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Solar Concentrators in Combination with Agricultural Fields: Azerbaijan and Mexico

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Abstract: This study is dedicated to renewable energy on the example of two countries, namely Azerbaijan and Mexico. The article indicates that the relief and climate of both countries have many common features, which are expressed particularly in the abundance of solar radiation, the predominance of mountainous regions with remote and hard-to-reach settlements that need to create autonomous life support systems. Moreover, it highlights the relevance of the use of green energy devices in agro-complexes, and analyzes the problem of combining the solar electricity generation and crops growing in one area. A methodology is proposed for evaluation of the impact of combinations of solar concentrators together with certain agricultural crops. The mathematical models are developed to establish the relationship between the parameters of agricultural fields and the concentrators' characteristics. The proposed mathematical model is simple and can be implemented for different cases of combination of solar concentrators and agricultural fields. Possible implementation options for the proposed models are discussed.

Keywords: *Solar concentrator, agricultural crops, mathematical model, Micro Equipment Technology(MET),flat triangular mirrors*

1. INTRODUCTION

At present, humanity has particularly felt that the uncontrolled production and use of traditional energy, emissions of which account for 75% of all greenhouse gases polluting the atmosphere, are leading the world to a catastrophe. Not by coincidence the issues of reducing the global climate change and the environmental problems, developing a "green economy" and clean energy, providing each inhabitant of the planet with the access to clean energy were the discussion topics at the annual general debate of the 76th Session of the UN General Assembly with the participation of leaders of states and governments of 193 member-countries, September 21-27, 2021, New York. The representatives expressed concern over the current situation and specific commitments were made to reduce the hydrocarbon share and "decarbonization" of energy industry in the following ten years in order to implement the Paris Climate Agreement, which is a legal international treaty on climate change [1].

To achieve these goals, several technological solutions modernizing energy systems through the introduction of new equipment and the use of renewable energy sources (RES) are already available. Solar photovoltaic stations today originate the development of low-cost and environmentally friendly power supply systems using solar energy in many countries. One of the possible areas for the application of solar energy is agriculture, since it is a leading field of activity ensuring the food security of a country. Therefore, the idea of integrating solar devices into agro ecosystems – Agro voltaic systems is currently in the focus of researchers around the world, for example in the USA, Italy, Spain, Mexico, India, etc. [2–6].

These studies highlight three principles for incorporating solar devices into agro ecosystems: 1) focus on crops that make up the agro ecosystem; 2) focus on the production of solar energy; 3) focus on the integration of solar panels into agro ecosystems. In the first case, the goal is to maximize biomass production by minimizing changes in production systems. Devices for electricity generation are placed on existing fields and do not drastically change agricultural production. In the second approach, developers are trying to maximize solar energy production and minimize changes in standard technologies in obtaining solar energy, by promoting the development of agriculture around renewable energy facilities. The third case attempts to combine both approaches and take advantage of the increase in biomass and energy capacity of solar devices.

This study was carried out within the framework of the third approach and involves joint placement of solar devices and crops, which is estimated to minimize the interaction between them.

2. AZERBAIJAN AND MEXICO: DRIVERS FOR THE DEVELOPMENT OF A GREEN ECONOMY

The main factors determining the need for the development of green economy in Azerbaijan and Mexico include the available traditional and alternative energy resources, global trends in environmental protection, geographical location, relief and climatic conditions, and the main priorities of the socio-economic development policy. A comparative analysis of Azerbaijan and Mexico through the prism of factors determining the relevance of developing new types of renewable energy identifies a number of common features for these countries expressed below.

2.1. The Oil Industry

The oil industry is the leading sector of the economy, and oil extraction and export are the most important source of foreign exchange earnings and a factor in the growth of the population’s welfare. However, as noted above, the extraction and processing of traditional energy resources are associated with environmental problems and considered one of the causes of environmental pollution and global climate change.

Both countries have traditionally relied on oil-fired power plants rather than gas-fired ones with relatively cleaner natural gas combustion. As of 2020, the share of electricity generation from renewable energy sources (RES) in the total volume of energy produced in Azerbaijan accounted for 17%. Azerbaijan has ratified the Paris climate agreement voluntarily undertaking a commitment to reduce the level of gases’ emissions by 2030 that create a thermal effect by 35% compared to the base year 1990 [7].

According to the statistics of 2020, in Mexico, the share of the electricity generated from green sources accounted for 27.8% of the total electricity produced in the country. Under the Paris climate agreement, Mexico has committed to increase its electricity generation from clean sources to 35% by 2024, and to achieve a zero share or low-emission electricity generation up to 40% by 2035 [5,8].

2.2. Relief Diversity of the Territories of the Countries

The relief of Azerbaijan covers mountains, foothills, lowlands, plains, and gorges. Moreover, about 60% of the country’s area includes mountainous territories. The geographical position and complexity of the relief determine the country’s inherent land shortage [9].

