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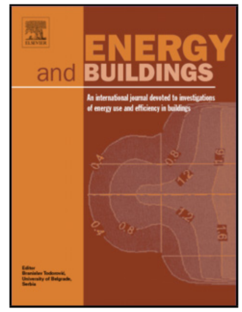

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Wind Energy to Thermal and Cold Storage – A Systems Approach

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Abstract

In this paper wind energy to thermal and cold storage scenarios were examined to enable high wind integration through converting renewable electricity excess into thermal or cooling energy, saving part of the energy used in an area and eliminating the need to possibly build a new coal fired plant. Case studies in Crete Island (not interconnected to the power grid of Greek mainland) with onshore wind power installed were investigated. The aim of this work was to review the options for greater integration of renewables into the grid and the main idea was to analyze the wind to thermal and to cold storage according to the needs of two small municipalities.

Keywords: Thermal Storage; Cold Storage; Wind Farms

1. Introduction

The majority of traditional electricity grids are not designed to comply with continually changing technical requirements or increasing demand. That is why a lot more research and development is required in smart grids and a more holistic approach is needed to be followed and to be soon put into practice. This approach

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intents to incorporate the electricity grid together with the district heating an cooling (DHC) grid aiming ultimately in increasing the efficiency of a power grid, to save energy and improve renewable energy penetration to the grid on a short term basis. How can this be done? By building a heat and a cold storage tank is the obvious answer. This way, the flexibility of production facilities will be increased (e.g. electricity can be produced when prices at market are high, and heat demand is low). It will also be possible to produce heat during nighttime when heat demand is significantly lower than in the day.

Many researchers have studied similar systems for the integration of renewable energy sources into the grid. Some publications were focused on storage devices used in the energy system. Zukowski [1; 2] presented a short term thermal energy storage (TES) unit (with paraffin wax (RT-56) as heat storage medium) which was tested experimentally and was mathematically modeled. Parameshwaran *et al.* [3] reviewed the energy efficiency of thermal energy systems (TES) systems dedicated to cover building heating, cooling and air conditioning (A/C) needs. Nielsen and Möller [4] examined how excess heat production from influences different types of DHC systems in Denmark, while Li and Svendsen [5] did an exergy analysis of low temperature district heating network. Fitzgerald *et al.* [6] examined the potentials for improving the power system efficiency integrating wind power using intelligent electric water heating. Water heating has been proposed as a possible solution from industry for utilizing the surplus of renewable energy as stored thermal energy. The applied market-based approach of this idea was used to benefit end-users lower their electricity bills by consuming and by storing electrical energy to heat when the price signal was low and by using the stored heated water when the price was high [7-8].

Several studies have shown that water heating using storage tanks can account up to 30% of residential electricity consumption [9-11]. Bitterlin [12] tried as a solution the combination of wind and PV power generation and an energy storage system – a battery with a diesel engine – for remote applications. The proposed storage solution proved that the battery will minimize the start/run demand on the diesel generator, minimizing as well the required battery storage capacity.

Another way, not widely used so far, for short term storage in small scale energy is cold storage. Excess of renewable energy could be stored as cold storage increasing the flexibility of the system (e.g. produced electricity can be sent to cold storage tanks when prices at market are low or when there are to be curtailed). Existing cold storing facilities for frozen products will utilize excess of wind energy the products stored will be cooled further below their usual temperature. Therefore when there is electricity shortage or the electricity prices are high, the refrigerating machines are then switched off and the cold storage will be "discharged" reaching reach the initial storage temperature without consuming at high prices or when there is no electricity for some reason. Few researchers are adherent on this topic. Blarke et al. [13] analyzed a smart grid concept for heating and cooling to buildings that gain from renewables in the energy system. Loisel et al. [14] proved that heat and cold storage is a very important option in avoiding grid congestion and wind curtailment. Night Wind project [15] was focused on simulations of this idea as well.

What was studied in this paper was how the curtailed wind energy can contribute to the system, saving some of the wasted energy. It was investigated how to improve of wind integration and create savings reducing peak demand providing balancing loads to help in the integration of variable wind energy.

2. Methodology

Two wind farms in Crete Island were chosen and data were examined for the wind farms (WFs) for ten years (years: 2000 – 2010). The first one (WF1), of capacity is 9.9 MW, is located near Chandras village, municipality of Ag. Varvara. The second one (WF2), of 4.95 MW, is located in Heraklion prefecture, close to Megali Vrysi village municipality of Lefki. Both are fully operational power plants since 2000.

Fig. 1. Location of the two wind farms in Crete Island

During the ten-year operation of the two wind farms the effected curtailment of the wind farms can be seen in figure 2.

