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Design Of An Agrivoltaic System Using 4.0 Technologies For Agricultural Farms On The Colombian Caribbean Coast

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Abstract-.
The generation of energy through renewable sources, including photovoltaics, has allowed Colombia to increase the indicators of clean generation, thanks to the fact that it is inexhaustible and increasingly competitive. The installation of solar farms occupies large areas of land, which are no longer useful for agricultural production or maintenance of the environment. This article proposes an agrivoltaic system that will allow to carry out technological, agricultural and environmental studies based on industry technologies 4.0, as well as the coexistence of electricity generation and agricultural activity in agricultural farms on the Colombian Caribbean coast.

Keywords: microgrid, agrivoltaic, renewable energies, industry 4.0.

I. INTRODUCTION

The generation of energy through renewable sources has allowed the clean generation indicators to increase in Colombia, thanks to the fact that it is inexhaustible and increasingly competitive. The Colombian Caribbean coast has high conditions for the generation of energy through photovoltaic systems. Thus, in recent years solar farm installation projects have increased. The installation of solar farms at ground level does not allow a mixed or shared use and occupies large areas of land, which are no longer useful for agricultural production or maintenance of the environment.

Figure 1 shows the typical implementation of a solar farm, in this example one with 32 thousand panels spread over 12 hectares and a capacity of 8.06 megawatts. It is observed that the land is completely occupied by the panels, and the land under the panels is completely unused and unproductive during the useful life of the system which is approximately 20 years. With the increase in solar farms on the Colombian Caribbean coast, it is likely that large tracts of land will not be productive in agriculture or livestock (1 to 4 hectares per MW).


Figure 1 Typical implementation of solar farms.

The proposed agrivoltaic system, which includes monitoring and management through industry 4.0 tools, allows the carrying out of technological, agricultural and environmental studies to present an adequate solution in which electricity generation and agricultural activity can coexist in agricultural farms.The system, first in Colombia and in the world in a tropical climate, will study the crops of the region in the microclimate generated under the photovoltaic panels. The model uses agrivoltaic technology, with the installation of a photovoltaic solar plant interconnected to the conventional electrical grid, but designed and installed in such a way that it allows agricultural production under the solar panels. The model will improve the competitiveness of farmers, since they will not only benefit from the sale of agricultural products but also from the advantages of renewable energy sources, including the sale of the energy generated.

The proposal includes the agricultural production of different products from the area, taking into account the benefits of agrivoltaic technology, as well as the implementation of transformation and management techniques through 4.0 technologies. The foregoing, supported by an information and knowledge management system for decision-making that assesses and includes the impacts on eco-systemic services.

II. BACKGROUND

Globalization and world competitiveness represent great and complex challenges for the Colombian agro-industrial sector. Currently, due to the little or no investment destined for the modernization of production systems, the technological and research gap is widening in relation to countries such as Mexico, Brazil, Chile, Peru and Ecuador. In the case of the productive chains of the agricultural items contemplated in this proposal, the demands that a producer must implement to meet the expectations of the clients are increasing every time. Maintaining the quality conditions of these products is difficult and, in some cases, impossible, since the technological infrastructure is limited and deficient, so incalculable losses are incurred during their production process, especially at harvest and post-harvest.

Information and Communication Technologies (ICT) have become an essential component in people's daily lives, which is why the agro-industrial sector should not be oblivious to the set of advantages and opportunities that its use provides. In an increasingly technical world with more global competition, ICTs are the necessary working tool for producers to explore new business formulas and improve their current production and management techniques.

From a holistic point of view, the application and development of information and communication technologies to agribusiness is mainly based on accessibility to information. Information that has to be translated into knowledge and tools for the management of the sector's value chain, and in consequence has to achieve an impact on productivity, accounting processes, risk management, the reduction of environmental impacts, and in improving people's quality of life. At a comparative level, it is not possible to establish a common framework between regions and geographical areas regarding the implementation and development of ICT in agribusiness, given the divergence of the competitive reality of each region and geographical area. However, the evolution in the use of ICT in Latin America and its expansion towards small and medium farmers is highlighted.

