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State of the art of the optimisation of the selection and use of renewable energies for the agricultural environment

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Abstract.

A combination of different energy generation sources, together with the possibility of installing batteries or other forms of energy storage systems, can enable the adaptation of the generated electricity to the needs of the farming sector. From optimal irrigation schedules for crops, to taking advantage of pruning waste to generate electricity at times when other sources are not able to generate it, this fitting can allow the farmers to focus solely on the wellbeing of the plants, without worrying about energy prices. On the other hand, it also provides the possibility of maximising energy production on days where the crop health is already ensured.

In summary, this study is the first steps to work on what is missing to create hybrid energy systems that can adapt to the needs of the crops and their ecosystem. These hybrid energy systems applied on farms can improve the wellbeing of isolated areas, such as islands, industrial sites, or villages, helping the owners provide benefits for themselves and their communities.

Key words. Renewable energy, Agriculture, Hybrid energy systems, Agrivoltaics

1. Introduction

Today's world is facing continuous global defining crisis, from the climate change to Covid pandemic and now with an energetic crisis caused by Russia's invasion of Ukraine. There have been different measures to minimize damages related to the last hardship named, including the REPowerEU Plan and the different national energy and climate plans (NECP) for the period 2021-2030. This strong push towards renewable energies is of great help to achieve a green and sustainable future, with projects such as GENERA with the aim of incentivising the use of renewable energies in European islands, or SMEmPower and EnTrainer, where one of the common options for SMEs to save on their electricity bills can be the installation of solar panels.

Besides the action and intervention of European projects, studies of different universities tackle possible options for the implementation of renewable energies, such as the combination of various technologies to achieve a more adaptable generation to the necessities of the people and industries, new and more efficient ways to store electricity power and combinations of worlds where a symbiosis can be obtained, such as agrivoltaics [1].

Generated power from an agrivoltaic system (combination of agriculture and solar panels) brings a series of benefits such as:

- Economic benefit, from reducing the demand on the electricity grid to being able to sell surplus generation, being able to create over 30% increase in economic value [2].
- Benefit for the crops, reducing water demand and protecting them from heat stress, drought and hail [3].
- Benefit for the solar panels, with the crops reducing the module temperature in comparison to a solar farm mounted over bare soil [4]
- Benefit for workers, providing shade during the examination of the state of the crops during the different stages and harvest.

The benefits listed above are just a small sample of what is known to date. Different types of installations have been studied, from solar panels that can be tilted optimising the sunlight the plants receive, to vertical solar panels set as a fence around the fields. However, most of the research is focused on solar panels, not considering other renewable energy sources as well as the combination of them, such as wind and biomass, the last obtained from both surplus and pruning waste.

Using agrivoltaics, the yield of the land can increase between a 35–73% [5]. Still, even if agrivoltaics are a good solution to tackle the scarcity of land that generates disputes between solar farms and arable farms, especially with the increase in the number of macro-farms, constricts regarding the dual use of the land are beginning to appear in form of new regulations and normalisations, to make sure that the main use of the land is not switched in exchange for a greater economic benefit. This is the case of the DIN SPEC 91434:2021-05 [6] or in the case of Germany, where a building permit is usually required for their construction [7].

The installation of different renewable energy sources that coexist in cultivated areas not only benefits landowners. Hybrid energy systems can provide energy to nearby villages and urbanisations, especially if they are far from the electricity grid [8] [9] (such as islands cases). These systems can also favour the creation of factories and industrial parks that treat and process the harvested crops in nearby areas, reducing the carbon footprint in terms of transport.

However, various methods used to study the optimisation of hybrid energy systems do not consider the possibilities and needs of farmers and the crop terrains. Depending on the type of crop, the land may be uneven, which affects the pattern of installation of solar panels [10]. Some methods for optimisation apply AI techniques [8], enhanced mixed particle swarm optimizer introducing quadratic transfer functions [11] and Markov Chain Monte Carlo simulations [12].

2. Objective

The objective of this paper is to study the state of the art regarding different hybrid energy systems with their optimisation methodologies and limitations. In addition, this paper analyses the economic and environmental benefits, as well as gaps in the agricultural sector.

