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Energy demand analysis via small scale hydroponic systems in suburban areas – An integrated energy-food nexus solution

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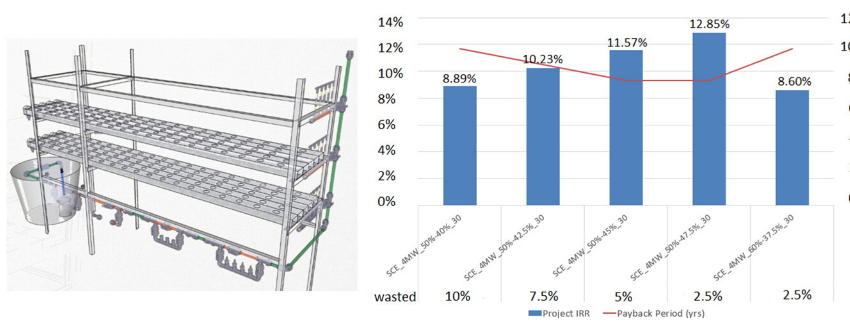
HIGHLIGHTS

- A market integrated Energy-Food nexus solution in suburban environment is presented.
- Scenarios of IRR and payback time of curtailment up to 10% at 30 €/MWh were examined.
- Projects' viability altered significantly (IRR 0–42%) on various electricity prices.

GRAPHICAL ABSTRACT



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ABSTRACT

The study is a qualitative approach and looks into new ways for the effective energy management of a wind farm (WF) operation in a suburban or near-urban environment in order the generated electricity to be utilised for hydroponic farming purposes as well. Since soilless hydroponic indoor systems gain more and more attention one basic goal, among others, is to take advantage of this not typical electricity demand and by managing it, offering to the grid a less fluctuating electricity generation signal. In this paper, a hybrid business model is presented where the Distributed Energy Resources (DER) producer is participating in the electricity markets under competitive processes (spot market, real-time markets etc.) and at the same time acts as a retailer offering – based on the demand – to the hydroponic units for their mass deployment in an area, putting forward an integrated energy-food nexus approach.

Abbreviations: *B*, blocks of flats available; DER, Distributed Energy Resources; DR, demand response; FIP, Feed-in Premium; FIT, Feed-in Tariff; GIS, Geographic Information Systems; IRR, Internal Rate of Return; kWh, kilowatt-hours; m.a.g.l., meters above ground level; m/s, meters per second; MW, megawatt; MWh, megawatt-hours; QGIS, QuantumGIS; RES, Renewable Energy Sources; RIX, Ruggedness Index; SMP, System Marginal Price; *TEd*, total electricity demand; *U*, ratio of buildings located in urban environment; VD_P, number of vacant dwellings in Peloponnese; VD_T, vacant dwellings in Tripoli; WAsP, Wind Atlas Analysis and Application Program; WF, wind farm; WT, wind turbine.

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1. Introduction

Under the approach of our electric future (*Our Electric Future*, 2016; *Planning Our Electric Future: A White Paper for Secure, Affordable and Low-carbon Energy*, 2011) that has been gaining more and more attention over the last decades, traditional production is evolving following alternative paths. Indoor farming has started leaving its mark. Farmers initiated examining alternative ways that could assist them to: a) produce indoors being protected from harsh environment and intense climatic conditions (either rough winters, or dry and hot summers), b) produce in a relatively isolated environment, controlling growth conditions, and c) avoid tares or other exogenous ground factors that influence productivity. Hydroponics is a method of growing plants using direct feeding of nutrients, light, water solutions, often in a soilless environment. This requires constant electricity supply (lighting, A/C and ancillary equipment), water, and heating in order to surrogate natural processes. This means that for large scale deployment, isolated environments, electricity, and heating (at least) are required. A promising solution is buildings. Buildings meet the requirements for a controlled environment, electricity, heating and water. In the building industry there is a tendency of growing interest to integrate systems into constructions. Integrated renewable energy systems (Kalogirou, 2016) is not the only obvious option; lately, buildings are operated similarly to batteries. Smart grids applications (Sossan et al., 2016; Behboodi et al., 2016) and demand side management programmes for communities (Xydis et al., 2013) have converted consumers to prosumers (Xie et al., 2008). End-users have the ability to respond according to the signal from the utility, and according to the demand response (DR) program chosen.

