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# Harnessing Renewable Energy for Sustainable Agricultural Applications

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**ABSTRACT**

The 2030 Agenda for Sustainable Development suggests that all countries both developed and developing strive to attain the seventeen sustainable development goals (SDGs). Some items on the SDGs like implementation of renewable energy technologies to electrify regions disconnected from power grids are targeted to eradicate extreme poverty and hunger while ensuring environmental sustainability. Hence, the role of integrated renewable energy in improving the productivity and environmental sustainability of the agricultural sector cannot be overemphasized. This paper presents a brief survey of the application of renewable energy resources technologies in the agricultural sector.

**Keywords:** Sustainable Agriculture, Water-food-energy Nexus, Renewable Energy, Techno-economic
**JEL Classifications:** Q2, Q4

## 1. INTRODUCTION

Energy is vital to human existence as it is required to meet various basic human needs ranging from food production to economic development (Oyedepo, 2012a; 2012b). Important activities that require energy inputs include: agricultural activities (irrigation, land preparation and fertilization, livestock rearing operations); household activities (lighting, food processing and conservation; cooking); commercial activities (lighting, processing); community and social services (water pumping, refrigeration in health centres, lighting of communal buildings) (Babatunde et al., 2018). Agriculture, however, requires intensive energy due to the following agricultural activities; water pumping for irrigation, refrigeration, drying agricultural products, livestock and many others in order to produce food for mankind (Oyedepo, 2013). These crucial agricultural operations are, however, of serious concern to stakeholders because a balance needs to be struck technically and economically to maintain a sustainable environment.

Hence, collective and integrated efforts must be explored in solving what has been regarded as a set of complex and interrelated multidisciplinary problems identified as threats to human civilization and existence. Majority of these challenges are associated with energy, water, and food production, particularly in developing countries. These aforementioned areas with challenges make up the foundation on which global security, prosperity, and equity stand. Based on this submission, energy, water, and food security have been identified as some of the key elements for achieving the United Nation's aspirational sustainable development goals (SDGs). The water–energy–food nexus is therefore proposed as a conceptual tool for the attainment of sustainable development. Many developing countries are faced with a difficult challenge of meeting the rising demands for food, clean water, and green energy, which is further compounded by climate change. According to (Rasul and Sharma, 2016), "effective adaptation to change requires the efficient use of land, water, energy, and other vital resources, and coordinated efforts to minimize trade-offs and maximize synergies." Deviation from this may result in the shortage of food production.

Water, energy, and food are critical to human existence, poverty eradication as well as sustainable development (Oyedepo, 2014). It is expected that the demand for clean water, energy and food will significantly rise over the next decades. This is due to the pressure that is exerted by population growth, urbanization, diet change, technological advancement, and change in social status, culture, mobility, economic development, and climate change (Hoff, 2011). Water is a very essential input resource in many agricultural productions (fishery, irrigation, forestry) and used to produce or transport energy in various state (FAO, 2011b). Consequently, 70% of the globally available freshwater extraction is credited to the agricultural sector. This makes the sector the highest consumer of freshwater globally. Furthermore, the production and supply of food account for 30% of the globally consumed energy (FAO, 2011a). Energy is essential for virtually every day agricultural activities such as irrigation, extraction, collection, lift, pump, and water treatment. With the development of new cities, there is an increasing demand for water energy and land resources with varying environmental consequences and resource scarcity in many cases. This challenge is expected to increase because, by 2050, the food expected to feed the population is predicted to increase by 60% (FAO, 2011b). Furthermore, by 2035, the global energy demand is expected to increase by approximately 50% (IEA, 2010). According to a report by FAO, "the total global water withdrawals for irrigation are projected to increase by 10 percent by 2050" (FAO, 2011b). The inter-relationship that exists among energy, water, and food security may experience a major challenge in the future. For example, between 1985 and 2008, South Africa was a major food exporter, but due to the population growth and decreased agricultural activities in recent years has become a major importer (Bazilian et al., 2011). Furthermore, between 2009 and 2010, the government of South Africa and Eskom announced electricity tariffs hike by 31% while also anticipating a rise of 25% for another three consecutive years (South African Government, 2008; ESKOM, 2008). Consequently, a major sector that could feel the effect of the electricity price hike in years to come is the agricultural sector due to its energy demand for irrigation and other farming related activities. Migrating from irrigation based-farming to rain-fed agriculture may ease the burden of tariff hikes but may as well pose a threat to the national food security especially during droughts. This is because 25% of the country's primary food is grown on irrigated farmlands (Bazilian et al., 2011). Elsewhere, farmland irrigation is responsible for about 15-20% of India's total electricity use (Bazilian et al., 2011). In India, irrigation loads are connected to the grid because electricity is subsidized (partially due to inadequate price signals). Due to this and lack of robust energy management of irrigation system, farmers pump underground water faster than can be replenished. As water levels drop, the energy required to irrigate increases and also the burden on the already weak and overtaxed grid (Hussain et al., 2010; Sallem et al., 2009) One alternative way to address these issues is the adoption of standalone renewable energy powered water pumps with adequate management technique that can introduce better pricing signals.

