduce the income loss. Both EAC and the municipalities would have benefits, since water is produced by lower impact on the operation of the local units reducing both operational costs and emissions.

However, the energy cost for the owner of the desalination units is higher for scenarios 2 and 5. This is mainly due to the fact that more units are required and the peak demand for these two scenarios is increased. The cost difference between scenario 4 and 5,which produce almost the same amount of water is mainly due to the peak charge which for scenario 5 is 103,000€.

Table 7-25 Impact of Desalination system for the various stakeholders in Cyprus

	Scenario 2	***Scenario 3***	***Scenario 4***	***Scenario 5***
W/T investors benefit (€)	621,625.1	152,229.6	165,505.4	295,229.2
EAC additional cost (€/MWh)	27.95	52.71	52.08	44.90
Desalination owners Energy cost (€)	4,622,667	3,774,960	3,653,045.04	3,754,940.4
Energy cost for water (€/m^3)	0.522	0.485	0.480	0.493
Cyprus municipalities CO_2 emissions(kg/m^3 water)	2.59	3.17	3.13	2.91

Table 7-26 Comparative table of all the scenarios studied for Cyprus

	Current situation	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*
Demand (MWh)	4354381	4354381	4394224	4389421	4388617	4388641
Peak Demand (MW)		849.9	850.9	853.9	851.9	851.9
RES Production (MWh)	0	639342.6	649175.6	641751.2	641961.2	644012.6
RES penetration (%)	0	14.68	14.77	14.62	14.63	14.67
RES curtailment (MWh)	0	34066.43	24233.46	31657.84	31447.83	29396.47
RES curtailment share(%)	0	5.06	3.6	4.7	4.67	4.37
Thermal units production (MWh)	4354381	3715038	3745049	3747670	3746656	3744629
Peak Thermal Station (MW)	849.9	841.47	842.47	845.47	843.47	843.47
Vasilikos units (MWh)	2939044	2641484	2658867	2661907	2661820	2661043
Dekheleia Units (MWh)	1262575	1015389	1027510	1027144	1026324	1025217
Moni steam Units (MWh)	151243	58016	58528	58469	58362	58219
Gas Turbines (MWh)	1520	148	142	148	148	148
CO_2 Avoided (tn)	00	520803	497861	496144	497027	498671
SO_2 Avoided (tn)	0	1082.9	1035.33	1031.8	1033.65	1037.07
NO_x Avoided (tn)	0	3688.735	3548.69	3546.49	3554.67	3566.98
Particulate Avoided (tn)	0	87.34521	83.5385	83.1624	83.2828	83.5373
Estimated Fuel cost (k€)	266132.483	224453.5	225567.1	226300.5	226236.8	225991.7
Estimated Fuel Cost of Energy (COE)- €ct/kWh	6.112	6.042	6.023	6.038	6.038	6.035

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7.3.3. Conclusions of the case studies -Cyprus

If Cyprus is to be operating under high RES, wind in this case, penetration, some of the produced energy 5.1% will be curtailed. This amount of energy is sufficient to provide 7.6 million m^3 from a desalination plant of average efficiency of 4.5kWh/m^3. However, the fact that the wind power curtailment takes place around 900 hours per year and the fact that the installed capacity should be high means that desalination plant cannot eliminate wind power curtailment. Thus, various scenarios of producing the same amount of water were studied under various levels of exploiting wind power curtailment information

If the amount of water produced followed the wind power curtailment pattern, and some of the desalination units were operating only to meet the requirement for additional demand during wind power curtailment hours, 14 units of 1MW would be required. Such an operation provides the maximum reduction for the wind power curtailment and the maximum percentage of RES production for the desalinated water among the studied scenarios. Thus, such an operation has the minimum impact for the EAC and the additional emissions. However, it increases the energy part of the water cost by about 8%. Moreover, 8 desalination units present very low capacity factor, around 10% which is prohibitive for further cost benefit analysis.

If the same amount of water was produced by constant number of operating units, then 4 units of 1 MW would be required. The increase in demand during hours when wind power curtailment takes place helps in reducing a bit the amount of wind power curtailment. The capacity factor of the operating units is very good, but the additional cost for the EAC and the emissions for producing water are the highest among the scenarios studied.

If the 50% of this amount of water was distributed according to the monthly variation of the wind power curtailment, then both wind power curtailment and cost for the EAC are decreased and so are the emissions for each m^3. However 7 units would be required, instead of 4, with 2 of them having capacity factor below 20%.

If the operation of the desalination units is updated every 120 hours but the operator of the island cannot make any suggestions for change according to wind power curtailment, the wind power curtailment avoidance is a result of the variation of the water production and not of actions of the operators themselves.On the other hand, if the same number of desalination units are installed and the operator of the island has the ability to give order for increasing water production when wind power curtailment is expected, decreases wind power curtailment by 6.52%. Moreover, the fuel cost for meeting the additional demand is significantly reduced by 13.7% while the additional emissions are reduced by 7%. The slight increase in the energy part of the water cost is due to the increased peak demand, which is however is during off-peak hours of the power system. This increase can be alleviated if all the rest stakeholders reduce a bit their benefits and provide some kind of subsidy to the owner of the desalination power plant.

