environmental sciences proceedings

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Proceeding Paper

Water Quality and Energy Consumption in Peri-Urban Agriculture: Lessons Learnt from a Real Case Study in a Municipality Close to Athens †

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† Presented at the 16th International Conference on Meteorology, Climatology and Atmospheric Physics—COMECAP 2023, Athens, Greece, 25–29 September 2023.

Abstract: The constant increase in urban population has resulted in, among others, increased food demand. Peri-urban areas are "transition zones from rural to urban land-uses located between the outer limits of urban and regional centres and the rural environment". The local agriculture businesses and farmers are expected to be considerably mobilised in order to deal with the food security issues. Peri-urban areas could offer a viable solution for supplying the cities, as they can offer food at reasonable prices due to their proximity to the cities, which allows logistics and the related food supply chain to smoothly operate. However, cropping intensification is directly linked to increased energy and water needs, which, in some cases, comes as the result of unsustainable practices as well. Water, energy and food are closely interrelated within the nexus concept (Water–Energy–Food Nexus); water is needed for irrigating crops, energy for irrigation, etc. Fortunately, technological evolution can improve the current situation; for example, precision irrigation can help with the water issue by supplying the plant with water (and nutrients) at the right time, and renewable energy projects, i.e., solar panels, can provide a sustainable resolution to the energy supply problem. Nevertheless, modern farmers face two problems: often lack knowledge regarding these issues and the have to find water of good quality to supply their plantations. This paper aims to address these issues through a real-case study in a peri-urban, agricultural area close to Athens. The application of precision irrigation in local agricultural production is presented and the results will evidence how the farming community of the Greek municipality can benefit. Data collection concerning water quality and quantity, the types of crops cultivated, and the energy consumed per hectare are collected in order to allow the transition to more sustainable agricultural practices.

Keywords: WEF-nexus; sustainability; precision irrigation; energy savings; the energy community

Citation: Santi, D.; Papapostolou, C.M.; Ktenidis, P. Water Quality and Energy Consumption in Peri-Urban Agriculture: Lessons Learnt from a Real Case Study in a Municipality Close to Athens. *Environ. Sci. Proc.* **2023**, *26*, 183. https://doi.org/10.3390/environsciproc2023026183

Academic Editors: Konstantinos Moustris and Panagiotis Nastos

Published: 7 September 2023

1. Introduction

Today, extended urbanisation results in increased food needs for cities (and in some cases, food insecurity) along with persistent climate changes (i.e., prolonged drought), and these have rendered more intense farming activities and placed challenging pressures upon the sector. Therefore, water quality and quantity issues, as well as energy consumed in cultivation, are crucial to be measured and controlled in the context of sustainability. On the other hand, the cost of water and energy are of critical importance; in some areas they are very expensive and limited in both quality and quantity. As a result, this has a direct failure effect in crop yield, and this situation is also triggered by extreme weather conditions that are frequent nowadays. This phenomenon is commonly met in many peri-urban areas around the world and similarly in Greece, in Aspropyrgos.

Aspropyrgos is a peri-urban area, not only characterised primarily by its agricultural activities, but also by its deep culture and remarkable history; nevertheless, it runs the risk of losing its deep agricultural identity due to industrial expansion and farming costs, thus leading to ineffectiveness. Considering that, the aim of this work is to explore water and energy quality issues in local cultivations in order to propose an economically viable and energy-efficient solution. The solution includes precision farming attributes as well as the active participation and engagement of the local community.

2. Materials and Methods

2.1. Modern Tools: Water and Energy Issues in Precision Irrigation in Agriculture

Agricultural production, i.e., food, requires a considerable amount of energy and water for irrigation. Due to the constant increase in world population, climate change and demographic and economic changes, advanced productivity, water, energy and food security has become a main issue in the field. The synergy between these two basic parameters of crop production can provide sustainable and effective yields [1].

At the moment, water used for irrigation of food cultivations takes up almost 70% of water applications and 30% of the energy consumption (food distribution included) [1,2]. The sustainability measurement of an agricultural system is based on water and energy consumption and productivity both in quantity and economy, along with the counting of the environmental imprint and financial profits [3].

In addition, the energy spent in agriculture (i.e., in machineries, irrigation systems, and people as well) is globally increasing, resulting in unbearable expenses for farmers who must deal with environmental phenomena like draught or floods, which in them using extensive amounts of water, sometimes ineffectually.

