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Hybrid energy irrigation system compared to conventional energy: a systematic review

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***Abstract:** This research is a systematic review of the irrigation system with hybrid energy compared to conventional energy, between 2015 and 2022. The main objective is to evaluate the effects of the irrigation system activated with hybrid photovoltaic - wind energy compared to conventional energy for water supply in agricultural areas, explained on energy saving, CO2 reduction, and irrigation of agricultural areas. The methodology used is based on the Prisma 2020 Declaration, Scopus, Google Scholar, and Redalyc databases were used, finding 20 articles; the results demonstrate the importance of the use of new emerging technologies such as IoT, Artificial Intelligence, among others, optimizing the proper use of water resources in irrigation for agricultural areas, however, renewable energies, such as hybrids, must be incorporated; which applies in countries such as India, China, Italy, Hungary, Colombia, Brazil among others. It concludes with the benefits of hybrid energies compared to conventional ones since it does not pollute the environment, apply emerging technologies, and rationally use water for irrigation systems and food production.*

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***Descriptors:** "Irrigation system" OR "hybrid energies"*

***Keywords:** energy saving, CO2 reduction, water management, hybrid energy, and irrigation system*

I. Introduction

The article seeks to distinguish and synthesize the evidence on the hybrid energy irrigation system compared to conventional energy in Latin America and the world. It seeks to evaluate the effects of the hybrid energy irrigation system compared to conventional energy, between 2015 and 2022. A systematic review has been conducted following the PRISMA guidelines; of the studies found in Scopus, Google Scholar, and Redalyc and a total of 20 studies have been included. The results show that, due to the finite supply of fossil fuels, it is critical to developing innovative non-renewable energy systems that can reduce dependence on conventional energy sources [1]. Energy harvesting devices have also been found to increase the amount of energy [2]. Likewise, the use of conventional energy sources has increased over the years as the demand for energy has increased to better meet society's standard of living [3]. The growing need for energy has led to an increase in the use of energy from renewable energy sources [4] [5]. In addition, it is certain that hybrid power will play a key role in future electricity generation due to the rapid depletion of conventional power [5] [6]. For the above, this research proposes to analyze: what are the effects of irrigation systems with hybrid energy compared to conventional energy between 2015 and 2022? for which the following objective was proposed: To evaluate the effects of the irrigation system with hybrid energy compared to conventional energy, between 2015 and 2022, through a systematic review.

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II. Materials and methods

In the present research, it was determined to use under the PRISMA statement that allows an orderly sequence of evaluation of the activities developed within the research process. Therefore, to answer the research question, the following inclusion criteria have been considered: irrigation system, photovoltaic and wind hybrid energy, the energy produced by the gasoline motor pump, energy saving, reduction of CO2 emissions, water supply, an agricultural area, and that are carried out in Latin America and the world; then the following search equations were defined in English: TITLE-ABS-KEY("Irrigation system" OR "hybrid energies") AND

TITLE-ABS-KEY ("conventional energy" OR "Latin America") AND TITLEABS-KEY("Irrigation system" OR "conventional energy"), also used the following search equation ("Irrigation system" OR "hybrid energies") AND ("conventional energy" OR "Latin America") in the same way, database engines such as Google Scholar were determined, Redalyc, and Scopus, obtaining a total of 1024, 174 articles were excluded in duplicate, 100 because they were considered ineligible for automation tools such as Mendeley and Zotero, 150 for other reasons. After 600 that remained, 320 were excluded for not being aligned with the research question, later of 280 articles, 160 could not be retrieved, leaving 120 articles for eligibility, of which 60 articles were eliminated because they are less than 2014, 33 are not related to the research topic and 7 do not provide useful information for the study leaving only 20 articles for the review process. No reports or reports were taken into account.

III. Results

The search has included 1024 documents, of which 20 meet the inclusion criteria, through titles and abstracts, as well as that the articles are between 2015 and 2022. The PRISMA flowchart for this review is presented below as shown in Fig. 1.