On the other hand, the phenomena and effects of climate change at the global level cannot be ignored. In Colombia during the last decade, El Niño and La Niña phenomena have affected agriculture and increases in climate variability are projected for the coming years, with high temperatures and erratic precipitation, which leads to a change in the prevalence of pests and diseases, flooding on the coasts, water stress, salinization of soils, therefore, great economic losses and increased production costs that result in approximately 60% of the cultivated areas 80% of the crops would be affected (Christensen et al., 2013)

Power generation sources

Electric energy is one of the most used forms of energy in the world, it is essential for the development of cities worldwide. There are different types of energy sources; non-renewable and renewable. Non-renewable sources are those sources that are found in nature in a limited quantity and once consumed in their entirety, they cannot be substituted, since there is no production or extraction system, for example; fossil fuels (coal, oil, natural gas) and nuclear fuels (uranium, plutonium, among others). On the other hand, there are renewable sources, which are those obtained from virtually inexhaustible natural sources, either due to the immense amount of energy they contain, or because they are capable of regenerating by natural means at a rate similar to that of their consumption, for instance; solar, wind, geothermal, hydroelectric, tidal, wave, biomass, among others.

Non-renewable energies are polluting and cause planet earth to undergo continuous transformations, which generate great problems in the natural course of the planet. One of these problems is the emission of carbon dioxide into the atmosphere due to the use of hydrocarbons, causing global warming. The many gases that are part of the atmosphere (carbon dioxide, water vapor, nitrous oxide, methane, sulfur hexafluoride, chlorofluorocarbons, hydrochloro fluorocarbons, hydro fluorocarbons) absorb infrared radiation, causing an increase in the temperature of the earth's surface and the atmospheric layer that surrounds it. Generating very serious consequences, which are manifested in phenomena such as the melting of glacial masses, flooding of islands and coastal cities, hurricanes, species migrations, desertification of fertile areas, impact on agriculture and livestock, among others.

Due to this great problem, many countries have been making great efforts supported by agreements, to mitigate this global issue, from the international level 17 sustainable development goals have been drawn up, to achieve a useful life of the earth and avoid the deterioration of nature.One of the most viable solutions that exist today to reduce the consequences of the greenhouse effect, are renewable energies or also called clean energies. Colombia is one of the countries that has been adjusting its public policies to support the work against the deterioration of planet earth. Currently, the main source of electricity generation in Colombia are hydroelectric plants with a production of 66% and thermal generation with a production of 33%. Faced with this scenario, in recent years there have been major problems due to the great electricity demand, which exceeds the generation of energy in the country, causing electrical blackouts, produced by multiple factors (increase in the number of users, illegal connections, poor maintenance to electrical networks, among others). Due to this great problem, the Colombian government issued laws framed to encourage and promote alternative energies. Available sources information about solar resource indicate that the country has an average daily irradiation of 4.5 kWh / m2 (Espinosa Lilian, 2021)which exceeds the daily world average of 3.9 kWh / m2. In the case of Colombia and the equatorial countries, there is an advantage of having a good average resource throughout the year by not experiencing the phenomenon of the seasons. In the department of Cesar, Enel Green Power Colombia (EGPC) inaugurated the largest renewable energy plant in the country, El Paso, which has an installed capacity of 86.2

MW. It is estimated that this plant could produce around 176 GWh per year, which would supply the annual energy needs of around 102,000 Colombian homes.

Technologies for productive restructuring

Industry 4.0 represents a new level of organization of production and management of the supply chain throughout the entire life cycle of the released product. One of the key directions of Industry 4.0 is the formation of "nature-like" technical manufacturing systems. The use of automated systems and sensors based on digital technologies makes it possible to track the operation of the plant and indicate possible errors and breakdowns and transfer this information to the manufacturer of the plant and the supplier of the raw material. The creation of a unified management information system will facilitate the timely receipt of adequate information on failures. The developer, manufacturer and supplier get the opportunity to analyze this statistical data in order to realize an organizational, construction or design solution. As a final result, this system will contribute to the efficient maintenance of the operational state of the agrivoltaic system.

Microgrids

Microgrids, due to their great utility and novelty, constitute one of the most researched topics worldwide as many countries seek to modify their traditional energy methods, replacing them with reliable and environmentally friendly alternatives. There are relevant success stories, some of them are highlighted below:

- According to the study by Red Mountain Insights LLC (RMI, 2021), there are more than 40 military microgrids installed and operating in the United States, and it is expected to have an installed capacity of more than 50MW by 2018.
- In the compilation text Microgrids architecture and control (Hatziargyriou, 2014) an investment activity of nearly € 4.5M is identified in continental Europe, with an important consortium made up of more than 14 allies from seven countries, including service providers such as Electricité de France (EDF), EdP (Portugal), manufacturers, research centers, among others.
- In (Widanagama Arachchige et al., 2017)17 concept tests of micro-networks are characterized, of diverse nature and with unique operational vocations, ranging from support systems to substations of companies providing public services, to micro-networks virtually coupled to through the cloud.
- As important social cases, for providing access to energy in non-interconnected areas, the micro-grid located in Huatacondo (Chile) and the project that is currently being designed in the Galapagos Islands (Ecuador) stand out.