Complementary, with the rise in world population, the food needs increase too and this has results space limitations, especially near cities, for food cultivations. Taking under consideration how climate change impacts farming, i.e., yearlong draughts, the need for real-time, precise irrigation, dependent on the weather conditions, is more than evident.

Irrigation scheduling is a smart solution that meets the criteria for efficient water usage. By monitoring the crop's needs at the time of the irrigation, a major quantity of water can be saved. This mechanism is applied in irrigation systems by monitoring and measuring the: soil moisture, weather and the specific plant's hydration needs [4].

In the Mediterranean climate of Greece, the increased watering of garden plants during warm seasons is inevitable. However, generally, during the cold months, the crops' needs for irrigation are lower due to the evapotranspiration of plants and rainfall, although, in Greece, there might be a lack of rainfall for extensive time periods, which means that the amount of water needed during winter does not differ from that of the harvest season. In general, demands for the water of vegetable plants are 120–250 m^3 per week, per hectare. This amount, though, depends on the crops' species, the plant's growth stage, the season (sun radiation), local weather conditions and irrigation water quality.

However, whichever irrigation technique is used, the basic criteria for a reliable system is its evenness regarding the water supply on the plants. Another basic essential for an effective irrigation session is post-inspection of the soil. The ground, after being irrigated, must contain the same amount of water as it had during the last session and that which was consumed due to evapotranspiration or draining into deeper ground layers [5].

A Precision Irrigation System (PIS) consists of a combination of networking computer programs and sensors, for the actual cartography of the areas and the recording of their characteristics (fertility, electrical conductivity) in various spots of the fields, crop development tracking and a differentiated quantity of irrigation technology based on the area's needs [6]. This is a valuable tool for any farming system.

2.2. Characteristics of a Peri-Urban Area: Peri-Urban Agriculture and Challenges

Peri-urban areas, settled between the urban and rural zones, are areas where peri-urban agriculture takes place. Nowadays, the definition and division of this type of area is of particular importance, as already underlined above, due to the rise in world population in general, and the large congregation of people in urban areas, which influences the demand for the production of larger food varieties and also highlights the affair of the devastation of rural grounds [7]. The definition of peri-urban agriculture has not been finalised yet. It describes the agriculture that takes place in suburban areas of cities, in spaces with lower concentrations of population, and it is indissolubly linked with urban population and lifestyle due to the proximity of the two zones [8]. Peri-urban areas have the following parameters/characteristics [9]: the distance of the land from the urban centre, its population density, its production system and natural climate conditions.

The Greek bill (par. 17.7/16.8.1923) for the distinction of a peri-urban area mentions that it can be defined as the area between inside and outside zoning areas. Therefore, it can be described as a transient area. Following on this characterization, in the district of Attica, Greece, two zones were created: the first one is close to the urban centre of Athens (<75 min) and refers to increasing popularity density, and the second one is far from the urban centre and has a sparse population density (>75 min).

Aspropyrgos is located in the Prefecture of West Attica and the administrative district of Attica. It is one out of four municipalities that pertain to Thriasio Pedio of Attica. It has two natural borders, Mount Parnitha at the north, and Mount Pikilo at the southeast. The area of Aspropyrgos is also close to the sea because of the Eleusis Gulf, and it borders the district of Viotia at the north, the municipality of Fili at the northeast, the community of Magoula at the northwest, the municipality of Eleusis at the west, the municipality of Ano Liosia and Petroupolis at the east, and the municipality of Haidari at the southeast (Figure 1).

Figure 1. The location of municipality of Aspropyrgos in Attica, Greece in red.

The town of Aspropyrgos seems to have attained a favoured transportation system, as two national highways cross it, Attiki Odos and the Highway of Athens-Corinth. It has also admitted citizens to the uptown railway, which has reduced the distance from Athens and has facilitated the access to the capital city (<30 min). It is generally referred to as an industrial area, because of the numerous industrial facilities that are located there. Some of these facilities are oil refineries, steel mills, cement manufacturers, an ammunition industrial facility, industries of storage and transportation, chemical and plastic—elastic industries, pits and other smaller units. Nevertheless, within the 20 categories of land usage that takes place in Aspropyrgos, beside the industrial activity and the habitable area, agricultural and farm usage is notable as, almost 20 years ago, they accumulated all of the land [10] and faced serious water quality problems.