Fig. 2. Effected curtailment of the two wind farms for the years 2000 - 2010

The effected energy curtailment from the Public Power Corporation (PPC) is significantly lower during the summer months and this is happening because of the touristic season. The increased population of the island during summer and therefore of the seasonal energy demand from June to September minimizes the wind curtailment levels. However, in total the effected wind curtailment accounts approximately up to 2.8 GWh for WF1 and 1.4 GWh for WF2 (table 1)

What the modern smart electricity system requires is these amounts of wasted energy to be used instead of the current curtailment option. The most economical way of utilization is to use the existing facilities. For instance, Thermosiphons – which are installed in more or less every house/apartment in Greece can utilize part of this energy to maintain the temperature of the water high enough as needed at all times. For solar assisted thermosiphons, which are more common, the energy needed will be much less, but for thermosiphons that work on electricity, it will bring about significant cost savings. Space heating is another option. Instead of burning oil to heat up water and use it in the radiator in a building the "to-be-curtailed" energy can be used for that purpose. Other existing facilities that can be used are cold storage facilities. Existing – industrial mainly but also residential – freezers can be exploited with a basic aim to store part of the electricity to-be-curtailed and release this energy during daytime peak hours. When there is available electricity produced, the temperature in the cold store may drop and the products can be further cooled down and the energy supplied can be transformed into thermal energy (lower product temperatures). When there is need for delivering energy back to the system, the temperature of the products can be risen "producing" and offering cheaper electricity back to the system (since it was stored when there was excess of energy).

3. Case Study in Crete Island

3.1 Cold Storage

The need to widely cut down costs in achieving a sustainable model of integration of renewable energy sources into the Greek system, forces local energy policy makers to support and decide on the improvement of the utilization scheme of household appliances. Under this perspective, residential freezers can be used to balance and further exploit wind energy. The aim of this paper was to describe in terms of wind curtailment avoidance the idea of a system with a number of cold stores connected to it, in order the wind power to be "stored" in the residential cold stores aiming at maximizing the benefit to the electrical network, utility or cold store owner.

Based on [16] and assuming average temperatures of the freezer at -18°C and a room with ambient temperature of approx. 24°C using a Carnot cycle in the freezer there is:

$$COP = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L} = \frac{273.15 - 24}{24 - (-18)} = 5.93\,, \tag{1}$$

where *COP* is the coefficient of performance, Q_L the heat transfer from the low temperature body, Q_H the heat transfer from the low temperature body, T_H the temperature from the high temperature body and T_L the temperature from the low temperature body. The equation below shows the relationship between volume, *V*, annual energy consumption, *AEC* for residential freezers and the Energy Factor, *EF* from the DOE test procedure (m^3·day/kWh). U.S. manufacturers are required by law to provide the *EF* for all products [18].

$$AEC = \frac{365 \times V \times 1.73}{EF}\,, \tag{2}$$

where 365 the days of the year and 1.73 the coefficient which multiplied by the freezer volume gives the freezers adjusted volume according to DOE [17]. As it is not known when most consumers have bought their refrigerators/freezers a weighted *EF* based on an average year that the freezer was purchased was taken (e.g. year 1995).

Assuming on average a 0.45 m^3 (15.89 cubic feet) freezer size per household and EF equal to 16.57 [17], the AEC is:

$$AEC \; ! \; \frac{365 \, !15.89 \, !1.73}{16.57} \; ! \; 605.5 \text{ KWh} \;, \tag{3}$$

which calculates the energy consumed per day, *E*, approximately 1.66 KWh on average (*AEC* divided by 365 days). Therefore from (1) and (3) it is obvious that the theoretical minimum power input to operate a freezer during the year can be calculated as:

$$W \; ! \; COP \; ! \; \frac{Q_L}{COP} \; ! \; \frac{\frac{AEC}{8760}}{COP} \; ! \; \frac{605.5}{8760 \; !5.93} \; ! \; 11.65 \text{ Watt} \;, \tag{4}$$

Based on a series of experiments implemented on upright freezers [19] and based on the forumal of Masjuki et al. [20] it was calculated the energy consumed for lowering the temperature of the freezer form -15 °C to almost -21°C. According to [20] for *E* there is:

$$E \; ! \; !512.8 \, ! \; 6.5 \, ! DO \; ! \; 34.4 \, ! Tr \; ! \; 129.7 \, ! TS \; ! \; 62.5 \, ! L \; ! \; 0.7 \, ! RH \;, \tag{5}$$

where *DO* is the times the freezer door is open during the day, *Tr* is the room temperature (in °C), *TS* is the thermostat setting position for the freezer, *L* the food quantity inside the freezer (in kg) and *RH* the relative humidity of the house environment (%). Assuming DO=5, Tr=24°C, L=5 kg and RH=50%, by varying the TS temperature is can be observed a significant difference in the energy consumed per day (table 2). It was proven also from [20] that the energy consumption increased about 10% for each degree decrease in temperature.