Providing electricity, heating and maintaining a proper indoor environment shall increase costs for those investing in this type of farming. It sounds as a comparable solution for all dry arid and semiarid (desert, steppe), polar, alpine, and subarctic climates and perhaps in cases for intense mountainous or even tropical environments. Even in Mediterranean climates and mild maritime climates, hydroponic systems for certain types of farming could be profitable. By increasing the number of harvests per year – based on the selected cultivation each time – profitability is also increased. Therefore, by selecting an efficient cultivation (e.g. with a harvesting rate of 20 times a year), this will ensue in crop output growth, and thus in maximizing profits. The immediate social impact out of this, is that consumers have easy access to fresh vegetables produced locally, throughout the year, avoiding transportation – and therefore CO_2 emissions – from distant areas (Ohyama et al., 2008). Indoor farming units, promote also food supply security in cities and achieve optimization of resources utilization contributing to the prosperous smart cities concept. Soilless cultivation methods are gaining ground – in comparison to the population-related increasing needs of available agricultural land – due to their improved space, energy, material and resources utilization (D'Autilia and D'Ambrosi, 2015; Ronay and Dumitru, 2015; Putra and Yuliando, 2015).

On the other hand, although it seems a far distant goal – yet so relevant – Renewable Energy Sources (RES) integration to the grid (in practice exactly where is mostly needed, where the demand is high, in the urban environment) can be maximized via hydroponics dynamic development in cities. A wind power integration analysis via DR of such units can be proven a powerful tool for minimizing wind power losses, due to curtailment. A detailed analysis was implemented aiming at identifying the opportunities for integration via a significant amount of hydroponic farming in urban areas. The main need of the independent power producer (IPP) is to offer (bid) the generated power into the electricity markets. There are high demand periods and low demand periods and thus, the integration requirements of the system can vary significantly. However, it should be stated that the regulation cost – which may influence the system price when RES integration is significant – is not considered in this study. A large scale deployment of urban indoor small scale hydroponic units can work towards integration of greater quantities of generated wind power – participating in the market as an authorised electricity supplier as well – and at the same time create career opportunities in cities in a protected environment for the weather-sensitive agricultural products.

In Greece, there is a large number of available building resource with more than 450,000 dwellings and 270,000 commercial buildings unrented and on top of that another 350,000 unused. These buildings are losing their market value since owners do not have the intention to rent or sell them for various reasons (ELSTAT, 2014; Liaros et al., 2016). Thus, buildings could act as a virtual batteries or virtual power plants by participating in DR programmes, assisting in achieving higher shares of renewables into the grid. Furthermore, taking into account the buildings' usage on setting up hydroponic systems, the perspective of WF development in an area, and according to the local power absorption, the option of WF extension is examined. For the extension of the WF, wind resource assessment results identify one by one the new wind turbines sites. Therefore, based on the wind resource analyses results and on the integration options, the final WF layout can be decided and a detailed economic analysis of the proposed layouts can specify the benefits for both the grid and the investor.

2. Methodology

In order to take this matter further, and investigate the concept in practice, a detailed wind resource assessment of the focus area is needed. Yearly measurements were taken and wind analyses and spatial analyses implemented to accurately determine the wind energy integration and urban plant units development perspectives of the area determining the WF layout and optimising the sales in the electricity markets (Fig. 1).

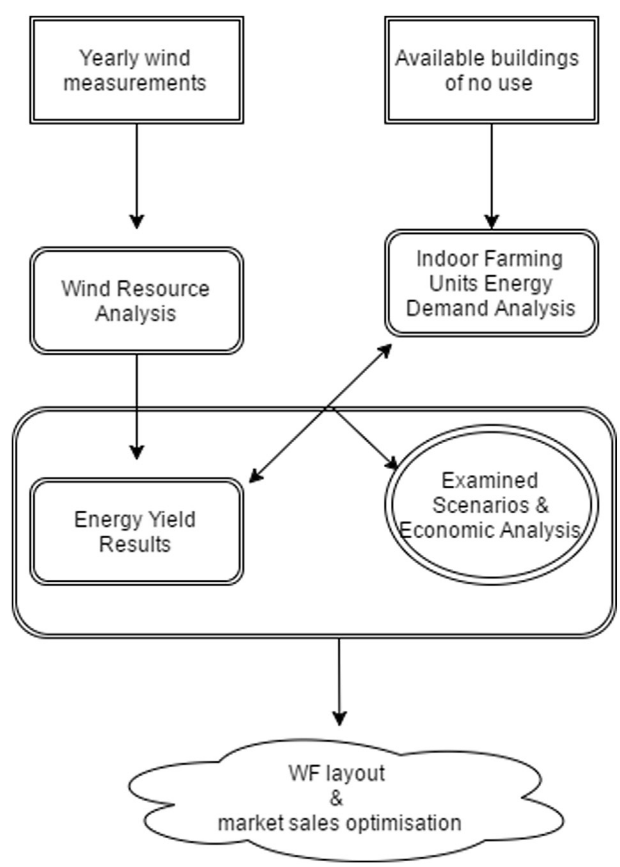

Fig. 1. A detailed flowchart of the proposed methodology.