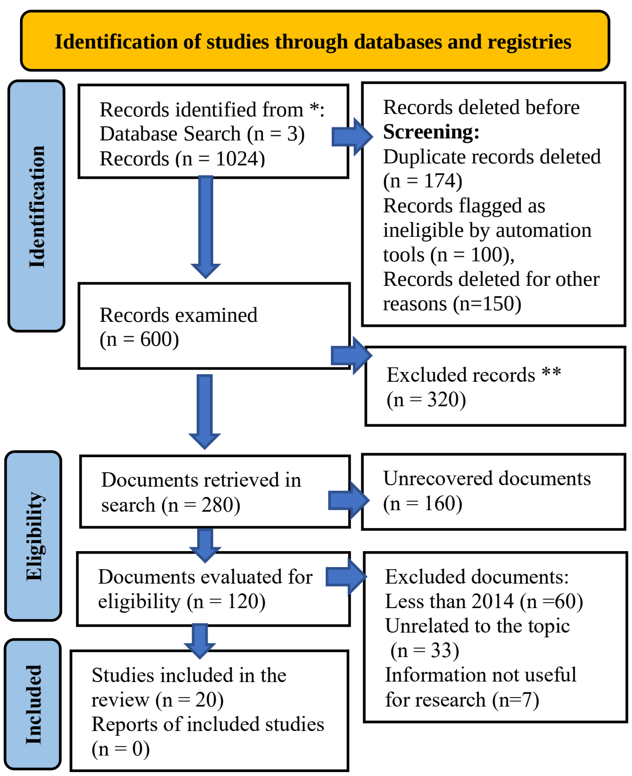

Fig. 1 PRISMA flowchart of the study selection. *Adapted* [7].

The results and findings found in the 20 articles of the present study, according to the inclusion criteria, are mentioned below, in Table 1.

Through the search in Scopus, during the period 2009-2019, and the VOSviewer© software as bibliometric tools, it is stated that it is important to analyze global trends in applied agent-based modeling (MBA) research to address the complexity inherent in agricultural systems [8]. In the same vein it is important to consider the constant supply of water either by rain, irrigation system services, along with innovative systems to ensure agriculture [9] [10]. Moreover, photovoltaic irrigation has been widely used in many areas without conventional energy sources; Solve the problem of unstable operation and little uniformity of irrigation caused by the diurnal variation of solar radiation, it is important to make a photovoltaic irrigation system of direct operation saving water with automatic regulation. By using automatic control technology and zonal rotation irrigation method, all the electrical energy generated by the solar panels can be converted into irrigation energy under different light intensities, so that water-saving irrigation equipment can work stably in different regions and irrigation uniformity is guaranteed in different regions [11]. In addition, considering that climate change could lead to water scarcity in the future, the lack of food in agricultural areas can be ensured by a treatment system to reduce the pollutant load of effluents with a domestic supply system coupled with a photovoltaic solar pump [10] [12].
Globally, there are concerns about food production such as Sichuan province, the main agricultural province and the only central grain-producing province in southwest China; since, in 2018, agricultural production in Sichuan province reached 34,937 million tons, including 14,786 million tons of cereal, 2,473 million tons of wheat and 10,663 million tons of corn, see Fig. 2. Likewise, the climatic condition has also changed, typically exhibiting characteristics of higher temperature and lower precipitation. This is also induced by the increase in CO2 emissions reported in the province annually [13]. In the same vein in Bangladesh, it was found that about 35% of installed solar pumps are used for irrigation purposes. Also, in Brazil in the provinces of Jaguaribe-Apodi, Tabuleiros de Russas, and Missão Vieja, the need for water supply for crops and dependence on the surface and/or groundwater sources is demonstrated [14] [15].

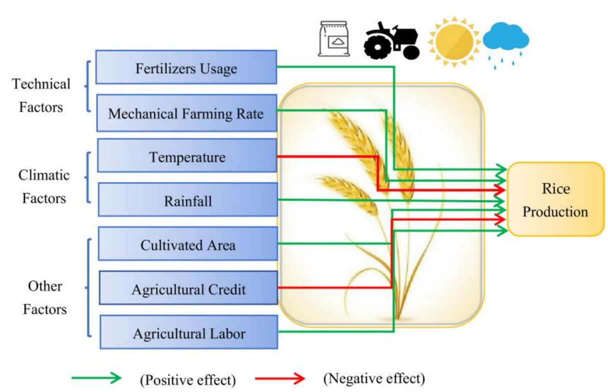

Fig. 2 Technical, climatic and other factors for rice production. *Adapted [13].*