What can be observed from figure 2 is that between months June to September the average PPC curtailment is significantly lower compared to the other 8 months. Therefore, if it is assumed that this could happen (lowering the temperature of the freezer from -15 to -22 °C) only once within the day for these 8 months (240 days) and only from -15 to -19 °C during the “summer” months (June – September: 120 days) then the yearly energy gain will be per freezer:

$$E = \Delta E_1 \times 240 + \Delta E_2 \times 120 = (E_{(-22)} - E_{(-15)}) \times 240 + (E_{(-19)} - E_{(-15)}) \times 120 = [(2.2 - 1.29) \times 240 + (1.81 - 1.29) \times 120] KWh/yr = (218.4 + 62.4) \text{ kWh/yr} \approx 280.8 \text{ kWh}_e\text{/yr} \quad (6)$$

3.2 Thermal Energy Storage

A typical residence was assumed, located in the area. A boiler-room was considered to be located in the basement in order to minimize thermal losses. For this study the following assumptions were made:

- Floor surface: 90 m^2, total exterior surface of the building, *F*: 294 m^2, volume of the building *V*: 718.4 m^3, Ratio F/V: 0.41 m^{-1}, heat transfer coefficient K_m: 0.393 kcal/m ²h°C, distance from the floor to the roof: 3 m

The hot water leaves the boiler, and is distributed through six separate pipes, directly from the boiler with six additional pipes for cold water for the return. The pipes are made from plastic and the radiators from steel, with an output of 530 KJ/m^2.

The typical boiler assumed here, it uses diesel oil with heating value of 10,200 kcal/kg. The basic boiler characteristics [21] are:

- Type: Diesel Oil Boiler Kiturami 30S, Thermal potential: 25,500 – 40,250 kcal/h, nominal power: 30000 kcal/h, boiler efficiency: 90,346%, fuel supply: 3.2 kg/h, electric Power: 130 W, λ: 1.15

The annual period of the heating system operation for Creta Island was considered to be from November till March (154 days). The building losses taken into account are the building shell thermal conductivity losses, Q_1, and the ventilation losses Q_2.

$$Q_1 = K_m \cdot F \cdot \Delta T \quad , \tag{7}$$

Assuming room temperature, *Tr*, 24°C and taken into account from data from the Hellenic National Meteorological Service that the medium temperature of the region during the months of November to March is 12°C [22], then ΔT equals 12°C. Also, according to DIN 4701/77 guidelines an increasing 7% of losses is assumed due to interrupted operation and therefore for Q_1 there is:

$$Q_1 = (1 + 0.07) \cdot K_m \cdot F \cdot \Delta T = 1.07 \cdot 1{,}386.5 \text{ kcal/h} = 1{,}483.6 \text{ kcal/h} \quad , \tag{8}$$

For the ventilation losses Q_2 there is:

$$\begin{aligned} Q_2 &= \dot{m} \cdot c_p \cdot \Delta T = \rho \cdot \dot{V} \cdot c_p \cdot \Delta T = \rho \cdot n \cdot V \cdot c_p \cdot \Delta T = \\ &= 1.2 \cdot 0.25 \cdot (90 \cdot 3) \cdot (1005 \cdot 0.239) \cdot 12\, kcal/h = 233.4 \text{ kcal/h} \end{aligned} \quad , \tag{9}$$

where *N* the rhythm of air renewal change per hour (N=0.25), *V* the volume of internal space ($90m^2$ times 3, which is the height), c_p the specific heat capacity of air - 1.005 kJ/kg ^oC, and 0.239 the factor to convert KJ to kcal.

Assuming roughly that the internal thermal gains of the building and the solar heat gain accounts are significant and account 50% of the building envelope [23-25], the total losses Q_{tot} are given from:

$$Q_{tot} \; ! \; \{(Q_1 \; ! \; Q_2) ! 24 ! 154\} ! 0.5 \; ! \; \{(1{,}483.6 \; ! \; 233.4) ! 3{,}696 ! 0.5\} \, kcal / yr \; ! \\ ! \; 0.5 ! 6{,}346{,}309 \text{ kcal/yr} \; ! \; 3173154.5 \text{ kcal/yr} \quad , (10)$$

and if we assume that the heating system operates in nominal power 30.000 kcal/h that means that the system works approximately for 106 hours during the year. And if kilocalories are converted to kWh within the year then this is approximately 3,689.7kWh_{th}/yr per residential heating system.

4. Results and Discussion

A conventional freezer and a conventional heating system both have a thermostatic control. The idea is not to replace these control systems but to generate set points for the existing controller so that curtailed wind energy can be used in the most appropriate way e.g. stored firstly in the freezer (virtual battery) and secondly initiating the boiler in order hot water to be produced for space heating.

By installing smart meters in all freezers and heating boilers of the area the PPC commanded curtailment can be used.

The population of the municipality of Ag. Varvara is 5,310 and the municipality of Lefki is 2,177. Assuming 4 persons on average per family, the number of households is 1327.50 and 544.25 respectively. Based on the cold and thermal energy storage results the optimal utilization solution is:

- 372.76 MWh/yr for the freezers of Ag. Varvara municipality
- 152.83 MWh/yr for the freezers of Lefki municipality
- (2,843.55 - 372.76) = 2,470.79 MWh/yr for the heating of Ag. Varvara municipality
- (1,379.29 - 152.83) = 1,226.46 MWh/yr for the heating of Lefki municipality.