Adoption of renewable energy technologies in agricultural activities offers promising prospects in addressing trade-offs and leverage on interactions between improving water, energy, food security and climate change for sustainable agriculture. The fluctuating patterns of energy demand together with the desire for safe, reliable and environmentally sustainable supply alternatives require that the energy sector undergoes a transformation through the rapid adoption of renewables. The United Nations' "Sustainable Energy for All" agenda spells out an interesting goal of doubling the global renewable energy mix by 2030 (Griggs et al., 2013). This transformation presents both challenges and various opportunities for the energy, water and food sectors. Yet, research into the role of renewable energy within the water, energy and food nexus as well as the quantitative and qualitative knowledge on the impact of expanding renewables on these sectors remains discrete and narrow (Bazilian et al., 2011). One of such opportunities is the adoption of renewables for farmland and grassland irrigation. However, agricultural irrigation exerts pressure related to water and energy security. This is because food and energy demand is dependent on both population growth and climate change. The principal technical bottlenecks to irrigation of farmlands are access to clean and cheap electricity as well as energy and water management in such systems. The use of renewable energy technology with appropriate management techniques can relieve the burden on the grid, reduce energy and water requirements in the agricultural sector and the cost expended on irrigation.

## 2. ENERGY DEMANDS IN THE AGRICULTURAL SECTOR

In recent decades, energy demand has dramatically increased particularly in the agricultural sector. Not until the advent of fossil energy supplies, many of the world's agricultural activities have always been implemented by hand. The industrial revolution has increased human reliance on the use of fossil fuel (Giampietro and Ulgiati, 2005). Thereafter, the Green Revolution in the 1960s has inspired the use of energy in the agricultural sector. Present agricultural activities and mechanism which aim to optimize yield are extremely dependent on the use of fossil energy (Johansson et al., 2012). Subsequently, knowledge about the production system is crucial in order to properly evaluate the amount of energy required in the agricultural industry (Jordan, 2013). The energy demands in the agricultural sector are multifarious and include inputs, such as and fertilizers; water pumping; irrigation; machinery; and labor essential to the production processes (Wiedmann, 2009). The steady global growth of energy demand has increased cost in almost every sector. The agricultural sector is a basic rural economy and one of the key economic resources of many nations. A larger portion of the food production is from the rural settlers. They are involved in the subsistence production, processing, and storage of agricultural produce which require the use of energy. It has already been established that water supply and irrigation system are crucial to agricultural production (Shinde and Wandre, 2015). The pumping of water from the ground or surface is a key energy demand. Water pumping is an important factor in many agricultural activities such as irrigation, livestock support and other on-site operations including cleaning. It constitutes a substantial if not the largest energy demand in a particular agricultural sector. Thus, water pumping is a key energy demand, which incurs a significant cost in the agricultural sector.

Generally, the three major factors that drive the cost related to the irrigation are; availability of water, energy, and pattern of use. Conversely, this cost can be reduced by water-energy-saving irrigation system (Chandel et al., 2015). Pumping of water has traditionally been implemented with the use of conventional energy sources such as diesel or grid electricity. The depletion of fossil fuel and an unreliable power supply have made researchers to seek alternative means. Besides, the associated cost and environmental degradation are challenges that must be addressed. Interestingly, renewable energy sources have been found reliable for such applications. Furthermore, evidence has shown that the ever-increasing population growth will directly affect food consumption. Therefore, there is a need to improve on the agricultural production for food security. However, minimizing the waste of food is a viable alternative. Food wastage occurs mainly in three different phases; harvest, post-harvest, and marketing. A case study in India has shown that major waste of food occurs at the post-harvest phase and this leads to a significant economic loss (Prakash et al., 2016). For instance, perishable commodities can easily get damaged. Thus, one possible way to keep it fresh is to use a low-temperature storage technology. Unfortunately, this technique is found to be expensive and need a reliable energy source. Consequently, the drying process has been established as one of the preservation methods in order to reduce the loss of food (Sharma et al., 2009). The dried product can be stored for a lengthy period of time. However, drying is a heat and mass transfer process where energy is crucial (Kumar and Tiwari, 2007). Drying of agricultural product is extremely energy demanding. In the developed nations, about 10% of energy is devoted to drying operations (Kudra, 2004). Not until sometimes in the 1970s, these operations were basically powered with the use of fossil fuel. However, the oil crises in the 1970s prompted the adoption of alternative energy supply for drying of agricultural products. Fortunately, renewable energy sources are feasible possibilities which are environmentally friendly and economically viable (Akinbulire et al., 2014; Babatunde et al., 2018).

Nowadays, farming is more practiced in a mechanized way. The operations of these machines require a direct or indirect energy. Machines are employed for field preparation, planting of crops, chemical spraying and even harvesting of crops. Furthermore, the production of fertilizers or chemicals produced off the farm is energy demanding which also belong to the agricultural sector. Generally, the energy demand in the agricultural sector can be broadly categorized into direct and indirect demand (Table 1).