Moreover, solar panels can meet the irrigation demand of a given area, which can guide the engineering design of solar irrigation to save water. In pumping systems, if we have higher values of solar radiation, the photovoltaic panel will provide more energy to the pump, generating higher pressures and flows to the irrigation system. However, this only happens when the system built under normal conditions takes advantage of the radiation of solar energy allowing a greater irrigated area, and increasing economic viability. In the same way, considering the angle of inclination of the solar panel is important; in fact, in India at the Energy Research Center, Chennai Institute of Technology, Kundrathur, Chennai it was found that the 8°, 15°, 30° and 45° tilt angles of the photovoltaic panel are related to the efficiency of the system and the pump [16] [17] [18].

On the other hand, the main factor that has a severe impact on the lives of millions of people below the poverty line is energy deficiency. To improve living standards and education, rural areas need to be electrified. India aims to achieve 175 GW of renewable energy capacity by 2022. In fact, the use of renewable energy technologies offers enormous benefits for rural areas. In general, during the last two decades, rural electrification has been a continuous process, accelerated through various programs and schemes [9]. Similarly in Bangladesh, a study shows that energy scarcity is critical, about 70% of its population is excluded from energy access, and most people are living in rural areas. That is why renewable energy resources, such as photovoltaic (PV) are becoming increasingly important as well as wind, biogas, minihydro and tidal. Therefore, it is important during the design of a photovoltaic system to include a maximum power point tracking controller (MPPT), and to consider that to provide the extraordinarily long service life of the lithium battery an optimal charging approach must be used that reduces the frequency of the battery charge and discharge cycle [19] [20].

According to Schindele et al. (2019), the Agrophotovoltaic system (APV), see Fig. 3, is a solar tracking system built on twoaxis suspended structures, where the solar panels are placed. The panels can be rotated by electric servo motors interconnected through a wireless control system, which will guarantee agricultural production [14]. In the same way, it is important to guarantee the supply of water for crops and dependence on the surface and/or groundwater sources. In the same vein, consideration should be given to reviewing strategies and policies to reduce the impact of climate change on food crop production and increase the adaptive capacity of farmers, as in the case of China [13] [15].

TABLE I

STUDIES INCLUDED IN THE REVIEW

Year of the publication of the article	Reference	Methodology	Place / Country	Dimension 1	Dimension 2	Author's contribution
March 1, 2021	Mora-Herrera, Denys Yohana; Huerta-Barrientos, Aida; Zúñiga-Escobar, Orlando (2021). [8]	Agent-based modeling (ABM).	Medellin Colombia	Review of Agent-Based Modeling (MBA)	Simulation of agricultural systems	MBA is applied under research and policy evaluation approaches in three main subject areas: computer science and systems, geography, environmental sciences, and ecology; to study essential phenomena of changes in land use, water management, and evaluation of agricultural policies.[8]
February 5, 2020	Balogh, J. M., & Jámbor, A. (2020). [11]	Systematic Review. Prism	Corvinus University Budapest, Hungary	Environmental impacts	Agricultural trade	Only a limited number of documents claim that the environment of a country or countries could benefit from agricultural trade. Research reveals the most important consequences of pollution and offers possible solutions. [11]
10 August 2022	Chandio, A. A., Nasereldin, Y. A., Anh, D. L. T., Tang, Y., Sargani, G. R., & Zhang, H. (2022) [13]	Literature Review	Sichuan-China	The impact of technological progress	Climate change in Food Crop Production	The study suggests that the Chinese government should consider reviewing its strategies and policies to reduce the impact of climate change on food crop production and increase farmers' resilience. [13]
2021	Junfeng Zhu, Xingtian Wang, Wenbing Liu, Shifeng Wang,and Qiujun Wang (2021). [16]	Optimization Design	International Conference on Energy Technology and Materials Science.	Photovoltaic direct drive water-saving irrigation system	Optimization design method	The minimum capacity of solar panels can meet the irrigation demand of a given area, which can guide the engineering design of solar irrigation to save water, and greatly improve engineering quality and energy utilization rate. It has the advantage of simple design, low cost, stable operation, and great energy saving. [16]