3. Energy uses in agricultural production

Agriculture is reliant on the availability of energy. Some of the different uses are [13]:

- Farm machinery for field work (tractors, mowers, etc.)
- Large trucks for input purchase and deliveries
- Small vehicles for farm management activities
- Irrigation equipment
- Post-production processing (drying of grain or fruit, curing tobacco, etc.)
- Heating for frost protection in groves and orchards
- Power for greenhouses
- Lighting for houses, sheds and barns
- Power for farm household appliances

However, many of them rely on diesel or gasoline, especially those related to the transport of personnel or product. Electricity is usually in the background, although for irrigated crops it gains more weight with the power of hydraulic pumps for the irrigation system.

Nonetheless, the push for net zero emissions forces a shift regarding our actual energy sources. This can be seen with the search for alternate fuels for vehicles, with options such as electric or hydrogen cells. Still, one way to reduce the carbon footprint from this kind of practices is minimising the distance the inputs and outputs of production have to travel.

With the objective of optimising the process, not only the transportation of materials is being affected. The implementation of the Internet of Things (IoT) to the crops seems to be the future where agriculture is heading [14]. This new trend, with the name of Agriculture 4.0, Smart Agriculture or Smart Farming, has different benefits, some of them being [15] [16]:

- automation of actuators
- disease detection
- irrigation management
- fertilizer management
- maturity identification
- marketing and supply chain
- soil fertility
- weather patterns

This Agriculture 4.0 revolution not only focuses on the vigilance of the status of plants and soil. Drones can synergise with the sensors installed by undertaking activities such as:

- checking areas with anomalous data and to detect crop health [17]
- detect and collect ripen fruit and vegetables [18]
- seeding the soil [19]

From the hydraulic pumps to the lights and sensors, all seem to be moving toward the use of electricity as the main power source. Yet, the increasing number of elements that need to be connected to the power grid, either to operate or to recharge batteries, can increase the costs of production. For this reason, an energy source inside the cultivation terrains could be beneficiary to reduce the costs named before.

4. Energy systems and energy algorithms

For this section, a brief description of the found energy systems and energy optimisation methods that are known nowadays.

A. Energy systems

Different forms of generating renewable energy that synergise with the agricultural sector are starting to be studied. Nevertheless, the process is slow, although there are some ways more consolidated than others, such of the case of solar photovoltaic panels.

For this section, due to the limitations of the article, the following will be discussed:

- Solar photovoltaic
- Eolic
- Bioenergy
- Batteries

Solar energy systems, in particular photovoltaic systems, are one of the renewable energy generation systems with most installed capacity in Spain, approximately 17% of the total with 19.912 MW [20]. However, this number comes from solar farms, not from the use of agrivoltaics.

Most of the solar photovoltaic panel's installations and studies regarding agrivoltaics center on flat monofacial plate PV devices as the standard. Their focus allocates within the positioning of the solar panels [10], either in the open air or in greenhouses.

However, studies are diversifying into different branches. On one hand, the use of organic photovoltaic modules is being studied mainly for greenhouse application due to their semi-transparency [21] [22]. On the other hand, bifacial photovoltaic panels are another viable option [23]. Even if the energy generation is not superior, it presents advantages such as covering less land, less obstacles to the farm machinery easier cleaning [24]. Last but not least, the use of beam splitting to optimize the wavelengths that reach the photovoltaic panels, and the crops could be an option in the future, selecting those solar cells that work with the wavelengths [25] of which the plants are not interested.

Wind powered systems don't usually come alone, being most of the time paired with solar systems. Most of the time the symbiosis with the cultivation terrain is non-existent. Nonetheless, these wind farms are part of the microgrid that powers the farm [26]. Another way to collect the energy from the wind can be found in wind energy harvesters, although due to the energy generated from them, they are relegated to power smart agriculture applications, such as sensing nodes [27].

Agricultural residue can transform into bioenergy. One way of bioenergy is the transformation to biodiesel, which could be exploited for current diesel vehicles as a way to obtain a more sustainable fuel source [28] [29], however, with today's research, most of them rely on algae for the biodiesel production. Another way of bioenergy is in the form of biofuels, which can not only power the farm, but also be transformed and sold as jet fuel, emitting during their whole life cycle less greenhouse gases than their petroleum-based counterpart [30]. Wastewater can also be employed to obtain different bioenergy and biochemicals by making use of several biological processing strategies [31].

Last but not least, although batteries do not generate energy per se, they provide energy flexibility by not binding certain energy-dependant procedures to the time nor weather, of which some of the renewable energies named are dependant. These batteries not only can be electric batteries, they also can be gravitational batteries (hydraulic and soil), but these options can be more expensive compared to the electric batteries [8].