A simple linear programming model was developed to find and describe the optimal way of this curtailed energy to be distributed inexpensively to local end-users and at the same time to reassure profits for the independent power producer. The mathematical representation of the optimization model of is given in the following equations:

$$Max(372.76 ! X_1 + 152.83 ! X_2 + 160.18 ! X_3 + 2207.4 ! X_4 + 837.1 ! X_5 + 492.54 ! X_6), \quad (11)$$

Subject to

$$26.76 ! X_1 ! 71.69, \quad (12)$$

$$26.71 ! X_2 ! 71.69, \quad (13)$$

$$18 ! X_3 ! 47, \quad (14)$$

$$X_4 ! 50, \quad (15)$$

$$71.69 ! X_5 ! 87.61, \quad (16)$$

$$71.69 ! \ X_6 \ ! \ 87.61, \tag{17}$$

$$0.4016 \ ! X_2 + 0.0472 \ ! X_3 + 0.5512 \ ! X_4 \ ! \ 57.2 \ , \tag{18}$$

$$0.4016 \ ! X_6 + 0.0472 \ ! X_3 + 0.5512 \ ! X_4 \ ! \ 64.95 \ , \tag{19}$$

$$0.3388 \ ! X_1 + 0.0414 \ ! X_3 + 0.6198 \ ! X_4 \ ! \ 56.015 \ , \tag{20}$$

$$0.3388 ! X_5 + 0.0414 ! X_3 + 0.6198 ! X_4 \ ! \ 62.62 , \tag{21}$$

$$148397.48 ! \ 372.76 ! X_1 + 102.29 ! X_3 + 1531.39 ! X_4 + 837.1 ! X_5 \ ! \ 181438.9 , \tag{22}$$

$$74236.27 ! \ 152.83 ! X_2 + 57.89 ! X_3 + 676.025 ! X_4 + 492.55 ! X_6 \ ! \ 90630.44 , \tag{23}$$

Regarding the numbers and the variables $X_1 – X_6$ in the equations (11) – (23) there is: Based on the current Law for Renewables Law 3851/2010 [26], there is a special provision regarding compensation due to grid curtailment. At the end of each calendar year, the Greek TSO pays each WF owner additional remuneration which is equal to the remuneration corresponding to 30% of the energy cuts imposed during the previous year. Therefore, based on the effected wind curtailment data (table 1), and multiplying each year the curtailment by this 30% remuneration factor and by the Feed-in-Tariff (FiT), there is 76,107.31 € (WF1) and 36,845.54 € (WF2). Dividing this numbers with the 2,843.55 (WF1) and 1,379.29 (WF2), the least of the FiT for the two WFs is found which equals 26.76 €/MWh for WF1 and 26.71 €/MWh for WF2. The maximum is defined from the current residential PPC tariffs [27] for consumption below 800 kWh per 4 months {eqs. (12), (13) for variables X_1, X_2 which correspond to the electricity price in Ag. Varvara and Lefki municipality respectively}. Regarding eq. (3), it was found from EUBIONET III Project report [28] that the cost of firewood in Greece for the last decade was approximately at 18€/MWh and the cost of pellets reached around 47€/MWh {eq. (14) for X_3 which represents the fuel price for firewood and pellets}. Therefore the price used in the model should be in between. Regarding heating oil a fixed price of 50€/MWh was taken based on [29] {eq. (15) for the heating oil price X_4}. X_5 and X_6 represent the electricity price used for heating. Therefore, in eqs. (16), (17), it was assumed that this charge should be higher since exergetically is not efficient to use electricity for heating purposes. Based on the current residential PPC tariffs [27] for consumption greater than 800 kWh/4 months but lower than 1,600 kWh/4 months, these prices were selected. Regarding eqs. (18) – (21), based on [30] a study was done which presented the mean used for heating per prefecture (heating oil, wood-pellets, and electricity) and lower and higher limits were selected. Finally, eqs (22) – (23) quantify the energy use in the two municipalities separately since geographically distant. The overall scope was to find out the optimal solution for the investor, for the end user and at the same time for the system. The wind energy investor wants to be remunerated more than what he earns from curtailment, the end user wants to save money spent on the electricity bill, while the system to consume the produced electricity which is about to be curtailed. Equation (11) fulfills that scope from the investor point of view. If we minimize (Min) as well the objective function (eq. 11) – and not only maximize – then we receive a range of acceptable results of electricity utilization which will benefit the end-user and the investor at the same time. The results from the minimization and maximization of the objective function based on the constraints are shown below:

! ! 71.66 ! X_1 ! 71.69,

! ! X_2 = 71.69,

! ! 18 ! X_3 ! 47,

! ! 71.69 ! X_5 ! 87.61

! ! 71.69 ! X_6 ! 87.58

These results offer to the wind operator the possibility based on the international energy scene and the oil prices to create tariff schemes that will create more revenues compared to the remuneration coming from curtailment. The objective function results for the profits are:

$246{,}244.9\text{ €} \leq \text{Profits} \leq 272{,}052.3\text{ €}$

Based on the effected wind curtailment data and the 30% remuneration the profit for the investor would have been 76,107.31 € from WF1 and 36,845.54 € from WF2, which in total is 112,952.85 € per average year.