Year of the publication of the article	Reference	Methodology	Place / Country	Dimension 1	Dimension 2	Author's contribution
			Zhoushan, China			
30 June 2021	Sharma Akanksha, Singh H.P, Viral KK, Anwer Naqui. (2021) [21].	Use of Hybrid Energy	Uttar Pradesh. La India	Development of renewable energy in rural areas	CO_2 mitigation technologies and analysis	The study presents the current state of renewables in India, options are based on renewables for rural electrification, unique systems are technology-based, and power systems are integrated and hybrid based on resource availability [21].
28 February 2019	Gómez Paes Rafael. [17]	Localized irrigation methodology	Minas Gerais - Brazil	Performance of a photovoltaic irrigation system Autonomous	Energy storage in batteries	If we have higher values of solar radiation, the photovoltaic panel will provide more energy to the pump, generating higher pressures and flows to the irrigation system. However, this only happens when the built system, under normal conditions, takes advantage of the radiation of solar energy allowing a greater irrigated area, and increasing economic viability. Therefore, it is of great importance to use quality panels and that they work according to your specifications. [17].
May 2019	Setty, K. C., & Reddy, P. P (202). [19].	Energy demand and various types of renewable energy	Banglades h	Applications of non-conventional energy sources	Energy demand	The study shows that Bangladesh's energy scarcity is critical, about 70% of its population is excluded from energy access, and most people are living in rural areas. That is why renewable energy resources, such as photovoltaic (PV) are becoming increasingly important as well as wind, biogas, mini-hydro, and tidal. [19]
11 August 2022	Sohan, M. F. A. A., & Nahar, A (2022). [20]	MPPT and IOT methodology	Banglades h	A network of low-power wireless sensors	Smart irrigation system powered by solar energy	The results show that, to fully utilize solar energy, the system must include a maximum power point tracking controller (MPPT), and that to provide an extraordinarily long lifespan, for the lithium battery an optimal charging approach must be used that reduces the frequency of the battery charge and discharge cycle. This system can be deployed using low-power technology, making it suitable for Internet of Things (IoT) wireless sensor nodes. [20]
March 2021	S. Praveena (2022). [22]	Based on IoT, wireless networks, and Artificial Intelligence	Departmen t of Biomedical Engineerin g, Paavai College of Engineerin g, India	Implementation of agricultural sensors in irrigation systems	Artificial intelligence through dedicated machine Learning algorithm	According to the data collected by the temperature and humidity sensors, and other sensors in the greenhouse, the automatic greenhouse control system transmits information using the RS485 bus, which is connected to the system for display, alarm, and consultation. The monitoring center will display and store the sample of obtained data in tabular form and then compare it. At the same time, instructions can be sent and the fan, water pump, and other equipment can be sent to cool and humidify, thus ensuring a growing environment for the crop. [22]
12 November 2021	Hernández-RamírezIII, I., Fernández-HungIV, K., & Méndez-JocikV, C. A (2022). [12]	Quantitative-Qualitative	The central region of Cuba	Use of renewable energies in agricultural processes	Producing food	The problem of food insecurity in the central region of Cuba is addressed, in a context characterized by the depletion of conventional energy sources and the negative effects of climate change. A treatment system is proposed to reduce the pollutant load of effluents, a domestic supply system coupled to a photovoltaic solar pump, and an irrigation system compatible with the schedule of lower electricity consumption. The results have a positive social and environmental impact on the province of Avila. [12]
25 February 2022	Vishnupriyan, J., Partheeban, P., Dhanasekaran, A., & Shiva, M. (2022). [18]	Quantitative-Qualitative	Energy Research Centre, Chennai Institute of Technolog y, Kundrathur , Chennai 600069, India	Analysis of the variation of the inclination angle of the photovoltaic panel	Water pumping system	It was found that the 8°, 15°, 30° and 45° inclination angles of the photovoltaic panel are related to the efficiency of the system and the pump. For an inclination angle of 8°, a system efficiency of 68% and a pump efficiency of 46% was achieved. For a tilt angle of 15°, a system efficiency of 64% and a pump efficiency of 41% was achieved. For a 30° tilt angle, a system efficiency of 70% and a pump efficiency of 47% were achieved. For a tilt angle of 45°, a system efficiency of 66% and a pump efficiency of 45% was achieved. [18]