Currently, Colombia, with the coordination of the Energy and Gas Regulation Commission (CREG) and the Mining and Energy Planning Unit (UPME), has been creating awareness among the inhabitants about alternative ways to generate electricity, reducing the amount of pollution that it causes. This is why Law 1715 of 2014 was created "Integration of non-conventional energy sources to the National Energy System", which seeks to promote the development and use of non-conventional sources, mainly of a renewable nature. Such a situation reinforces the initiative of universities, research centers and companies to study and develop the subject of micro-networks.

ICT trends, technologies and solutions in agribusiness

At the global level, according to the ICT White Book (2011), the following priorities stand out: the conservation and integral management, efficient and sustainable agroforestry and fishery resources; the integral management and conservation of genetic resources; the sustainable improvement of agricultural, livestock and forestry production systems (comprehensive pest control, disease diagnosis, phytosanitary products, accuracy, efficacy and sustainability, farm management, improved productivity, quality and efficiency of the final product); agriculture and environment; mechanization; and information management.

In general, trends in communication and information technologies in agribusiness focus on a network of integrated sensors that allow measuring certain parameters and changes in physical and in some cases chemical characteristics, as well as allowing control, in a certain way or to a certain extent, parameters in order to improve and facilitate the management of any activity to which they are applied.

III. PROPOSED SYSTEM

By 2050, it is forecast that approximately 600TWh will be generated from photovoltaic solar energy in the world (IEA – International Energy Agency, 2021). This growth for electricity generation purposes requires large areas of land and many of these lands are fertile, creating a dispute between the use of the land for photovoltaic generation purposes and agricultural activity (Nonhebel, 2005). This dispute over land use can be solved with the concept of agrivoltaic, which consists of a set of photovoltaic panels raised from the ground and underneath them exercise agricultural activity. This design was first proposed by(Goetzberger & Zastrow, 1982) which consisted of a Microgrid raising the solar panels to 2m from the ground and increasing the space between them to avoid excessive generation of shade.

The new concept of energy and food co-production has been implemented in different countries with the aim of expanding the research on the behavior of crops with solar panels raised to the open ground and evolving to smart agriculture (figure 2). Examples are from France(Dupraz et al., 2011),
Japan(Movellan, 2013),Italy(Marrou et al., 2013), United States (Majumdar & Pasqualetti, 2017).

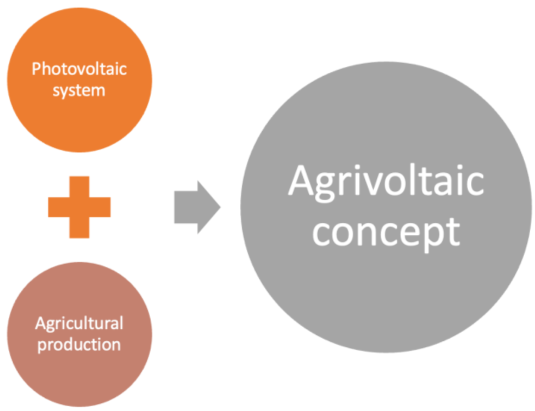

Figure 2 Agrivoltaic concept

The Colombian territory is characterized by an average annual sunlight of 4.5 kWh/m2 and especially the Caribbean region has an average radiation of 5 and 6.55kWh/m2. This particularity is being used for the implementation of solar projects with a participation of 72% of the 122 current projects according to the Mining Energy Planning Unit (UPME)(Espinosa Lilian, 2021).

According to the SIPRA application (https://sipra.upra.gov.co/) of the Rural Agricultural Planning Unit (UPRA), the national agricultural frontier is 39,239,481 Hectares, and in turn, it has 12,196 Hectares in legal exclusions (Government of Sucre, 2020). Many of these solar projects are located on land suitable for agriculture and livestock. As the population increases, the consumption of electrical energy grows and the demand for food increases, in the not too distant future we will be facing the problem of using the land for electricity generation or agricultural activity.

