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Research Paper

Wind pumps for irrigating greenhouse crops: Comparison in different socio-economical frameworks

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A simple methodology was used to compare the economic feasibility of wind pump technology, solar photovoltaic pumping, diesel generators, and connection to the electrical grid to provide energy for pumping irrigation water in commercial greenhouses in Spain, Cuba and Pakistan (countries with different developmental backgrounds). The analysis took into account wind resources, distance to the grid, water storage tank volume requirements, and planting dates. Comparisons were made in terms of the levelised cost of energy associated with each system. For all three countries, if a grid connection was already in place, installing wind pumps would be economically unwise. Where no grid connection exists, the distance to the grid and the wind resource available are key factors to be taken into consideration when deciding between options: a 10% increase in the average wind speed is equivalent to a 20% reduction in the distance to the grid in terms of costs return. Finally, the water elevation has a major influence on the economic feasibility of wind pump technology, much more than, for example, on solar photovoltaic pumping technology. The results reveal that, generally, the critical factors to consider when making energy management decisions differ depending between countries. In Spain, the proximity of the electrical grid makes the connection to it the best option. In Pakistan, scarce wind resources are a serious limiting factor. Cuba, however, has good wind resources; water elevation, distance to the grid and water storage needed are the critical factors when determining the economic feasibility of wind pumping there.

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Nomenclature

AO	annual energy output, m^3 water (with water volume understood to represent potential energy)
$C_{m,ds}$	annual diesel pump set maintenance cost, fraction
$C_{m,PV}$	annual photovoltaic maintenance cost, fraction
$C_{m,g}$	annual grid connection maintenance cost, fraction
$C_{m,wind}$	annual wind pump maintenance cost, fraction
d	discount rate, fraction
D	days per year, days $year^{-1}$
EC	energy demand for pumping, kWh $year^{-1}$
EP	minimum power, kW
ETc	outside crop evapotranspiration requirement, mm day^{-1}
ET_0	reference crop evapotranspiration, mm day^{-1}
ETr	greenhouse tomato crop evapotranspiration, mm day^{-1}
FCR	fixed charge rate, fraction
g	gravitational acceleration, 9.8 m s^{-2}
H	water elevation, m
I	initial investment, €
I_{ds}	diesel pumpset capital cost, € W^{-1}
I_g	grid connection capital cost, € km^{-1}
I_{PV}	solar photovoltaic capital cost, € W^{-1}
I_t	storage tank capital cost $V < 30$ m^3, € m^{-3}
I_T	storage tank capital cost $V > 30$ m^3, € m^{-3}
I_{wind}	wind pump capital cost, € $pump^{-1}$
Kc	crop coefficient, dimensionless
L	distance, km
LCOE	levelised cost of energy, € m^{-3} water
N	period of analysis, years
O&M	annual operation and maintenance cost, €
P	power, W
p_{ds}	market price of diesel, € l^{-1}
p_e	market price of electricity, € kW^{-1} h^{-1}
$Q(H)$	water discharge for height H, l min^{-1}
r_{ds}	annual diesel price increase rate, fraction
r_e	annual electricity price increase rate, fraction
r_{if}	inflation rate, fraction
t_{ds}	lifetime cycle of diesel pump set, year
t_{op}	operating time, h day^{-1}
t_{PV}	lifetime cycle of solar photovoltaic system, year
t_{wind}	lifetime cycle of wind pump, year
V	water volume, m^3
W	wind velocity, m s^{-1}
WN	annual tomato water needs, m^3 $year^{-1}$
σ	standard deviation
ρ	water density, kg m^{-3}
η	pumping efficiency, dimensionless
η_{ds}	average efficiency of diesel pump, dimensionless
η_{PV}	average efficiency of solar photovoltaic pump set, dimensionless
η_{wind}	average efficiency of wind pump, dimensionless

1. Introduction

Water management plays a decisive role in agricultural development: an adequate, economic water supply at the crop/farm level is vitally important (Rodrigues & Pereira, 2009). Energy and water supply management are commonly bound up with one another (Rodríguez, López, Carrillo, Montesinos, & Camacho, 2009), and using wind pumps for irrigation etc. is an energy option commonly contemplated.

Traditional direct shaft wind pumps, such as American multi-blade windmills, have seen little development in recent decades; indeed, these pumps have given reliable service since the early 20th century (Mathew, 2006, 241 pp.). However, different types of wind pump system have been developed for different applications. Windmills using piston pumps are now the most common worldwide (Vázquez, 2004).

The main alternatives to wind energy for pumping are electricity from the grid, diesel engine systems, and solar photovoltaic (PV) energy (Al Malki, Al Amri, & Al Jabri, 1998; Al-Smairan, 2012; Ghoneim, 2006; Koner, 1995; Mustafa, 2001; Parida, Iniyan, & Goic, 2011; Ramos & Ramos, 2009). The feasibility of connection to the electrical grid depends mainly on the distance to it and the connection costs. Diesel engine systems are less expensive and easier to assemble, but require a regular supply of fuel and lubricant, frequent maintenance and more user attention. Solar PV energy, which uses a simple and safe technology, is initially expensive but requires little maintenance (Walker & Jenkins, 1997). Hybrid systems might also be used (Jaramillo, Borja, & Huacuz, 2004). Studies that have compared the performance of wind and solar technologies (Vick & Clark, 1996) have shown the former to be a better choice under the conditions in which the comparisons were made (annual average wind speed of 5.73 m s^{-1} at 10 m height, annual average solar radiation – latitude tilt – 2098 kWh m^{-2}, 30 m pumping depth). However, further studies are required that take into account both the water demand, and the developmental conditions of the country and production sector in which the water is needed.

The countries contemplated in the present work were Cuba, Pakistan and Spain – nations with very different developmental backgrounds and socioeconomic frameworks – and the production sector requiring an energy supply for irrigation was the greenhouse agricultural sector.

In Cuba, this is still a small sector; the latest report reveals the area occupied by commercial greenhouses to be only 42 ha (Ajete, Bonet, Duarte, Vargas, & Pérez, 2011), largely producing horticultural products. However, this agrotechnology is of great interest in Cuba, and there are plans to increase the sector size to meet demands of the tourism industry for fresh vegetables. One of the problems faced is the supply of energy to these greenhouses since the country electrical grid does not extend everywhere, and at times the supply quality is poor. The official price of electricity is similar to that in other countries, but these problems make the use of small, renewable energy facilities at the site of consumption quite attractive.

In Pakistan, the agricultural greenhouse sector is growing rapidly, and although it is not one of the country most important industries, it is firmly established and has high

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