Year of the publication of the article	Reference	Methodology	Place / Country	Dimension 1	Dimension 2	Author's contribution
21 February 2022	Rahman, M. M., Khan, I., Field, D. L., Techato, K., & Alameh, K. (2022). [14]	Exploratory.	Departmen t of Electrical and Electronic Engineerin g, Jashore, 7408, Banglades h	Current state, future potential of agriculture	Challenges of renewable energy applications	It was found that about 35% of solar pumps installed in Bangladesh are used for irrigation purposes. In addition, the application of wind energy in agricultural irrigation can lead to higher plant performance and reduced energy costs with the integration of agriculture-compatible turbines. These systems are widely used in higher-income countries, such as Turkey, which has exceeded 7600 MW with 3500 turbines. Wind energy for agricultural applications in Turkey has increased in recent years. [14]
15 February 2022	Oliveira, V. R. D., Costa, R. N. T., Nunes, K. G., & Barros, V. D. S. [15]	Based on Water Footprint	Federal University of Ceará, (UFC), Fortaleza-CE, Brazil	The water footprint of bananas in the Brazilian semi-arid region	Implementation and Crop management in the different watersheds	It was found that the average agricultural water footprint of Jaguaribe-Apodi, Tabuleiros de Russas, and Missão Vieja was 998.3; 1048, and 1107 $m^3\ ^{T-1}$, respectively. For Missão Velha, the blue water footprint was 780.9 m^3 t-1 and for Jaguaribe-Apodi and Russas it was 830.6 and 862.7 $m^3\ ^{t-1}$, respectively. The regions studied demonstrate the need for water supply for crops and dependence on the surface and/or groundwater sources. [15]
April 29, 2022	Soto, J. P. T., Navarrete, O. G., & Martínez, J. C. G. (2022). [23]	The design was based on previous studies in the 2019	Finca el Porvenir in Cundinama rca, Colombia	Design proposal for a wireless sensor network and actuators	Irrigation, with the Internet of Things technology	Once the different materials and components to be used in the IoT architecture were decided, an irrigation prototype was used, which has a solenoid valve, and the corresponding programming was made, which was used for small and medium producers in Colombia [23].
June 27, 2022	Ali, E. A., Adame, M. M., & Bedadi, B. (2022). [9]	Based on smart water use practices for Transformation of agriculture	Ethiopia	Smart agriculture practices in the use of water.	Agricultural processing	The findings show that farming systems are shifting from traditional systems to more diversified systems that are commercialized and linked to agribusiness. These need to be more reliable, flexible, and diversified, and with constant water supply, either by rain or irrigation system services, along with innovative systems, different Smart practices regarding water use based on the Ethiopian case and also from global experience are compared [9].
3 June 2022	Tropea, M., Campoverde, L. M. S., & De Rango, F. [10]	SMART Irrigation Techniques	University of Calabria, Cosenza, Italy	IoT and Artificial Intelligence in the intelligent management of the irrigation system	Reinforcement Learning Models Vs. Fuzzy Logic	The results show that both the Reinforcement Learning Model and the fuzzy logic-based systems meet the requirements to achieve savings in water consumption, which has become very urgent, considering that climate change could lead to water scarcity in the future. In the proposed systems, IoT, sensors, Raspberry Pi, and Arduino devices have been used to control water pumps based on two important parameters: soil moisture and evapotranspiration. The evaluation and efficiency have been carried out considering the water and energy consumed [10].
1 December 2022	Basack, S., Dutta, S., & Saha, D. (2022).[24]	In-depth performance studies of a vertical-axis wind turbine	India	Study and installation of a wind turbine.	Performance of a Prototype Model of Vertical Axis Wind Turbine	The study considers that in-depth performance studies of a vertical axis wind turbine model should be carried out, including experimental and theoretical studies (analytical and numerical), as well as the application potential of the turbine, in order to consider its installation and operability [24]
March 2018	Brown-Manrique, O., Méndez-Jurjo, N., & Espinosa, M. B. (2018). [25]	Quantitative - Qualitative	Departmen t of Civil Engineerin g, Ciego de Ávila, Cuba.	Evaluation of a Motorized Micro Irrigation System	Wind power	The results showed that the multi-blade mill evaluated has a design flow of 25.00 $m3\ ^{d-1}$, produces a power of 261.36 W, and has 15.36 hours of pumping in the day. The micro irrigation system with wind drive has a storage tank of 5000 L that allows for meeting the water demand of the crop for the established irrigation area with a degree of satisfaction of 113%. [25]
2018	Ingalkar, A. M., Khekare, D. A., & Sabley, M. M. H. [26]	Based on the ATmega 16 microcontroller	Departmen t of Electrical Engineerin g, DBACER,	Smart irrigation with RF technology	Photovoltaic energy measurement	The results demonstrate the use of an intelligent system that uses solar energy to control the irrigation system. The sensors collect information about the water level of the rice paddies, the ATmega 16 microcontroller is used. The farmer can regulate, change, and turn the engine on and off according to the water level, even from distant