## 3. THE RELATIONSHIP BETWEEN WATER-ENERGY-FOOD NEXUS AND CLIMATE CHANGE

The concept of the water-energy-food nexus was introduced at the Bonn Nexus Conference, 2011 by the German Government. The concept was developed in reaction to climate change and social changes such as population growth, globalization, economic growth, and urbanization (Hoff, 2011). Water, energy, and food are the ultimate resources for human beings and society. In spite of the reduction of losses, there is a possibility that the demand for these resources will increase due to the population growth, climate change and other aspects of global change. Recently, the water-energy-food nexus has become a standalone technical term due to its increasing popularity.

Even though such a concept may have its shortcoming, the benefit of drawing a systematic concern of sustaining human future existence cannot be overemphasized. Particularly, the theoretical, practical, policy and management approaches to address Nexus (which is still at an infant stage) must be considered. The literature reported that the optimal policy spawned for water, energy, and food, was described in three general phases. The first is the incorporation of water resources to other various water sectors such as agriculture, industry, and others. Subsequently the integration of various types of energy sources such as gas, oil, coal, nuclear and renewable energy follows. The second stage centers on the protection of the nation, human health, and other livelihood services. Issues surrounding water, energy and food security were treated separately before the birth of Nexus. The third stage established the optimal policy for the interconnected relationship of water, energy and food system. The water-food nexus aims to minimize the rate of water consumption for the production of food and to improve the productivity of water resources for food preparation. A study conducted in 2007 described the environmental activities of the water-food nexus which includes the analysis of food imports (Qadir et al., 2007). Also, an improvement of the application of green water and preclusion of depleted residual soil moisture after harvest with low water consumption was explored by (Karimi et al., 2012). Meanwhile, a study conducted by (Akangbe et al., 2011) focused on the environmental activities, social, economic and governance approaches which center on the climate protection models for agriculture.

The activities of water-energy nexus have been known for many years. For instance, water is an active resource in the production of energy such as hydropower generation and biofuel; pumping of water for food production and treating of wastewater also consume energy. The study of Hardy (Hardy et al., 2012) revealed that agricultural irrigation in the Spanish water industry requires a large quota of energy consumption. However, the synergy of the water-energy-food nexus was encouraged through an integrated water

**Table 1: Energy demand in the agricultural sector**

| S/N | Direct energy demand | Indirect energy demand |
|---|---|---|
| 1 | Pumping of water/irrigation | Farm machinery and buildings |
| 2 | Drying | Pesticides production |
| 3 | Other farm activities | Fertilizer production |

resource management. Furthermore, a study conducted by (Karimi et al., 2012) established that the higher the application of irrigation, the higher the energy consumption, the lower the carbon emission of groundwater. An investigation of the land and water requirements for the production of bioethanol by using maize was discussed by (Yang et al., 2009). Multiple perceptions on the regional integration of hydropower investment, irrigation reform and power market development were reported by (Granit et al., 2012).

Nowadays, the concern of climate change is increasing and frequently debated around climate variability sectors. The increasing climate change results from the activities of notable sectors such as agriculture and other industrial activities (Pardoe et al., 2018). Rainfall is a major source of water and important in the food preparation and agricultural sector. Still, both agriculture and hydropower are reliant on the rainfall. Nevertheless, it is possible that the quantity of rainfall, timing, and its intensity be varied due to climate change. Some climate-related nexus actions have steered towards curtailing the susceptibility of climate-induced tragedy and environmental poverty in the long term. Figure 1 depicts one of the inseparable relationships these ultimate resources have in common with climate change.

## 4. SUSTAINABILITY IN AGRICULTURE

Climate change is one of the greatest threats to mankind in the 21st century. The rise in global temperature is the main cause of the changes in the earth's natural systems. The increase in global temperature is responsible for the sudden change in the regular cycle of the ecosystem to cause natural disasters such as droughts, flooding, and early frosts. Consequently, the extreme climate is aggressively threatening the future sustainability of the agricultural sector and food supply. It is reported by UN that if the global temperature rises by 3°C, the effect could be negatively drastic on water and food supply, biodiversity, pests, disease proliferation and outbreak, during planting and harvesting times. Consequently, this may negatively impact crop yield and livestock thereby resulting in a failure to meet food demand.

Researchers have found out that it is essential for global agriculture and food security to achieve the long-term goal of limiting the increasing global temperature to <2°C compared to the temperature experienced in the pre-industrial era, in order to avoid catastrophic consequences. Climate change will result in negative consequences for small-scale farmers in rural communities thus impeding the certainty of food security. As a result, building flexibility to the effects of climate change and limiting agro-based emissions of greenhouse gases is important. It has been reported that the agricultural sector accounts for almost 24% of the total greenhouse gas emissions globally (Lenka et al., 2015). Based on this, the agricultural sector can play a significant role in addressing climate change by implementing smart and green agriculture techniques to guarantee farm level resilience against climatic fluctuations.