This article proposes the implementation of an agrivoltaic system in the department of Sucre so that electricity generation and agricultural activity can coexist in the region. The microgrid with a storage system will allow efficient management of renewable energy sources, integrated into the conventional electrical network by applying an innovative management model through Industry 4.0 tools, which allows to lower the costs paid for the consumption of energy and agricultural activity, tests are carried out with crops from the region, such as: sweet pepper, sesame, beans, among others that are contemplated in the Colombian agricultural extension plans.

Solar photovoltaic system designed

The design has been carried out according to a study of agricultural farms on the Colombian Caribbean coast and the conventional electrical infrastructure available in the area. A photovoltaic system has been designed with a structure 4 meters high and 10 meters wide, in such a way that it allows agricultural work underneath, even for the passage of heavy machinery for plowing or other work. Each structure supports 60 panels. The pilot system has 600 panels, that is, 10 structures will be installed like the one shown in figure 3, until an area of approximately 1780m2 is completed, in the configuration shown in figure 4.

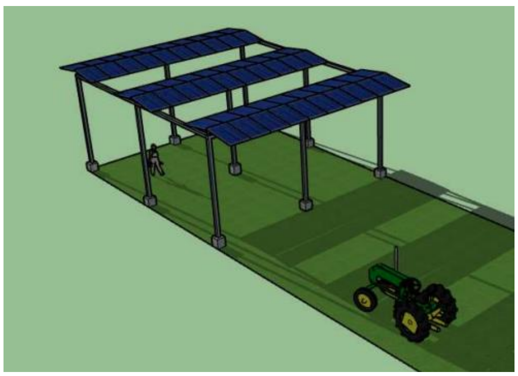

Figure 3. Photovoltaic system installation structure

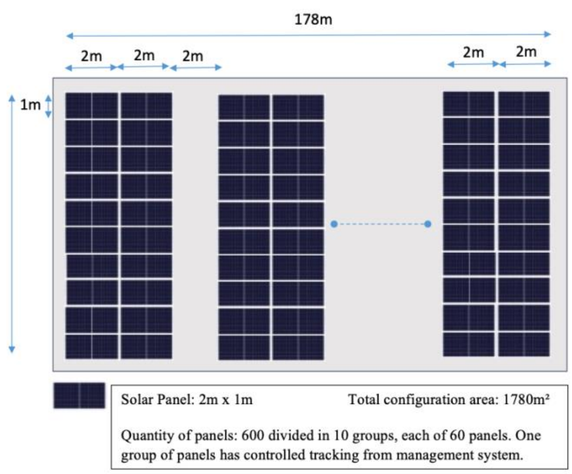

Figure 4. Solar panel installation configuration

Each group of 60 panels has an electrical design connected to the conventional network. Figure 5 shows the one-line diagram of each group of 60 panels, where the solar PV array consists of an inverter with the following configuration:

- Inverter 1; MPPT 1, 2 arrangements of 15 panels connected in series for a total of 30 panels, MPPT 2, 2 arrangements of 15 panels connected in series for a total of 30 panels which have the following electrical characteristics:

- Cheetah HC 72M-V Module
- Nominal power 465 Wp
- Vmpp 41.7 V
- Voc 49.8 V
- Impp 9.6 A
- Icc: 10.36 A
- Module efficiency 19.88%

