Journal of Cleaner Production xxx (2013) 1–10

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# A wind energy integration analysis using wind resource assessment as a decision tool for promoting sustainable energy utilization in agriculture

G. Xydis*

*Centre for Research and Technology Hellas, Institute for Research & Technology of Thessaly, Technology Park of Thessaly, 1st Industrial Area, 38500 Volos, Greece*

ARTICLE INFO

*Article history:*
Received 14 August 2013
Received in revised form
11 November 2013
Accepted 12 November 2013
Available online xxx

*Keywords:*
Wind energy integration
Wind resource
Capacity factor
Agricultural flexible demand for energy
Demand side management

ABSTRACT

The wind potential in a mountainous area of northern Greece close to an intensively exploited agricultural area has been studied via an experimental study aiming at identifying the wind farm (WF) development potentials of the area based on wind energy penetration/integration criteria. The first priority of the independent power producer (IPP) is to sell the generated electricity into the grid. However, the energy needs of the agricultural area are to be met using the non absorbed wind power. The study is a qualitative approach and examines ways for the load shed of a wind farm to be used for agricultural purposes and meet the demand and at the same time “offer” to the grid a less fluctuating electricity production signal. Based on the integration and wind resource analyses results, the final wind farm optimized layout can be decided.



## 1. Introduction

Wind energy penetration and integration are critical issues in modern grids and a much debated topic over the last decade, since the share of intermittent renewable energy sources is continuously increasing. The need for scientists to control electricity production and match production availability with demand was always intense. Nowadays, is even more as it focuses strongly on integrating large amounts of electricity from fluctuating renewable energy sources in the power system such as wind energy and photovoltaics. A smart grid solution combining flexible demand side units (with the needed communication and control schemes) can be based on the principle of increasing power consumption in high wind periods and decrease power consumption in low wind periods.

What specifically was studied in this paper was the option to increase the wind penetration level by using exactly that principle using local flexible needs (in particular energy demand of the agricultural sector in the wider area). This analysis together with a wind resource analysis (as a decision support tool) of the area will lead to the optimization of the proposed wind farm size and layout and at the same time will solve partially the integration problem.

Wind resource analyses in flat terrain are well established on the contrary to the applications in strictly mountainous terrains. Accurate wind resource measurements, using wind meteorological masts or optical remote sensing technologies, are absolutely necessary for the exploitation of wind energy. However, wind farms in a mountainous area are not just difficult to be constructed – seen from the independent power producer’s perspective – but many times it is difficult even to complete field measurements for the needed period. Wind resources are rarely consistent and vary with time, season, terrain type, height above ground level and from year to year, and consequently it is needed to be thoroughly – especially in rough terrain – investigated prior to any exploitation (Potts et al., 2001).

Air flow above mountains, is very advantageous for wind farms as it is characterized from increased wind speed compared to the incoming flow. Hills and mountains suitable for wind farms tend to increase the wind speed because of the obstructions on the incoming wind (orography) and therefore are many times preferable as this way the power output is increased (Røkenes and Krogstad, 2009).

Greek terrain is mostly mountainous extending into the sea as peninsulas most of the times. In many cases for determining wind speed profile different modeling techniques are used to correlate

* Tel.: +30 6937568556.
*E-mail addresses:* gxydis@mail.ireteth.certh.gr, gxydis@gmail.com.

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.11.030

measurements from other sites of the same area using meteorological masts where possible and therefore often results are not trustworthy. However, some of these techniques at least render a method and in some cases new sites appropriate for wind farm installation are revealed. In this study the method presented is focused on integrating wind with the assistance of wind resource analysis. A draft literature review on wind resource analysis and wind integration, site experimental and analytical results, and a results and discussion sections follow.

## 2. Literature review

A large body of literature concerning wind resource assessment applications worldwide has been carried out over the past few decades. Not that many though deal with wind measurements and meteorological parameters exclusively in mountainous terrain and its particularities. Literature includes studies concerning optimal wind farm sitting models based on the exergy analysis and the inverse distance weighting methodologies in Southern Greece (Xydis et al., 2009), comparisons of wind velocity based on numerical weather prediction models over rough terrain (Mitchell et al., 2008), and outcomes of wind prediction in coastal mountains using WAsP tool (Berge et al., 2006). It also includes studies about comparison of real and model wind speeds (Reid and Turner, 2001) or turbulence effects (Nishiyama et al., 2002), and studies about the tunnel effect in wind speed (Imamura et al., 2004; Li et al., 2010; Hertig, 1988). According to the literature, there are also wind studies on modeling related to the evaluation of models designed for siting wind turbines in areas of mountainous terrain (Maurizi et al., 1998; Barnard, 1991), critical evaluation of different correlation methods in wind resource assessment of an area using short term data correlated to long term data in a mountainous environment (Bechrakis et al., 2004). Regarding speeding-up only few studies have been made so far. Lubitz and White (2007) investigated the phenomenon not only in a tunnel but also in the field, while Pellegrini and Bodstein (2004) revealed what happens just over low hills. Lemelin et al. (1988) and Miller and Davenport (1998) made some simple calculations regarding wind profile from flow over hills or complex terrain.