Year of the publication of the article	Reference	Methodology	Place / Country	Dimension 1	Dimension 2	Author's contribution
			Nagpur, India			locations using a cell phone using DTMF technology. [26]
April 14, 2021	Nakashima, K., Yanagihara, S., Muranaka, S., & Oya, T. [27]	Qualitative	Japan	Incorporate Technologies	Adapt to the climate change	There are currently 821 million people, more than one-ninth of the world's population, who do not get enough food to eat (World Food Programme 2020). In sub-Saharan Africa (SSA), where one in four of the population remains undernourished, it is expected to double by 2050, making achieving food security in terms of quantity and quality an immense challenge. [27]

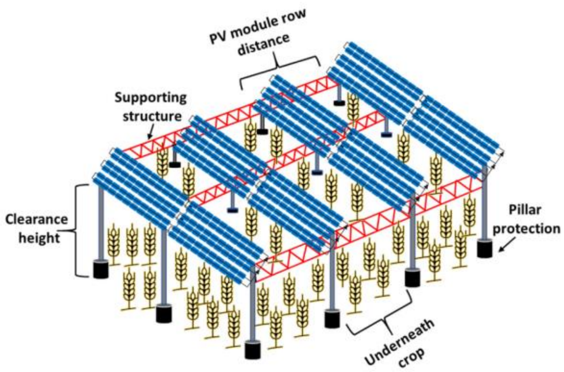

Fig. 3 A typical agrophotovolatic system. *From* [14]

There are different solar-powered water pumping systems, and the most popular design is based on photovoltaic panels. Fig. 4 is a schematic diagram of a solar-powered water pumping system based on photovoltaic panels, including an energy collection and conditioning system, a deep-water pump, and a water storage tank, however, energies such as biogas must also be taken into account, mini-hydraulic and tidal [14] [19].

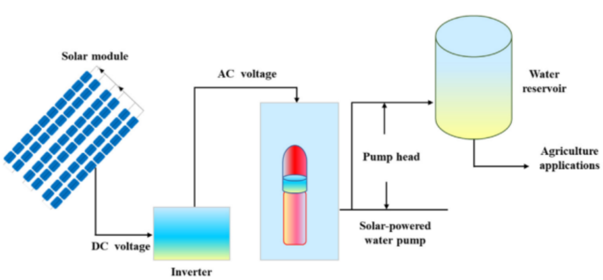

Fig. 4 A scheme of a solar-powered water pumping system. *From* [15].

On the other hand, the application of wind energy in agricultural irrigation can lead to a higher yield of the irrigation system and a reduction in energy costs with the integration of compatible turbines for agriculture, since by means of a submersible pump water can be extracted from the subsoil (see Fig. 5). In addition to that renewables are also considered for rural electrification, where single systems are technology-based and energy systems are integrated and hybrid according to resource availability [14] [21].

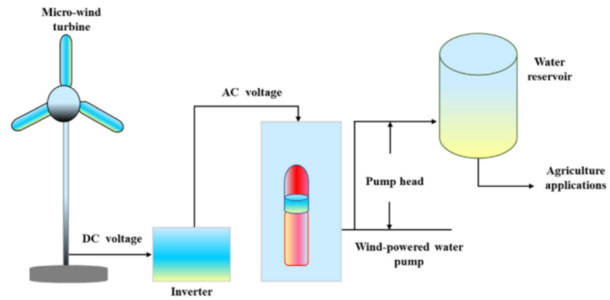

Fig. 5 A scheme of a wind-powered water pumping system. *From* [14].