The use of renewable-powered technologies in the agricultural sector has a tendency to mitigate climate change. Renewable energy is power generated by the use of natural resources that are perpetually replenished. The utilization of RETs does not contribute to natural resource depletion and emissions. Renewable energy is potentially able to provide solutions (which are effective and sustainable) to the various problems of conservation in agriculture. Examples include solar, wind, biomass, hydropower, and geothermal. RETs represent a viable alternative to fossil fuels and can be used to generate heating and/or electricity. This will contribute to sustainable agriculture.

The sustainability of agriculture is based on the concept of increasing the productivity of crops and ensuring a stable economy while ensuring a massive reduction in the use of natural resources and the negative effects of climate change (Yunlong and Smit, 1994). The sustainability of agriculture should be a shared societal responsibility which should be guided by widely accepted regulations and principles (McPherson, 2011). The principles and practices involved in sustainable agriculture are discussed in Table 2.

**Figure 1:** A schematic representation of interactions of water, energy, food and climate change (adapted from [Zhang and Vesselinov, 2017])

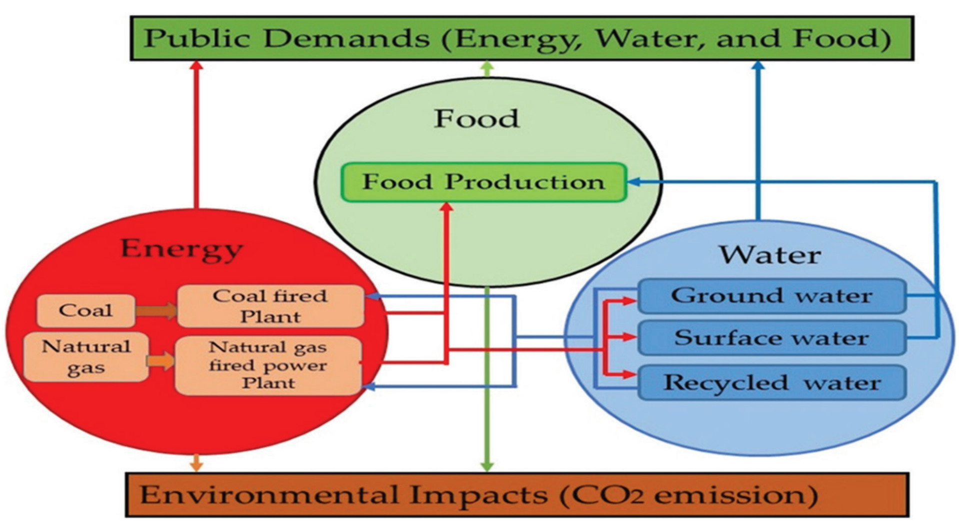

**Table 2: Sustainability in agriculture**

| Principles of sustainable agriculture (McPherson, 2011) | Sustainable practices of agriculture (Tilman *et al.,* 2002) |
|---|---|
| A sustainable agricultural system ensures the continuous protection of the natural environment through the conservation of natural resources. | The use of rotational grazing which reduces the costs of animal feeds while providing high-quality animal feed. |
| A sustainable system of agriculture is dependent on the efficient management and utilization of renewable energy resources. | The use of methods of soil conservation to prevent the loss of soil via erosion. |
| A sustainable system of agriculture is based on environmental ethics which ensures the protection of all water, soil, biotic and air species. | The use of information technology for efficient management of crops. The use of water conservation practices for the protection of wetlands. |
| Sustainable practices possess techniques which are non-toxic and harmless. | The use of pest management tools for the reduction of risks related to environment and health. |
| A sustainable system of agriculture provides profits for agricultural users and investments. This is because sustainable agricultural practices are based on efficiency and effectiveness which leads to profitability. | The use of management practices for nutrients used for the nourishment of crops such as fertilizer and manure. This ensures a cheap and cost-effective use of nutrients. |
| A sustainable system of agriculture ensures an improvement in the quality of life of members of a community and society through the creation of opportunities in terms of employment, social services, education, and healthcare. | The use of agroforestry practices for conservation of the natural environment. Renewable energy can also be used to implement sustainable practices of agriculture. |

## 4.1. Applications of Renewable Energy in Agriculture

Renewable technologies are now being used to meet various energy requirements ranging from pumping of water to space heating within the agriculture sector. Renewable energy use in agriculture has the ability to solve various challenges related to the use of fossil fuel as it involves little or no production of environmental emissions and non-reliance on imported fuels. The application of renewable energy in agriculture therefore yields huge profits. Renewable energy sources can be harvested for life, providing a long-term source of revenue for agriculturists. Presently, there are various cases of farmers and ranchers involved in the production sale of excess energy. This contributes significantly to the continuous development in energy security within the agriculture sector. This further result from the independent supply of energy reduced environmental pollution and the application of diverse energy sources. Renewable energy sources like solar, wind, geothermal and biomass have various applications in agriculture as discussed in the next sub-section.