B. Energy optimisation methods

To optimise multiple energy sources from different origins, optimisation methods have to be able to solve the non-convex and non-linear optimisation problem, with decision variables both discrete and continuous [32].

For big data analysis, some of the most common energy prediction models are machine learning, data mining, pattern recognition, fuzzy logic, artificial neural networks and support vector machines. Each of these prediction models contain different algorithms

Different energy optimisation methods for hybrid energy systems exist. Some of them are as follows:

- HOMER (Hybrid Optimisation of Multiple Energy Resources). This software program can model entire hybrid microgrid and grid-connected systems combining generated power (traditionally and renewable), storage and load management [33]. Depending on the version, different optimisation algorithms are available. Regarding HOMER Pro, features a grid search algorithm and a "derivative free" optimisation algorithm.
- HOGA (Hybrid Optimisation by Genetic Algorithms). The use of genetic algorithms to obtain the optimisation model. An example of genetic algorithms are evolutionary algorithms [34].
- Markov Chain Monte Carlo algorithms due to their probabilistic nature can be applied to generate models of wind and solar generation [12].
- Machine learning algorithms can be used to control other types of algorithms, such as bin packing algorithms, for managing smart grids. This is possible due to the algorithm capabilities for predicting client's energy usage behaviour, which includes bill's predictions and maintenance requirements [35].
- To predict energy usage, a machine learning model which includes nonlinear autoregressive model, linear model using stepwise regression and random forest (least square boosting) approaches can be trained, although they require information of energy usage and environmental data [36].
- Another methodology can be the hybridisation of an artificial neural network and chaotic search, harmony search and simulated annealing algorithms, used in [32] study to size a stand-alone energy system using weather forecasting.

The methodologies identified in this paper focus mainly on their applicability to the agricultural environment. The beneficial aspect can be shown in the optimisation of the energy system using weather forecasting, controlling both humidity and energy necessities, and being able to predict the user's behaviour, taking weather into account.

5. Conclusion

Hybrid energy systems suffer from different challenges, which can be compiled in 4 big groups: energy management, unit sizing, demand response and energy storage management. To those challenges, we have to add the challenges regarding the agricultural sector and the ones created by the combination of both worlds.

The generating power installed not only depends on the available area and the needs of the farm. It also includes the projection of their expected growth and the amount of extra energy they want to generate, either for batteries or for selling. Nonetheless, all these installations must take into account the regulations and laws of the country where it would be installed, as there may exist some limitations [6] such as the maximum percentage of terrain occupied by solar panels, or the minimum harvest compared to nearby terrains without renewable energy installations.

We cannot forget that the main objective of the agricultural sector is to produce high-quality crops at the highest possible profit. Energy is secondary, reducing costs and acting as a secondary source of income but it can never be the main source. Sometimes, mostly when the effects are not detrimental to the crops, the system will have to adapt to the current energy situation, such as changing irrigation times. However, most of the time the energy systems installed will have to prioritise the plants' benefits to secure the quality of the harvest. This protection can be shown as turning on the pumps to irrigate the plants during heat waves for cooling purposes, to changing the orientation of solar panels to protect them from frost and hail [37].

On the other hand, the acceptance or rejection of RES is key to the development of these technologies. As a study in Athens (Greece) shows, most of the participants are in favour of the development of RES and declare themselves supporters to these investments. However, they do not want the projects to be located near their residences and they are not willing to contribute financially to their development [38]. This may also affect farmers, who will need to be incentivised to implement these projects on their own terrains.

About the Agriculture 4.0 and implementation of IoT, drones are not only able to check for the crops' situation. Some can be destined to the energy infrastructure for periodic checks in a way to prevent power outages due to system failures.

New ways to synergise renewable energy sources with the crops are being studied, focused mainly on photovoltaic panels. A new way of approaching uses of solar photovoltaic panels could be combining vertical solar panels, thus allowing machinery to operate with less obstacles, with the use of beam splitting to divide the wavelengths that reach the solar panels and the crops.

Most methodologies do not take into account the global needs of a farm, focusing most of the time in the irrigation aspect or greenhouse necessities, over areas such as post-production processing or transport. New studies could focus on those areas, searching new ways to create biodiesel to power the actual vehicles or pushing towards electric charged ones. Also, most of the methodologies focus on self-consumption, not taking into account the prosumer aspect and benefits (economic and social) that comes with it.

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