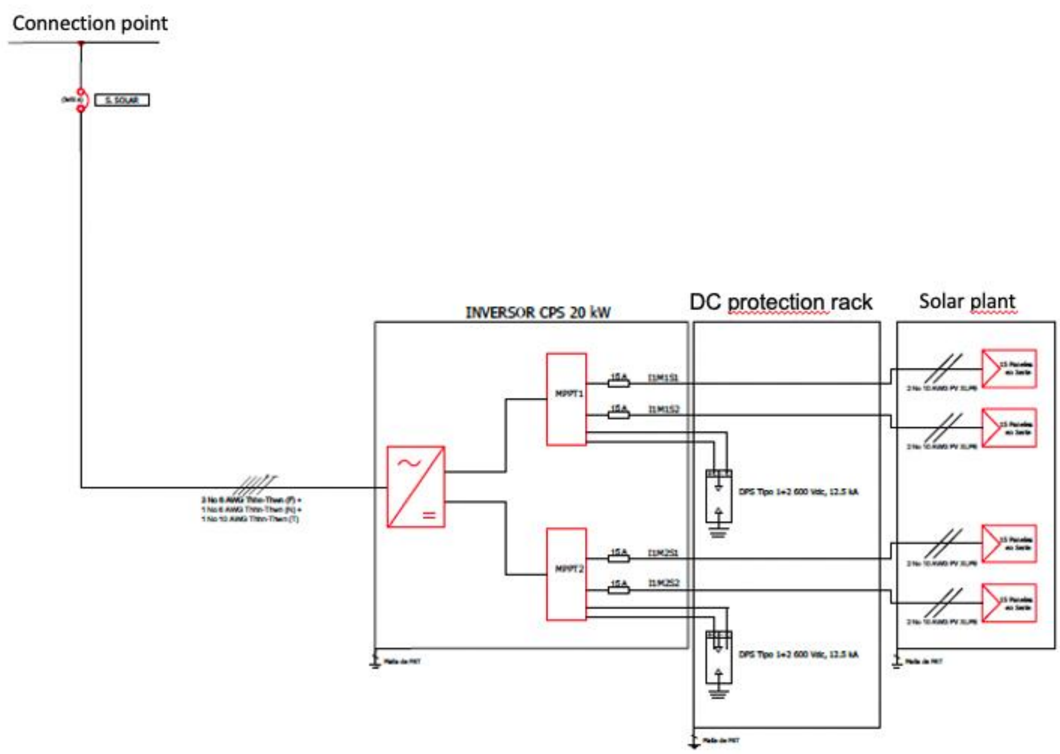

Figure 5. One-line diagram of each group in the solar system

In general, the system allows the generation of 279.93kWp (Jinko Photovoltaic Panel 465kWp. Quantity 600, Inverter CPS 50kWp. Quantity 4, Inverter CPS 20kWp. Quantity 1, Structural System with height 4m, connection to the conventional system, without affecting the land, Wiring and accessories, Bidirectional Meters, RETIE Certification. Equipment such as inverters and meters allow connectivity under RS485 protocol, which allows system management and configuration of a microgrid.

Modeling and analysis through Industry 4.0 tools

With the solar system operating, generation monitoring is proposed, control activities are carried out on each of the inverters to optimize the model (figure 6).

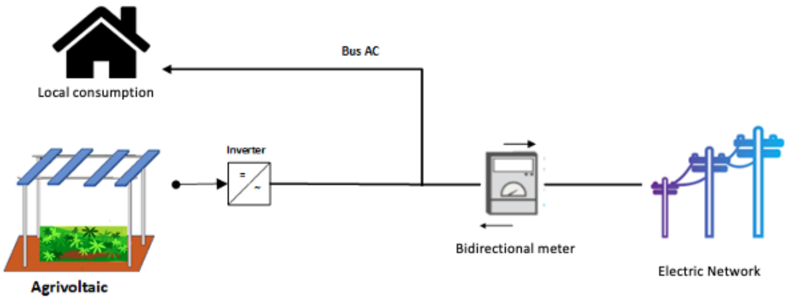

Figure 6. Agrivoltaic diagram

To study the impact of the agrivoltaic system on crops, a measurement system is implemented, based on a digital controller that will manage the various sensors, store the information and send the data to a central control for processing and analysis.

The measured variables are the following:

- Irradiation in the plane of the panels, horizontally and at the level of the crop.
- Ambient temperature and relative humidity.
- Humidity of floor.
- Power produced by the photovoltaic system.

Regarding solar resources, it is interesting to compare the existing radiation levels in the Caribbean region to know the great potential existing in the area, since this variable will allow knowing the electrical energy produced by the photovoltaic panels in the different months of the year.

Description of wireless sensors

Remote sensing is one of the preferred methodologies for obtaining information for non-invasive environmental monitoring. This technology has a number of applications in various areas of human activity, from scientific and ecological studies, to economic, urban and social prospects, and therefore also constitutes an instrument specifically used to obtain quantitative and qualitative information for decision making and policy setting.

Wireless networking technologies have seen rapid development in recent years. It has gone from infrared (Irda) for point-to-point communications to short-range and multipoint WPANs such as "BlueTooth" or multi-hop mid-range networks such as "ZigBee". Other more common wireless technologies today are WIFI technology for local networks (WLAN) and “WIMAX” for WMAN networks. Also, long-range cellular telephony (GPRS) or the development of M2M communications with wireless technology.