## 4.2. Solar Energy

Solar energy is useful in agriculture in various ways which include maximizing self-reliance, saving funds, and reduction of pollution. Solar energy reduces electricity consumption thereby saving cost.

Solar energy is advantageous in agricultural applications by ensuring (Chel and Kaushik, 2011):

- Low cost of farm operations through the elimination of fuel/diesel use.
- Low rate and level of maintenance through the absence of moving parts in solar panels.
- System reliability thereby ensuring the efficiency of farm operations.
- Clean form of energy thereby preventing gas emissions and ensuring environmental conservation.

With photovoltaic (PV) systems, there is a cheap provision of electricity for agricultural operations in ranches, farms, and orchards. The use of Photovoltaic systems is cheaper than the use of transformers and power lines for applications in farm operations like the lighting of agricultural lands, pumping of water for crop irrigation or watering of livestock, and electric fencing (Carbone et al., 2011). One of the simplest applications of photovoltaic in the agricultural sector is pumping of water. The use of pumping systems powered by photovoltaic can be used for a wide variety of watering purposes ranging from watering of stocks to irrigation of crops and use in domestic activities (Schwarz, 2006). The PV system has water storage abilities during the absence of sunshine which removes the need for the use of battery thereby increasing system simplicity and reducing the overall cost of operating the system. PV systems can also be applied in orchards, farms, and ranches through (Xue, 2017):

- Refrigeration of agricultural product.
- Cheap provision of power for grinding agricultural products.
- Photovoltaic systems for egg collection and egg handling.
- Photovoltaic powered pumps and compressors for use in fishery.
- Photovoltaic powered livestock feeding equipment.
- Photovoltaic powered fencing for protecting livestock.

Furthermore, the use of solar energy for the production of heat has a wide variety of applications in agricultural operations (Chikaire *et al.,* 2010). These applications include;

- Solar water heaters (used for cleaning domestic animals) in the production of livestock.
- Drying of grains and crops via exposure to the sun.
- The use of solar-powered driers for effective and hygienic drying of crops.

Solar energy also has agricultural applications in greenhouse heating. While solar energy can only be used for purposes of lighting by conventional greenhouses (Carbone et al., 2011), solar greenhouses are capable of using solar energy for both purposes of lighting and heating (Bellows and Adam, 2008). Greenhouses depend on heaters powered by oil or gas for proper maintenance of temperatures needed for the growth of plants in the months having cold weather (von Zabeltitz, 1986). A solar greenhouse has a thermal mass for collection and storage of solar heat energy and also has an insulation chamber to prevent the loss of heat which is required for use during cloudy days and night. In the northern hemisphere, a solar greenhouse is oriented to maximize southern glazing exposure (Taki et al., 2017). Solar greenhouses minimize the need for fossil fuels for heating purposes. Sonneveld et al. gave an in-depth analysis of the design and development of a greenhouse having an integrated filter which works as a delivery system and reflects near infrared radiation (NIR) (Sonneveld et al., 2009). The filter uses a cover which is spectral selective to ensure that about 35% of the solar energy found outside the region of the greenhouse is blocked, this will, therefore, ensure a reduction in the capacity which is needed for cooling. The NIR coating can be integrated with a solar energy system since the reflection of solar energy present in a Photovoltaic cell ensures the delivery of electricity. They made a computer program which traces ray(s) of light thereby creating an optimal geometry of the reflector using the collecting efficiency as a reference. Sonneveld et al. established that the issue of Cooled greenhouses is very important to solve the challenge of high global radiation and high outdoor temperatures combination (Sonneveld et al., 2009).

### 4.3. Wind Power

The wind power source is different from solar power as it lasts for 24 h on a daily basis. Both mechanical and electrical energy is generated by wind energy technologies for agricultural use. Wind power technology is identified as the fastest growing renewable energy technology overtaking bio-power. In the United States, there are already plans in motion by the U.S. Department of Energy (DOE) to make wind energy become the producer of five percent of the electricity used in the nation by 2020 (U.S. Department of Energy, 2010). The improvements in technology through the development of hybrid energy systems will continue to increase the economic efficiency involved in the use of wind energy. This will encourage agricultural producers to maximize their engagement in wind power infrastructure for reductions in costs of energy thereby leading to self-sufficiency. The use of wind energy is very reliable and cost-effective for solving various needs of power on ranches and farms. Wind turbines can be used for the construction of water pumps for the purpose of irrigation and can also be used for generating electricity thereby eliminating the cost of installing transformers, electric poles and power lines which are used for conventional power generation (Clark, 1991).