2.3. Water Quality Issues in Aspropyrgos

In Aspropyrgos, due to industrial contaminants, pesticides and fertilizers, the aquifer is contaminated from time to time. More specifically, the Laboratory of Environmental Chemistry of the University of Athens tested the aquifer from several boreholes far from the coast, and it appeared that pollution tends to diminish thanks to the natural environment self- cleaning capacity; especially with the help of rainfalls [10]. Therefore, the local water quality eventually is characterized as "safe" for use. On top of that as analysed above, farmers must also deal with water and energy extensive costs that are currently challenging the local cultivation activities.

The present case—study is part of a greater pilot farming-project taking place in the area of Aspropyrgos, in collaboration with the Soft Energy Applications and Environmental Protection Laboratory of the Department of Mechanical Engineering of University of West Attica (UNIWA). The aim is to find viable solutions for the water and energy issues of local framing activities to preserve the peri urban farming character of the area. Therefore, the creation of a local energy community that with the installation of PV panels will assess the energy needs' aspect is suggested, along with the application of precision irrigation techniques for the water attribute. By applying precision irrigation to the crops, farmers can avoid over-irrigation and can remotely overlook their farming fields and manually interact –open/close the water supply (pumps).

3. Data and Results

Case Study: Precision Irrigation and Water-Energy Nexus in the Pilot Field

In the peri-urban area of Aspropyrgos (Attica, Greece), a pilot application took place on a field planted with vegetables. The experiment aimed at calculating the actual needs of the plants for irrigation depending on climatological conditions and the characteristics of each particular plant species. Precision irrigation, which is the type of irrigation that can be adjusted to the crop's particular needs, can support the creation of a more viable environment, economically and ecologically, for agriculture, as it helps to save significant amounts of resources.

The information collected by the smart meters installed in the fields also includes the amount of water used on irrigation, humidity of the ground, temperature, pH, turbidity, total dissolved solids and electrical conductivity of the water. They also offer the ability of automations for remotely turning off and on the valve and the pump saving both water and energy.

So, in our case, smart meters were used in two areas, as shown in Figure 2. The sensors allow the estimation of the soil condition and the plant's moisture content (Figures 3 and 4), while the weather and environmental conditions of the area close to the fields are recorded using the Internet of Things (IoT) method for the digitalisation of the measurement results (Figure 5).

Concerning the identification of water quality issues, seven irrigation water samples were collected for examination by the SEALAB team, and the results showed that agricultural water in Aspropyrgos -based on soil, water composition, crop species, SAR (Sodium Absorption Ratio) and EC_w (Electrical Conductivity of water) factors-, appears to be both of good quality and suitable for irrigation, except for plants with a sensibility to salts or grounds with bad drainage, and considered average in quality, that can be used in irrigations with constraints. As mentioned in Section 2.3, the appropriate use of irrigation water ranges from 120 to 250 m^3/week/ha for vegetables. Metered on the first quarter (January–April), approximately 491 m^3/week/ha was used to irrigate. Similarly, on the second quarter (May–August), 545 m^3/week/ha, and on the third quarter (September–December), 573 m^3/week/ha.

(**a**) (**b**) (**c**)

Figure 2. The farm-field in Aspropyrgos (**a**,**b**) and the measuring device (**c**).

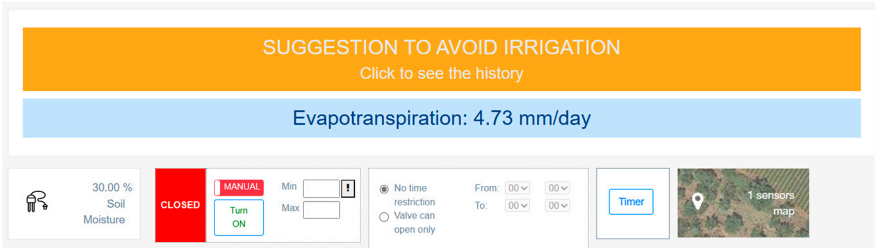


Figure 3. Measured evapotranspiration in the field (reflecting crop's humidity).