Furthermore, for the integration of wind power to the system, following the approach of [31-33] exergy efficiency of the WFs, including all losses can be estimated by using the equation:

$$ExergyEfficiency = \frac{NetAEP}{8760 \times C_i} \times 100\%, \qquad (24)$$

where *NetAEP* is the Net Energy [MWh], 8760 h are the total hours within a year (365 days · 24 hours), and Ci the installed capacity of the wind farm [MW]. It was found after the power output measurements (table 3), that the Exergetic Capacity Factor (ExCF) on average for the years 2001 – 2009 of the WF1 and the WF2 was 31.91 % and 30.79 % respectively. However, having had the chance to use the wind curtailed via the cold storage and thermal energy storage described above the new Accumulated Capacity Factors (ACF) could have been 35.18% and 33.97%.

The graphical representation of the ExCF and the ACF on average for the years 2001 – 2009 of the WF1 and the WF2 is presented in figure 3.

Figure 3. Graphical representation of ExCF and ACF for years 2001 – 2009

Conclusions

In this paper wind to thermal and cold storage scenarios were examined to enable higher wind energy integration. A mechanism was proposed for the wind energy surplus to be converted into space heating or electrical energy storage (via the use of freezers), using part of this energy in the local area. The optimal solution for the investor, for the end user and at the same time for the system was found. Following this methodology for two WFs of 9.9 and 4.95 MW in Crete Island it was found that:

a) the wind energy investor can be remunerated more than what he gets from curtailment (at least 246,244.9 € compared to the 112,952.85 € per average year coming from the curtailment fee based on the Law 3851/2010),

b) the end user can save more money spent on the electricity bill (since compared to PPC tariff schemes the proposed schemes do not allow to the WF operator to charge more to the end-user than what he should be charged if his consumption was always below 800 kW per 4 months). Also, regarding the charge for heating it can be 71.69 ! $X_{5,6}$! 87.61, which is the charge of PPC when the electricity consumption per 4 months is from 800 kW ! electricity consumption ! 1600 kW, which is objectively very low, and

c) the system to consume the already produced electricity which is about to be curtailed, which this way will increase the ACFs by 3.27% (WF1) and 3.18% (WF2). This way, the DSOs or TSOs will have the chance to reduce costs by using the energy already produced and not reimburse companies for not used energy.

Therefore, the win-win-win situation (operator – consumer – system) revealed covered the scope of this work which was to review the options for greater integration of renewables into the grid.

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Figure Captions

Figure 1. Location of the two wind farms in Crete Island

Figure 2. Effected curtailment of the two wind farms for the years 2000 - 2010

Figure 3. Graphical representation of ExCF and ACF for years 2001 – 2009

Table 1. Effected Wind Curtailment [MWh] for the 2 WFs per year for 2001 – 2009

year	**[MWh] - WF1**	**[MWh] - WF2**
2001	2,114.70	1,052.70
2002	1,534.37	670.85
2003	4,526.88	1,964.53
2004	4,620.95	1,294.44
2005	2,944.50	1,440.01
2006	2,779.64	1,887.27
2007	2,462.73	1,552.76
2008	2,118.43	1,321.82
2009	2,489.76	1,229.25
Average	**2,843.55**	**1,379.29**

Table 2. Energy consumption per day from -15°C to -22°C in a freezer

E (kWh)	**DO**	**Tr (°C)**	**TS (°C)**	**L (kg)**	**RH (%)**
1.29	5	24	-15	5	50
1.35	5	24	-15.5	5	50
1.42	5	24	-16	5	50
1.48	5	24	-16.5	5	50
1.55	5	24	-17	5	50
1.61	5	24	-17.5	5	50
1.68	5	24	-18	5	50
1.74	5	24	-18.5	5	50
1.81	5	24	-19	5	50
1.87	5	24	-19.5	5	50
1.94	5	24	-20	5	50