Windmills powered by wind energy are used to grind legumes and grains used in farms (Halliday and Lipman, 1982). Wind energy is environmental-friendly as it does not need diesel/ fuel for operation. This ensures a reduction in noise and air pollution. Among others, it prevents the formation of toxic and radioactive waste, it prevents the emission of greenhouse gases, and it prevents acid rain by minimizing the concentration of oxide compound (Kondili and Kaldellis, 2012). The use of wind-powered farms is very feasible economically through a strong reduction of maintenance and operation costs, non-necessity for use of fuel, and the need for fuel importation is minimized (Leung and Yang, 2012). According to Ali et al., the use of small wind generators can provide electricity within the range of 400 watts to 40 kilowatts or more, which can cater for all operations taking place in the farm (Ali et al., 2012). Farmers and ranchers can, therefore, become wind energy producers as it requires only a small space of land for its development. The use of net metering will allow farmers and ranchers to gain huge benefits from the use of wind turbines in their farms and ranches respectively (Poullikkas et al., 2013). When power produced by a turbine is more than the instantaneous power required on the farm, the excess power flows back to the source of electricity for other farm operations and needs, causing a backward movement by the electric meter. When power produced by a turbine is less than the power required at that moment by the farm, there is a forward spin by the meter.

### 4.4. Biomass Energy

The renewable energy source of biomass can be obtained from organic wastes (generated from agricultural activities) and plants which include trees, crops, manure, and crop residues. There can be a large production of crops and biomass wastes which will be used for the purpose of energy production through conversion. The converted energy can be used by energy companies dealing in the production of fuel for vehicles, and power for use in homes and businesses. The U.S. Department of Energy states that the use of biomass energy could bring about reductions in greenhouse gas emissions and could also realize over $20 billion in revenue for rural communities and agriculturists (U.S. Department of Energy, 2003). Although most residues or wastes from crops and animals are used for the reduction of erosion, recycling of soil nutrients and reduction of disposal costs, some of the waste could also be used beneficially for the production of energy without causing any type of destruction to the soil (Jovanovski et al., 2005). Biomass energy can be used in small-scale farming without any form of artificial processing. Biomass is used majorly in agriculture for bringing improved sustainability to farming systems.

Biomass is also used for the development of biorefineries which have numerous applications in agriculture. A biorefinery is an industrial facility or technology that converts biomass resources to energy and other valuable products such as electricity, ethanol, steam, biodiesel and high-value chemicals (Elmekawy et al., 2013). These products are an efficient replacement for petroleum in use as a chemical feedstock and vehicular fuel which brings about a reduction in greenhouse gas emissions and an increase in energy security. With a biorefinery, corn can be converted to animal feed, corn syrup, and ethanol while trees can be transformed into a number of wood products, heat, and electricity.

### 4.5. Geothermal Energy

The use of geothermal energy which is the combination of heat and water is very common in agriculture. Three types of power plants powered by geothermal energy are presently in operation which includes: Binary-cycle plants, dry steam plants, and flash steam plants. Geothermal energy can be used indirectly for electricity generation and directly for the production of hot fluids which can be used in farming and fisheries operations. Such operations include dehydration of alliums, heating buildings, milk pasteurization, and growing plants in greenhouses (Lund, 2010). Geothermal resources with a high temperature of over 149°C can be used to generate electricity in agriculture. Geothermal technologies can improve agriculture and ensures economic efficiency through the use of cascade where the same source is simultaneously used for different purposes, thereby making geothermal energy a reliable resource for agriculture (Lund, 2010).

## 5. CONCLUSION AND RECOMMENDATIONS

The opportunities involved in the use of renewable energy for agriculture include energy efficiency and self-sufficiency/ independence while the challenges involved include difficulty in obtaining accurate data in undeveloped and developing nations, high costs of initial investments on renewable energy startups, lack of technical skills on installation and maintenance, lack of societal awareness on the benefits of renewable energy, and lack of incentives to encourage agriculturists, and stakeholders in the agricultural sector to participate in the use of renewable energy. These challenges can be solved effectively through partnerships between governments and the private sector and through international collaboration between nations.

In summary, renewable energy guarantees clean energy farming by carrying out agricultural practices whilst ensuring the protection of the environment and improving the efficiency of energy thereby saving energy and finances. Following recommendations are suggested:

1. The use of renewable energy sources for powering agricultural related activities can reduce the expenditure on energy and consequently increase the overall profit of the business. Flexible and cost-effective methods by which these technologies can be adopted are important.
2. With the use of renewable energy sources to power agricultural activities, emissions to the atmosphere can be curtailed thereby reducing the contributions of agricultural related activities to global warming. Investigations on the type of environmental related incentives that will encourage the use of renewable energy are of importance.
3. Business-friendly state legislation that encourages adoption of renewable electricity generation in the agricultural sector should be passed. Creation of an innovative public benefits fund to leverage private investment in renewable energy projects benefiting the agricultural sector is also essential.
4. The installation of small-scale energy capacity within the agricultural business should be encouraged. It will help in combating climate change and improvement of business viability.

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## REFERENCES

Akangbe, J.A., Adesiji, G.B., Fakayode, S.B., Aderibigbe, Y.O. (2011), Towards palm oil self-sufficiency in Nigeria: Constraints and training needs nexus of palm oil extractors. Journal of Human Ecology, 33(2), 139-145.