The most interesting development known so far is that of wireless sensor networks (WSN), due to its multiple applications, in different sectors of security, environment, industry and agriculture. The main technology analysts, within wireless technologies, value wireless sensor networks (WSN) as one of the most promising options for the future. Manufacturers such as Microsoft, Intel, IBM, Motorola and Texas Instruments, to name a few, have launched lines of research in this technology.

Wireless sensor networks (Wireless Sensor Networks) also fall within the concept of smart agriculture or smart farming driven by the trend of the internet of things proposed by Kevin Ashton at the Auto-ID Center of MIT in 1999. This concept "Internet of things "refers to the digital interconnection of everyday objects with the internet that allow greater intelligent interaction between user and machine. The IoT represents the next evolution of the Internet, which will be a huge leap forward in its ability to collect, analyze and distribute data that can be turned into information, knowledge and ultimately wisdom. In this context, IoT becomes immensely important.

IV. CONCLUSION

This article proposes a new model for the sustainable co-production of energy and agricultural products, through an agrivoltaic system, which includes the installation of a photovoltaic solar system supported by Industry 4.0 tools. When installed, the system will allow the carrying out of technological, agricultural and environmental studies, as well as the coexistence of electricity generation and agricultural activity in agricultural farms on the Colombian Caribbean coast, improving the competitiveness of farmers, since not only will they benefit from the sale of agricultural products but from the advantages of renewable energy sources, including the sale of the energy generated.

REFERENCES

Christensen, J. H., Kanikicharla, K. K., Aldrian, E., An, S. I., Albuquerque Cavalcanti, I. F., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J. K., Kitoh, A., Kossin, J., Lau, N. C., Renwick, J., Stephenson, D. B., Xie, S. P., Zhou, T., Abraham, L., Ambrizzi, T., … Zou, L. (2013). Climate phenomena and their relevance for future regional climate change. En Climate Change 2013 the Physical Science Basis (Vol. 9781107057999, pp. 1217-1308). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.028

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A., & Ferard, Y. (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. Renewable Energy, 36, 2725-2732. https://doi.org/10.1016/j.renene.2011.03.005

Espinosa Lilian, E. L. R. (2021). Hay más de 122 proyectos de energía solar y eólica avanzando siete departamentos. Diario La República. https://www.larepublica.co/especiales/el-poder-del-caribe-2021/hay-mas-de-122-proyectos-de-energia-solar-y-eolica-avanzando-siete-departamentos-3172704

Goetzberger, A., & Zastrow, A. (1982). On the Coexistence of Solar-Energy Conversion and Plant Cultivation. International Journal of Solar Energy, 1(1), 55-69. https://doi.org/10.1080/01425918208909875

Hatziargyriou, N. (2014). Microgrids: Architectures and Control. https://doi.org/10.1002/9781118720677

IEA – International Energy Agency. (2021). IEA. https://www.iea.org

Majumdar, D., & Pasqualetti, M. (2017). Dual use of agricultural land: Introducing 'agrivoltaics' in Phoenix Metropolitan Statistical Area, USA. Landscape and Urban Planning, 170. https://doi.org/10.1016/j.landurbplan.2017.10.011

Marrou, H., Guilioni, L., Dufour, L., Dupraz, C., & Wery, J. (2013). Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels? Agricultural and Forest Meteorology, 177, 117-132. https://doi.org/10.1016/j.agrformet.2013.04.012

Movellan, J. (2013, octubre 10). Japan Next-Generation Farmers Cultivate Crops and Solar Energy. Renewable Energy World. https://www.renewableenergyworld.com/solar/japan-next-generation-farmers-cultivate-agriculture-and-solar-energy/

Nonhebel, S. (2005). Renewable energy and food supply: Will there be enough land? Renewable and Sustainable Energy Reviews, 9(2), 191-201. https://doi.org/10.1016/j.rser.2004.02.003

RMI. (2021). Red Mountain Insights. https://redmountaininsights.com/

Widanagama Arachchige, L., Rajapakse, A. D., & Muthumuni, D. (2017). Implementation, Comparison and Application of an Average Simulation Model of a Wind Turbine Driven Doubly Fed Induction Generator. Energies, 10, 1726. https://doi.org/10.3390/en10111726