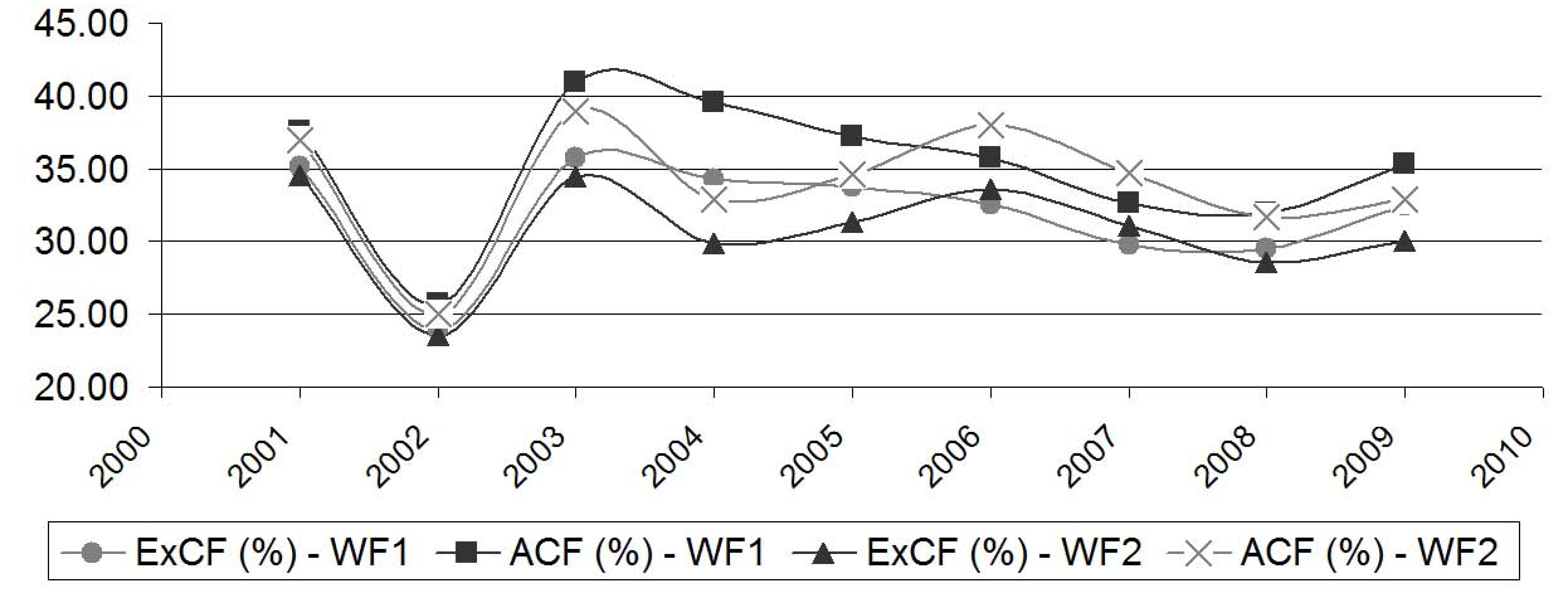
2.00	5	24	-250	5	50
2.07	5	24	-21	5	50
2.13	5	24	-21.5	5	50
2.20	5	24	-22	5	50

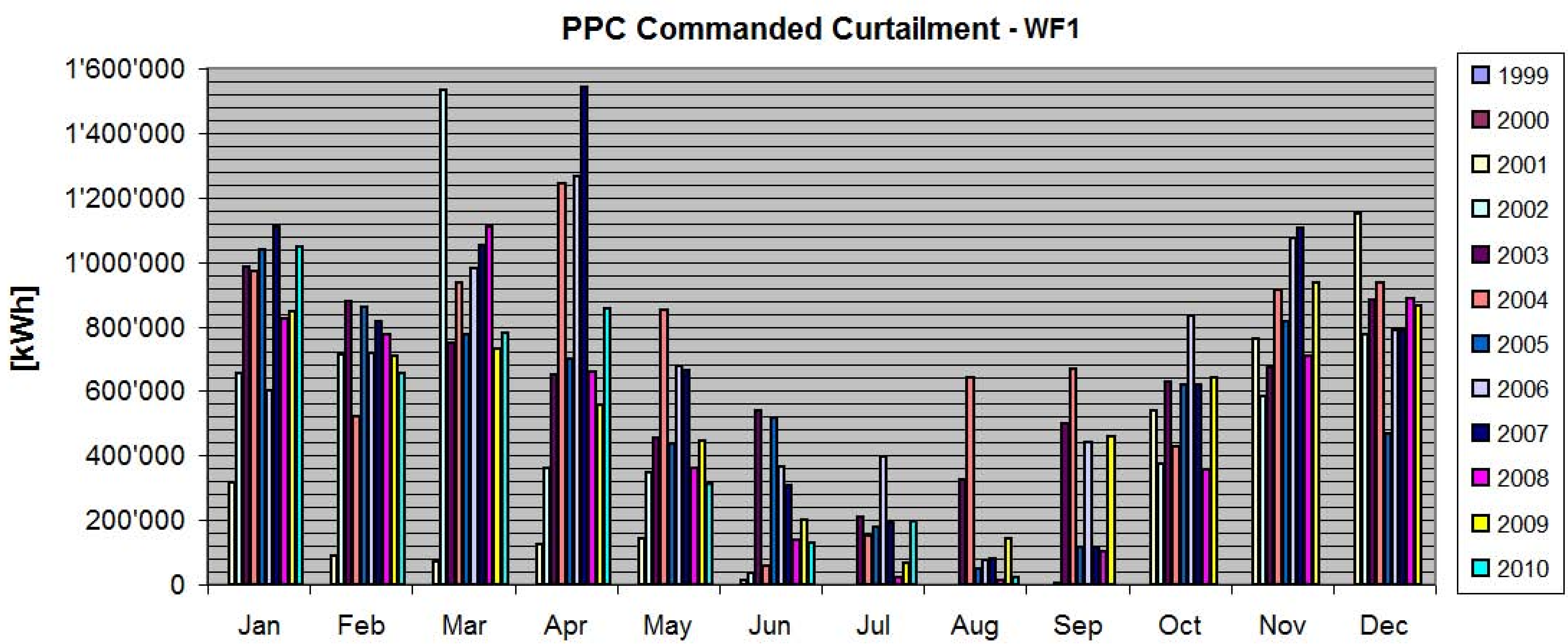
Table 3. Power output measurements, ExCF, wind curtailment and ACF [34]