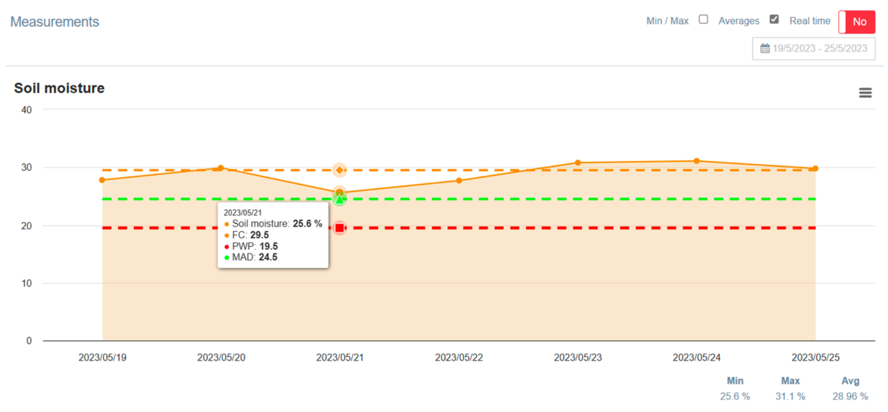
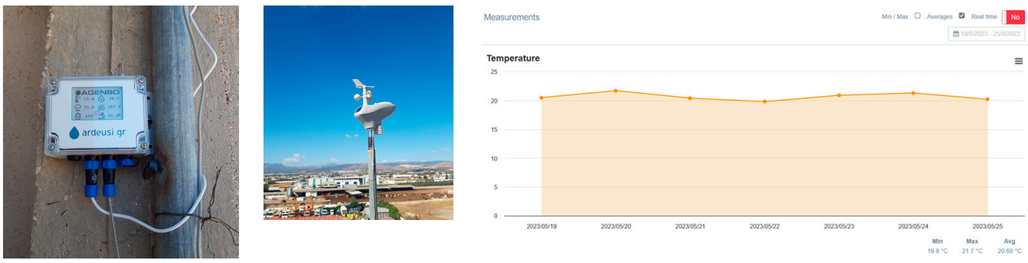


Figure 4. Soil moisture measurements from 19 May to 25 May 2023.



(**a**) (**b**) (**c**)

Figure 5. Environmental monitoring devices (**a**,**b**) temperature measurements from 19 May to 25 May 2023 (**c**).

4. Discussion and Conclusions

From the collection and processing of the data, it is evident that irrigation water is used excessively in the examined cultivation (vegetable) area. Based on the bibliographic quantity range of water needed for this species of crop, farmers used more irrigation water than necessary (almost the double amount). This fact, as analysed above, burdens the ground and leads to water waste, energy spent on irrigation, and naturally, a waste of economic recourses.

Using smart meters enables precision irrigation, which also, if combined with environmental recorded data (i.e., weather conditions) and associated forecasts, allows, for example, calculating the humidity of the crop's ground and the area's air, which can save a large amount of irrigation water as the crop's needs are fulfilled without excessive amounts of water. Specifically, almost 50% of the converted energy and water that is used can now be saved: at least $491-250 = 241$ m^3/week/ha on the first quarter, $545 - 250 = 295$ m^3/week/ha on the second, and $573 - 250 = 323$ m^3/week/ha on the third. Also, for a typical (5.5 kW) water pump operating on an annual basis, one may calculate that, approximately, 14,000 kWh (out of the 28,011 kWh) of the energy consumed for 5900 h (annually) for irrigation can be saved. So, water and energy consumption are decreased to the point where food production stays at the same level, while ground burdening and contamination is lowered, in addition to higher sustainability, due to water savings and lower functional costs.

Author Contributions: Conceptualization, C.M.P. and P.K.; methodology, C.M.P.; software, P.K. and D.S.; validation, C.M.P. and P.K.; data curation, D.S. and C.M.P.; writing—original draft preparation, D.S.; writing—review and editing, C.M.P., P.K.; visualization, D.S.; supervision, C.M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data on weather and climate conditions in Aspropyrgos https://temperature.gr/ (accessed on 5 September 2023).

Acknowledgments: We would like to thank and acknowledge the farmers' Agricultural Association and, especially, Ev. Mouzakas, the municipality of Aspropyrgos and the non-profit organization of EMILIA BOURITI + SYN + ERGASIA for their interest and support. Special acknowledgment to the innovative corporation for agriculture and the environment, AGENSO.

Conflicts of Interest: The authors declare no conflict of interest.

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