Generally, the wind power penetration level remains at the same level, close to 15%. Taking into account the size of the island and the relatively low wind power curtailment, the desalination plant cannot increase wind power penetration drastically. In all cases studied the demand is met at lower average fuel cost than currently and the emissions are reduced. Increasing the demand during valley hours can help the power system in Cyprus reduce the wind power curtailment and maintain the significantly high technical minima of the operating units of the island. Therefore, motivation to the customers for increasing the demand during these hours, especially during spring should be provided additionally to installing desalination plants and give incentives to increase production during periods when wind power curtailment is expected.

7.4. Conclusions of the case studies analysed

All the case studies analyzed, Milos,Mljet and Cyprus share two common characteristics, scarcity of water resources and favourable or very favourable RES potential conditions. Adding solely a desalination plant in order to meet partly their water needs will increase the electricity demand of the island, the fuel cost and the emissions levels of the upstream network even at higher percentage level than the demand, such as the case of Milos. Installing RES will decrease this effect and the local people will have potable water at significantly lower emission levels.

For two of the islands however, Milos and Cyprus, if only additional wind power is to be installed, significant amount of wind power should be curtailed due to difficulties in co-operation with the local grid thus reducing the value of wind power on these islands. Even worse for Milos, if the additional wind turbine considered to be installed belongs to a stakeholder other than the owner of the existing wind park, the latter will face significant income loss. Therefore, RES development even for medium wind power penetration on islands requires a storage method, or at least a demand management method for loads of significant demand such as the desalination plants.

Taking this fact into account, ways of co-operation between RES and desalination have been examined for all the islands studied and especially for the above mentioned two islands as a means of alleviating wind power curtailment.

For the islands that may face problems with RES curtailment, even the simple addition of the desalination plant without any control strategy for exploiting the excess wind power production, would decrease curtailed RES production. RES curtailed can be even more reduced if a strategy for taking into account RES production or RES curtailment when scheduling the desalination plant is taken into account. For the case of Milos wind power estimations are used for the desalination plant scheduling, increasing wind power penetration slightly higher compared to wind power addition only. Thus, the economic and operational impact on the power system for the increased demand due to the desalination plant is limited. At the same time, water to the municipality is provided at significantly lower costs compared to the transportation price from mainland. RES penetration in such a case may remain practically the same but the absorbed wind power increases significantly, providing additional income to the potential private RES investors.

For the case of Cyprus, when the TSO is given the permission to ask for increasing water production by the desalination power plant, the impact on the power system of Cyprus is lower compared to the case of the same number of desalination units operating only with production pattern that partially follows the expected monthly wind power curtailment.

In both cases however, the operating cost for the owner of the combination desalination plant and wind power according to the tariff schemes on these islands is higher when these two plants co-operate closely compared to considering these two installations running completely independent. The financing benefits for the rest stakeholders on the island, such as power plant operators, independent wind power investors and the municipalities seem sufficient to finance this shift of more active co-operation of the desalination plant and RES. The externalities for the cost of energy and the cost benefit analysis performed are the subject of Deliverable D2.3

Finally, for the Croatian island, due to its small size, the interconnection with mainland and the relatively low RES capacity considered, the impact of combination of RES and desalination plant is more limited. However, the benefits by simply adding RES can be significant compared to operation of desalination plant only, especially if wind power is installed on the eastern part of the island. In such networks, where RES curtailment is not an issue, the desalination addition will not provide any other significant impact other than meeting the local water needs. Moreover, relatively limited wind power exploitation with rather small wind turbines strategically placed in the network grid and taking into account environmental constraints can help significantly the Croatian island networks. The results have shown that the value in terms of emissions avoided per installed kW is higher for wind than for PV due to higher capacity factor of this technology. Therefore, a total ban of installing wind parks on Croatian islands should start being revised into a more flexible framework which takes into account the fragile environment of these islands.

8. GENERAL SYNOPSIS

The provided results in Deliverable D2.1 shortly presented here and in more detail in the corrsponding document have focused on the impact that the combination of RES and storage means can have on the operation of an island power system mainly in terms of system economics and emissions. Further analysis on the results of the cost benefit analysis for the society as well, is provided by the Deliverable D2.3 and in the summaries per technology documents.

For the case of batteries, two islands have been studied assumed that they operate without their interconnections to other islands. Thus, the optimum configuration of the proposed power system with as high as possible wind power penetration was identified. For both islands, La Graciosa and San Pietro, scenarios that lead to 80% RES penetration were simulated. The cost for La Graciosa is significantly lower due to its smaller size, and the higher correlation between load and RES especially during the periods of high demand compared to San Pietro. For levels of penetration above this percent, the excess electricity is geometrically increased as well as the installation cost. Unless other methods of exploiting excess energy are exploited, such as hydrogen used for transportation or desalination for potable water, RES penetration cannot be further economically increased for the cases studied. A scenario with lower RES penetration target, e.g. 50% for La Graciosa will provide lower benefits for the grid in the emissions levels and fuel consumption, but with significantly lower excess energy. Such a configuration can be used a first step in introducing RES on this Spanish island and during the construction phase to consider ways of exploiting additional excess electricity and apply demand side measures for smoothening the peak of the island. Then the additional works than can lead to much higher penetration, always considering storage, can be constructed increasing the expected benefits.