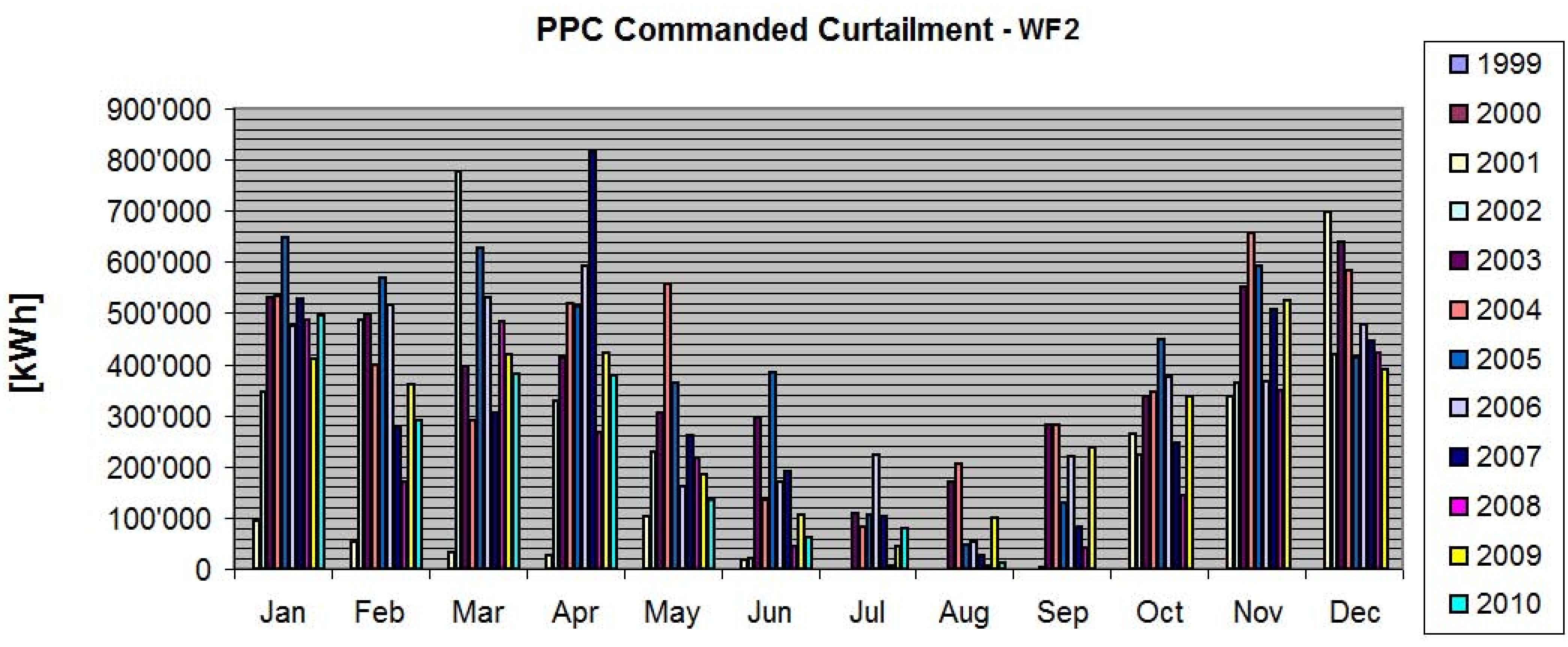
Net Electricity Produced Delivered to the System (WF1)									
WF1	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
[kWh]	30477639	20786341	30965827	29702400	29294652	28254624	25817520	25587563	28141526
ExCF (%)	35.14	23.97	35.71	34.25	33.78	32.58	29.77	29.50	32.45
Wind Curtailment [kWh]	2114700	1534370	4526880	4620950	2944500	2779640	2462730	2118430	2489760
ACF (%)	37.58	25.74	40.93	39.58	37.17	35.79	32.61	31.95	35.32
Net Electricity Produced Delivered to the System (WF2)									
WF2	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
[kWh]	14989487	10191754	14939494	12962400	13575480	14570000	13491600	12399600	13033200
ExCF (%)	34.57	23.50	34.45	29.89	31.31	33.60	31.11	28.60	30.06
Wind Curtailment [kWh]	1052700	670850	1964530	1294440	1440010	1887270	1552760	1321820	1229250
ACF (%)	37.00	25.05	38.98	32.88	34.63	37.95	34.69	31.64	32.89