Akinbulire, T.O., Oluseyi, P.O., Babatunde, O.M. (2014), Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria. International Journal of Energy and Environmental Engineering, 5(4), 375-385.

Ali, S., Dash, N., Pradhan, A. (2012), Role of renewable energy on agriculture. International Journal of Engineering Sciences and Emerging Technologies, 4(1), 51-57.

Babatunde, D.E., Babatunde, O.M., Akinbulire, T.O., Oluseyi, P.O. (2018), Hybrid energy systems model with the inclusion of energy efficiency measures: A rural application perspective. International Journal of Energy Economics and Policy, 8(4), 310-323.

Babatunde, O., Akinyele, D., Akinbulire, T., Oluseyi, P. (2018), Evaluation of a grid-independent solar photovoltaic system for primary health centres (PHCs) in developing countries. Renewable Energy Focus, 24, 16-28.

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R.S.J. (2011), Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy, 39(12), 7896-7906.

Bellows, B., Adam, K. (2008), Solar greenhouses. Sites J Twent Century Contemp Fr Stud, 9140, 1-27.

Carbone, R., De Capua, C., Morello, R. (2011), Photovoltaic systems for powering greenhouses. In: 3rd International Conference on Clean Electrical Power: Renewable Energy Resources Impact. Otranto: ICCEP. p474-479.

Chandel, S.S., Naik, M.N., Chandel, R. (2015), Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renewable and Sustainable Energy Reviews, 49, 1084-1099.

Chel, A., Kaushik, G. (2011), Renewable energy for sustainable agriculture. Agronomy for Sustainable Development, 31(1), 91-118.

Chikaire, J., Nnadi, F.N., Nwakwasi, R.N., Anyoha, N., Aja, O.O., Onoh, P.A., Nwachukwu, C.A. (2010), Solar energy applications for agriculture. Journal of Agricultural and Veterinary Sciences, 2,58-62.

Clark, R.N. (1991), Design and initial performance of a 500-kW vertical-axis wind turbine. Trans ASME, 34(3), 986-991.

Elmekawy, A., Diels, L., De Wever, H., Pant, D. (2013), Valorization of cereal based biorefinery byproducts: Reality and expectations. Environmental Science and Technology, 47(16), 9014-9027.

FAO. (2011a), Energy-smart Food for People and Climate. Rome: Issue Paper. p1-78. Available from: http://www.fao.org/3/a-i2454e.pdf.

FAO. (2011b), The State of the World's Land and Water Resources for Food and Agriculture (SOLAW)-Managing Systems at Risk. Food and Agriculture Organization of the United Nations. London: Rome and Earthscan. p1-308. Available from: http://www.fao.org/3/a-i1688e.pdf.

Giampietro, M., Ulgiati, S. (2005), Integrated assessment of large-scale biofuel production. BPTS, 24(5-6), 365-384.

Granit, J., Jägerskog, A., Lindström, A., Björklund, G., Bullock, A., Löfgren, R., Pettigrew, S. (2012), Regional options for addressing the water, energy and food nexus in central Asia and the aral sea basin. International Journal of Water Resources Development, 28(3), 419-432.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Noble, I. (2013), Policy: Sustainable development goals for people and planet. Nature, 495(7441), 305.

Halliday, J.A., Lipman, N.H. (1982), Wind energy in agriculture. Wind Engineering, 6(4), 206-218.

Hardy, L., Garrido, A., Juana, L. (2012). Evaluation of Spain's water-energy nexus. International Journal of Water Resources Development, 28(1), 151-170.

Hoff, H. (2011), Understanding the Nexus. Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm: Stockholm Environment Institute. p1-52.

Hussain, Z., Azam, M., Irfan, M. (2010), Soil and tillage research water energy and economic analysis of wheat production under raised bed and conventional irrigation systems : A case study from a semi-arid area of Pakistan. Soil and Tillage Research, 109(2), 61-67.

IEA, O. (2010), OECD, and World Bank. Analysis of the Scope of Energy Subsidies and Suggestions for the G-20 Initiative. Washington D.C: World Bank. p26-27.

Johansson, T.B., Patwardhan, A., Nakicenovic, N., Gomez-Echeverri, L., Turkenburg, W.C., Council, G.E.A. (2012), Global Energy assessment-toward a sustainable future. Global Energy Assessment, 1, 1-33.

Jordan, C.F. (2013), An Ecosystem Approach to Sustainable Agriculture.