Pump hydro is an interesting option for larger scale applications of energy storage, wherever the morphology of the island can help. The case studies of Ios, Cyprus and Corvo have covered all the range of demand and various levels of wind power potential. In all of these cases Pump hydro storage can help in increasing significantly the wind power penetration on these islands. Especially for Corvo, with very favourable RES conditions and good correlation with the load, penetration level of 100% can be easily achieved reducing the operating cost to ½ of the current operating cost.

Pump hydro storage can help in even rather moderate wind power conditions such as Cyprus to increase wind –power penetration and provide a viable solution for wind power development even in such cases. Finally even if any of these islands are interconnected to greater networks, like the case of Ios, the pump hydro will provide significant aid to the weakly interconnected area without decreasing the value of the hybrid plant created. In the meantime, a WHPS (wind hydro power station) can help in further exploitation of the wind potential with significant fuel avoidance.

A general conclusion that may be drawn from both case studies simulated with hydrogen energy storage is that hydrogen may complement renewable energy sources as it has the potential to tackle their intermittent nature and thus to assist in achieving high level RE penetration. The combination and introduction of wind energy and hydrogen storage into the power system of Milos and Corvo showed that the reduction of fossil fuel dependency, the enhancement of security of supply and the decrease of the production of harmful emissions associated by fossil fuel consumption are feasible and can be achieved at a lower than the current power generation cost, more specifically it results in :

- decrease in the power generation cost of the island (ca. 1% for Milos 43% for Corvo)
- a huge increase on RE penetration on the island (from 13.4-84% for Milos and from 0% to 80% for Corvo
- a significant reduction in emissions produced (especially CO_2) (63- 69%)
- a significant reduction in diesel fuel consumption (from 288,051 L/year to 89,009 L/year) (ca 64%-69%)

For Milos, the thermal units capacity can be also reduced. In none of the cases the impact of using hydrogen as a means of transportation has been studied. The excess electricity could help in producing more hydrogen for this purpose. The results become more favourable as the cost of hydrogen infrastructure decreases.

Desalination may not be a direct storage method but can incorporate storage in the form of potable water. It can provide significant aid in managing RES providing also a valuable good for the inhabitants and visitors of the islands. The islands selected have scarcity of water and either have or are about to install desalination plants.

The results from the applications show that RES can mitigate the demand in increase of the islands due to the desalination plants and thus the associated emissions and fuel cost for the power system. This mitigation can be even higher if the schedule of the desalination plant is based on RES estimations or RES curtailment estimations, with significant benefits for both the power system and the owners of the RES installations on the islands.

Simultaneously, it was identified that in the vast majority of the scenarios simulated, the water demand was met at lower emission level when both desalination and RES are installed compared to the current practice of transporting water and simply adding RES. Thus, environmental benefits are achieved especially when desalination plant schedule is based on RES production or even curtailment estimations.

More specifically for Milos and Cyprus if RES only are installed, wind in specific, for penetration levels around 14-16% there will be significant wind power curtailment 5.1% for Cyprus and 15.9% for Milos. This can be reduced by adding desalination plant down to 4.7% and 11.7% respectively. If there is co-operation in the schedule of the desalination plant and the wind power estimations or curtailment, wind power curtailment is reduced to 4.37% and 8.89% respectively. Wind power penetration remains practically the same within ±0.5%, due to increase in demand but the wind power that can be absorbed is significantly higher. Thus both wind park owners and the power system operator can have sufficient benefits to provide also benefits to the owners of the desalination plants who may be affected by the existing tariffs and the proposed operation prectice. These benefits are higher if some of the wind park owners decide to build the desalination plant.

For Mljet, the impact is not as high due to no problems of RES curtailment and relatively lower penetration. Strategic placement of RES can help in reducing losses for the energy transported to the island from the mainland.

Thus desalination cannot only provide a method for meeting the water demand of population with limited access to potable water but also for islands with RES curtailment can help with appropriate management to reduce the amount of RES energy curtailed.

The key findings of Deliverables D2.1 are:

- in order to achieve significant penetration of RES on an island system, energy storage or demand management methods or even combination of them is required. Utilizing energy storage will maximize the value of RES for the island, decrease fuel dependency and reduce emissions. At the same time, storage devices can help in achieving higher capacity factor for RES installations for the same potential.

- energy storage is a vital component for managing grid issues in Autonomous power system when high RES penetration is considered and efforts in eliminating barriers to installing storage in such networks should be intensified.

9. REFERENCES

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