The use of technology is a key factor for agricultural development, which is why IoT and Artificial Intelligence are used in the intelligent management of the irrigation system for agriculture. In this way an IoT system is basically composed of three different types of devices that use Raspberry PI and Arduino platforms, see Fig. 6. Where the respective IoT devices are illustrated in a work environment, controlled by actuators with IoT, as well as a tank that allows collecting the water that will be irrigated on the ground when necessary; a water pump that provides the necessary pressure to generate jets of water that must reach the plants, a filter that has the function of filtering impurities from the water such as small stones that can obstruct the water pump or even damage the pipes and a solenoid valve that allows or prevents the passage of water through the pipes [10]. In the same way in Bangladesh, a network of low-power wireless sensors has been considered to improve the irrigation system being this SMART and powered by solar energy [20]. In any solar-powered smart irrigation system, instructions can be sent and various components such as the fan, water pump, and other cooling and humidifying equipment can be sent, thus ensuring a growing environment for the crop [22]. Once the different materials and components to be used in the IoT architecture have been decided, it is recommended to use an irrigation prototype, which will have a solenoid valve, and perform the corresponding programming which will serve small and medium producers as was done in Colombia [23].

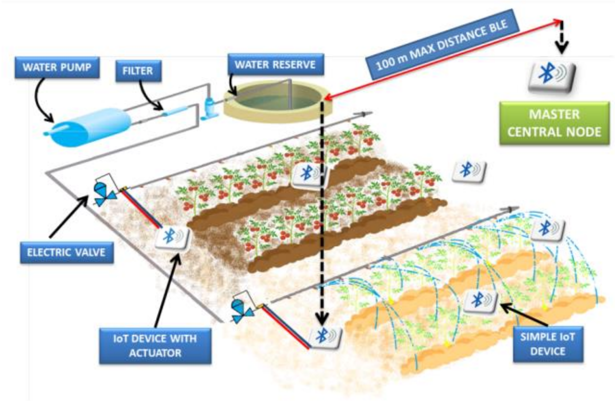

Fig. 6 Main components of the IoT system implemented. *Taken* [10]

IV. Discussion

In the selected research, there are many coincidences regarding the use of hybrid energy compared to conventional energies, in this regard it is valid to give importance to the agricultural sector both in agriculture and livestock [8] [9] [10], in the same line photovoltaic systems help the agricultural sector in improving irrigation systems allowing water savings and operating stably with uniformity of irrigation in different regions, ensuring its availability [10] [11] [12]. In addition, there is a relationship between the impact of technological progress, and climate change on Food Crop Production as evidenced in China [13] [14] [15]. In the same vein, several studies mention that photovoltaic irrigation has been widely used allowing energy to reach rural areas using renewable energy. It is also stated that the main factor that has a severe impact on the lives of millions of people under the poverty line is energy deficiency, which is why it is necessary to improve the standard of living and education accompanied by electrifying rural areas through hybrid energies [16] [17] [18] [24]. The findings indicate that the systematic review of the 20 selected articles, between 2015 and 2022, demonstrates the importance of the use of cutting-edge technologies such as IoT, Artificial Intelligence, with a single objective that is to achieve the efficient use of water resources since climate change is affecting this resource; therefore proper water management is needed; Many authors mention in their studies on different optics the use of hybrid energies, however, a very little talk about conventional ones, since it is considered that renewable energies are always more beneficial for the world community, more research is suggested in different contexts, especially in countries that were not represented.

V. Conclusion

In the present systematic review and according to the findings found, it is concluded that the trend worldwide is to use renewable energies, in various sectors such as the agricultural sector since this is a source of life for all human beings, accompanied by good rational use of water within irrigation systems. The findings of this review allow us to conclude that hybrid energies should be used instead of conventional ones since they do not pollute the environment, they are more efficient. Models have been detailed as good practices of the use of these renewable energy technologies, mainly hybrid, and it seems that it is likely that political, social, and cultural contextual factors will determine the correct use of these energies in the near future mainly in developing countries, where technologies such as IoT, Artificial Intelligence, Among others, they are having more and more effect on the rational use of water mainly for irrigation systems and therefore affecting food production.

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