Dordrecht: Springer Netherlands. p1-246.
Jovanovski, N., Jovanovska, V., Michailov, M. (2005), Alternative and Renewable Energy Sources. Orlando, Florida: 33rd International Conference Symposium Actual Tasks on Agricultural Engineering. p37-42.
Karimi, P., Qureshi, A.S., Bahramloo, R., Molden, D. (2012), Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran. Agricultural Water Management, 108, 52-60.
Kondili, E., Kaldellis, J.K. (2012), Environmental-social benefits/impacts of wind power. In Comprehensive Renewable Energy, 2, 503-539.
Kudra, T. (2004), Energy aspects in drying. Drying Technology, 22(5), 917-932.
Kumar, A., Tiwari, G.N. (2007), Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. Journal of Food Engineering, 79(4), 1337-1350.
Lenka, S., Lenka, N.K., Sejian, V., Mohanty, M. (2015), Contribution of agriculture sector to climate change. In: Climate Change Impact on Livestock: Adaptation and Mitigation. New Delhi: Springer. p37-48.
Leung, D.Y.C., Yang, Y. (2012), Wind energy development and its environmental impact: A review. Renewable and Sustainable Energy Reviews, 16(1), 1031-1039.
Lund, J.W. (2010), Direct utilization of geothermal energy. Energies, 3(8), 1443-1471.
McPherson, B.D. (2011), Urban Agriculture: Design Principles for Enhancing Sustainability. ProQuest Dissertations and Theses. p1-98.
Oyedepo, S.O. (2012a), Energy and sustainable development in Nigeria: The way forward. Energy, Sustainability and Society, 2(1), 15-25.
Oyedepo, S.O. (2012b), On energy for sustainable development in Nigeria. Renewable and Sustainable Energy Reviews, 16(5), 2583-2598.
Oyedepo, S.O. (2013), Energy in perspective of sustainable development in Nigeria. Sustainable Energy, 1(2), 14-25.
Oyedepo, S.O. (2014), Towards achieving energy for sustainable development in Nigeria. Renewable and Sustainable Energy Reviews, 34, 255-272.
Pardoe, J., Conway, D., Namaganda, E., Vincent, K., Dougill, A.J., Kashaigili, J.J. (2018), Climate change and the water energy food nexus: Insights from policy and practice in Tanzania. Climate Policy, 18(7), 863-877.
Poullikkas, A., Kourtis, G., Hadjipaschalis, I. (2013), A review of net metering mechanism for electricity renewable energy sources. International Journal of Energy and Environment, 4(6), 975-1002.
Prakash, O., Laguri, V., Pandey, A., Kumar, A., Kumar, A. (2016), Review on various modelling techniques for the solar dryers. Renewable and Sustainable Energy Reviews, 62, 396-417.
Qadir, M., Sharma, B.R., Bruggeman, A., Choukr-Allah, R., Karajeh, F. (2007), Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agricultural Water Management, 87(1), 2-22.
Rasul, G., Sharma, B. (2016), The nexus approach to water energy food security : An option for adaptation to climate change an option for adaptation to climate change. Climate Policy, 16(6), 682-702.
Sallem, S., Chaabene, M., Kamoun, M.B.A. (2009), Energy management algorithm for an optimum control of a photovoltaic water pumping system. Applied Energy, 86(12), 2671-2680.
Schwarz, M. (2006), Innovations in agriculture and renewable energy. BioCycle, 47(5), 60-63.
Sharma, A., Chen, C.R., Lan, N.V. (2009), Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews, 13(6-7), 1185-1210.
Shinde, V.B., Wandre, S.S. (2015), Solar photovoltaic water pumping system for irrigation: A review. African Journal of Agricultural Research, 10(22), 2267-2273.
Sonneveld, P.J., Swinkels, G.L.A., Bot, G.P.A. (2009), Design of a solar greenhouse with energy delivery by the conversion of near infrared radiation part 1 optics and PV-cells. In Acta Horticulturae, 807, 47-54.
Taki, M., Rohani, A., Rahmati-Joneidabad, M. (2017), Solar thermal simulation and applications in greenhouse. Information Processing in Agriculture, 5(1), 83-113.
Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., Chikowo, R., Li, L. (2002), Agriculture sustainability and intensive production practices. Nature, 418, 671-677.
U.S. Department of Energy. (2003), Roadmap for Agriculture Biomass Feedstock Supply in the United States. Biomass. Washington, DC: U.S. Department of Energy. p1-100.
U.S. Department of Energy. (2010), Wind Power Today. Wind and Water Power Program. Washington. D.C: U.S. Department of Energy. pp 1-32.
von Zabeltitz, C. (1986), Greenhouse heating with solar energy. Energy in Agriculture, 5(2), 111-120.
Wiedmann, T. (2009), A first empirical comparison of energy footprints embodied in trade MRIO versus PLUM. Ecological Economics, 68(7), 1975-1990.
Xue, J. (2017), Photovoltaic agriculture new opportunity for photovoltaic applications in China. Renewable and Sustainable Energy Reviews, 73, 1-9.
Yang, H., Zhou, Y., Liu, J. (2009), Land and water requirements of biofuel and implications for food supply and the environment in China. Energy Policy, 37(5), 1876-1885.
Yunlong, C., Smit, B. (1994), Sustainability in agriculture: A general review. Agriculture, Ecosystems and Environments, 49(3), 299-307.
Zhang, X., Vesselinov, V.V. (2017), Integrated modeling approach for optimal management of water, energy and food security nexus. Advances in Water Resources, 101, 1-10.