There are also studies focused on the effect of meteorological parameters in wind resource assessment and wind farm planning (Xydis, 2012a; Baskut and Ozgener, 2012; Boroumandjazi et at., 2012; Saravanan et al., 2011; Baskut et al., 2011) or other renewable energy projects (Xydis, 2012b) and some of those correlate the terrain characteristics with the wind flow around – and not only over – significant mountainous masses (Xydis, 2012c).

However, for this analysis wind integration studies using demand response (DR) units are also needed and recent developments in the field are enlightening. Agricultural flexible energy demand is a key topic in modern energy environment. Agriculture customers require taking full advantage of energy efficiency resources and of demand response tools. By controlling machinery energy needs, a significant amount of energy resources can be saved from being wasted. Energy consuming for greenhouses and livestock units when renewable energy is abundant means – in most cases – that electricity price will be lower. On the other hand consuming when there is a demand peak and an electricity generation shortage means high electricity pricing or even power cut in cases. Szarka et al. (2013) presented the market and legislative situation in Germany for demand-oriented electricity generation, focusing mostly on the potential for bioenergy. Beckman and Xiarchos (2013) worked on the renewable energy adoption from Californian farmers correlating the electricity price and other parameters, such as environmental practices, with the renewable energy operations of producers. Tewari (1990), initially had primitively started research on energy pricing impact in the agriculture sector. Finn et al. (2013) worked on peak load reduction capabilities through the smarter use of domestic dishwashers examining several scenarios. Fitzgerald et al. (2012) worked on wind energy integration with electric water heaters proving that by applying intelligent control algorithms it results in electricity reductions of 25% and cost reductions in the electricity price of 38%. Finn et al. (2012) also worked on demand side management (DSM) of electric cars charging pointing out the benefits for the end-users and the grid, while Moura and de Almeida (2010) highlighted the importance of DR and DSM measures as in Portugal combined with both type measures, can reduce the peak load of the country, in 2020, by 17.4%. Dietrich et al. (2012) proved that in isolated systems, in days with exceptionally high wind energy production during low demand periods, DSM achieved up to 30% cost savings adding flexibility to the system avoiding load shedding. Østergaard (2012), starting from the 100% renewable energy scenario developed for Aalborg based on wind energy, bio-resources and low-temperature geothermal heat has proven that electricity storages give better integration of wind power compared to heat storage and biogas storage. Xydis and Koroneos (2009) examined several scenarios for the integration of renewable energy sources in small prefectures presenting an alternative VPP approach in Lasithi prefecture.

Regarding renewables and agriculture a lot has happened in general. One of the oldest studies in the field originates from Jarach (1989). Ardehali (2006) presented rural energy development in Iran. Firbank et al. (2013) rather recently focused on sustainable agriculture and renewables in British farms, while Burns (2011) reviewed the relation between solar energy and rural energy.

Although, these studies have been implemented over the past years of intensive research in the field, there is not a study that uses agriculture and agricultural needs as a DR strategy. It seems that only recently Gruia (2011) have dealt with the topic of renewables integration in the agricultural sector. To fill the gap an analytical study has been carried out in this paper.

## 3. Site experimental and analytical results

The submitted Renewable Energy Sources (RES) projects (such as wind farms; photovoltaic parks; hydro or hybrid plants) under evaluation in the Greek territory can be seen and followed – regarding their licensing procedure – from the online Geographical Information System (GIS) tool of the relevant Regulatory Authority for Energy. During the past years an intensive submission of RES projects took place in Greece driven mainly from the encouraging feed-in-tariff schemes.

It can be seen that wind farms (green, in web version), photovoltaics (red, in web version), hydros (blue, in web version) and hybrid plants (yellow, in web version) in some islands mainly (Crete, Rhodes etc.) (Fig. 1A). What can be seen also from Fig. 1B is that in some areas though, RES project submissions are very few, especially for wind farms. This of course has to do with the availability of resources – of wind in specific. The idea and the problem at the same time is the congestion. What can be seen from Fig. 1C is that the measuring station and therefore the under development area is near by a high voltage line (HVAC) and the in any case the generated electricity could be absorbed easily. Nevertheless, the question remains: If in an area where the electricity transfer losses and the congestion are relatively low – despite the fact that the wind resources are not ideal – can the integration be higher? Is this possible in this case?

### 3.1. Wind analysis

To study that, the first step is to evaluate the areas specific resource characteristics. As a part of this research paper, this study