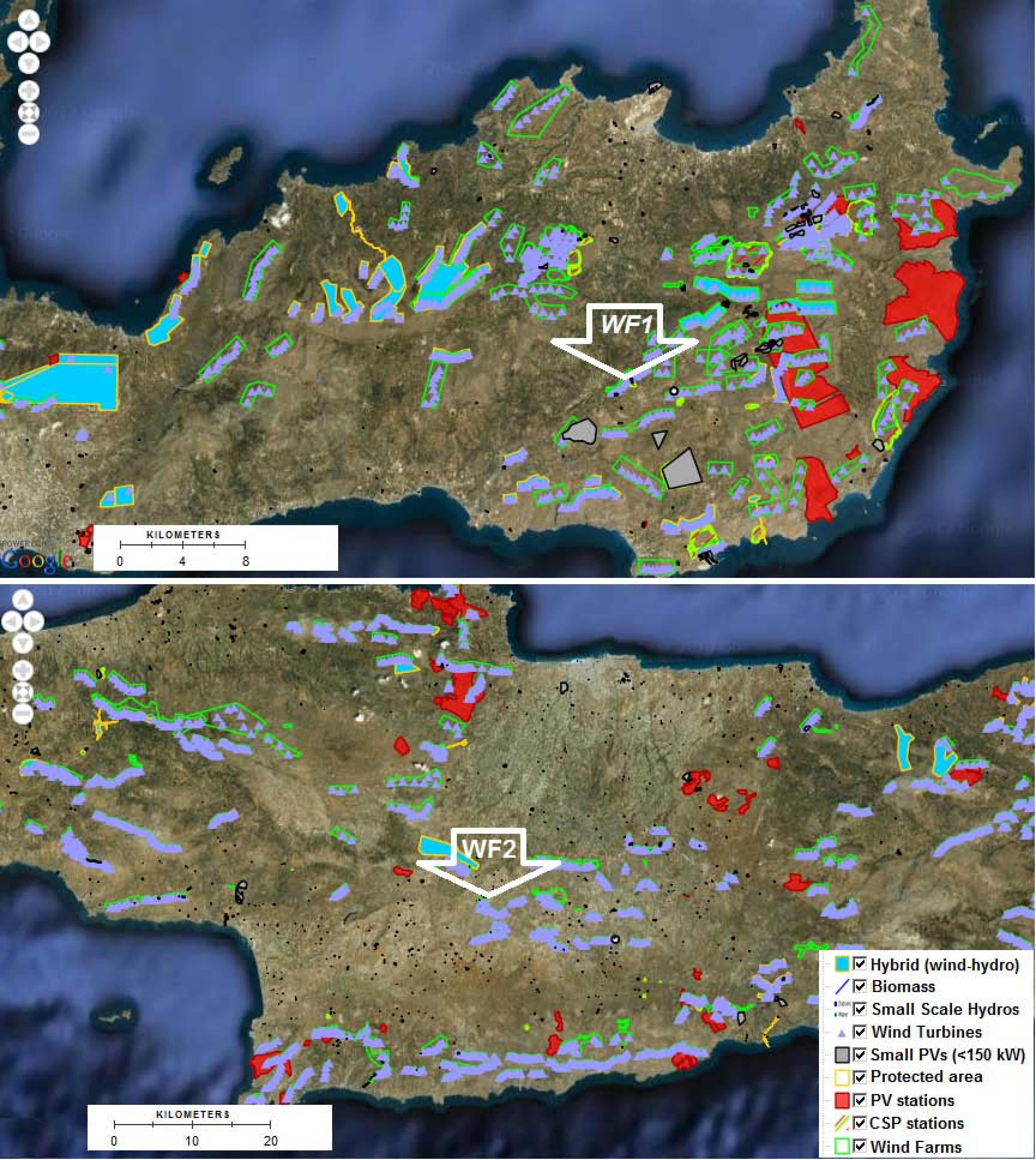
Highlights

- A freezer and a heating system can store electricity "to-be-curtailed"
- WF operator's remuneration is at least double compared to the curtailment earnings
- Under this methodology the end user saves money spent for the electricity bill
- From a systems perspective, the ACFs increased by 3.27% (WF1) and 3.18% (WF2).


45.00
40.00
35.00
30.00
25.00
20.00
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
ExCF (%) - WF1
ACF (%) - WF1
ExCF (%) - WF2
ACF (%) - WF2


PPC Commanded Curtailment - WF1
[kWh]
1'600'000
1'400'000
1'200'000
1'000'000
800'000
600'000
400'000
200'000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010


PPC Commanded Curtailment - WF2
[kWh]
900'000
800'000
700'000
600'000
500'000
400'000
300'000
200'000
100'000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010


WF1
KILOMETERS
0 4 8
Google
WF2
KILOMETERS
0 10 20
Hybrid (wind-hydro)
Biomass
Small Scale Hydros
Wind Turbines
Small PVs (<150 kW)
Protected area
PV stations
CSP stations
Wind Farms