The relief of Mexico is made up of high mountain ranges, low coastal plains, high plateaus and deserts. Most area lies at a height of 1000 m above sea level. Mountainous regions and highlands occupy almost 2/3 of the country’s area, while lowlands and plains are rare [10]. Thus, Mexico is also characterized by a land shortage and the predominance of remote mountainous regions with hard-to-reach settlements.

2.3. The Climate

The climate of Azerbaijan is shaped by the geographical position, relief and the Caspian Sea. Several climate types namely dry steppe, humid subtropical, cold mountainous, etc. are observed in the country. The climate of Azerbaijan provides ample opportunities for increasing the production of electricity and thermal energy through the use of solar radiation. The number of sunny hours in Azerbaijan is 2400-3200 hours per year [7, 9].

The climate of Mexico is also shaped by the geographical position, relief, the Mexican segment of the Pacific Ocean and the Caribbean Sea. The climate of Mexico in the north is subtropical, and tropical in the rest of the country, with humid and hot coastal plains. There are about 3126.3 hours of sunshine in Mexico during the year. On average, the duration of solar radiation reaches 102.84 hours per month [10, 11].

2.4. Non-Oil Sector

The main priorities of Azerbaijan's policy in the socio-economic sphere are aimed at diversifying the economy through the development of the non-oil sector, including agriculture, renewable energy, etc. International Renewable Energy Agency (IRENA) experts estimate the solar and wind potentials of Azerbaijan to be very high, along with its biomass, geothermal and hydropower resources [12]. Political documents adopted in recent years actively support the development of green energy [13-15]. The work has already begun on the creation of the first Industry 4.0-based "smart village". Renewable energy sources are vital and have great potential in stimulating the socio-economic development of Mexico. Thus, the government adopted and is implementing a framework to provide modern environmentally friendly energy to almost 3 million people in remote rural areas of Mexico without access to electricity, as well as to reduce the use of traditional biomass for domestic purposes [5, 8]. In recent years Mexico sets world's lowest prices for solar energy [16].

2.5. Solar Energy

At present, the technical potential of solar energy is estimated to be the highest among RES, particularly in countries with significant annual solar radiation resources. The use of solar energy could help address the problems associated with energy supply in remote and hard-to-reach areas of Azerbaijan and Mexico, which have a difficult landscape and suffer from land shortages. Along with power generation, solar installations can contribute to agricultural systems by reducing wind erosion, as well as saving water.

Azerbaijan has favorable climatic conditions, sufficient amount of heat and light, which enable growing and harvesting some agricultural crops twice a year. The main trends of agricultural production in the country include crop production, as well as grain-growing, vegetable-growing, fodder crops, tea-growing, potato-growing and various types of fruits. [17].

Crop production is also the leading branch of Mexican agriculture, and the main crops grown include wheat, corn, soybeans, rice, beans, coffee, tomatoes, fruits, and cotton [10].

Azerbaijan and Mexico already have experience in installing and operating solar power plants. Thus, in Azerbaijan, solar power plants operate in Gobustan, in the villages of Surakhani and Sahil, on the island of Pirallahi, in the regions Samukh and Garadagh, Sumgayit and Nakhchivan. A wide network of solar power plants installed in various regions of Mexico is available [5]. Many of proposed solar installations consist of large photovoltaic systems [3].

3. CHALLENGES OF COMBINING SOLAR ENERGY AND AGRICULTURE

As photovoltaic plants continue to grow, the use of land for solar farms upsurges the competition for land resources between food production and clean energy [18]. Although photovoltaic systems require less land than other renewable energy options [19], in fact, commercial photovoltaic power plants can occupy a significant area of land locally.

One of the first experiments recorded and described in the literature to develop an agro-power plant on a farm was the system in Montpellier, France, in 2013 [20]. The system grew lettuce in combination with a system consisting of photovoltaic modules mounted on 0.8 m wide piles. The same piece of land was used for electricity and food production. The results of the experiments showed that the shades of the PV matrices had no significant effect on lettuce yield.

To date, three types of agro-electric systems have been proposed for simultaneous growth of crops and electricity production on agricultural lands. The first type was proposed in early 1980s using photovoltaic panels in the spaces between crop rows [21]. The second type is the photovoltaic greenhouse, in which a part of transparent roof is replaced by photovoltaic panels [22]. The third type is the photovoltaic systems mounted on poles above the crops, which consist of pipes and rows of photovoltaic panels. They are installed on the ground and located at regular intervals allowing enough sunlight to reach the plants for photosynthesis. An example of the placement of solar concentrators is described in [23].

In 2018, Amaducci and Colauzzi [24 proposed an agro-electric system, solar tracking, mounted on suspended structures (piles). The horizontal main axle is mounted on frames, on which the secondary axles supporting the solar panels are pivotally connected. The two shafts rotate driven by interconnected electric motors through an innovative wireless communication and control system.

To simulate the growth and production of crops in the shade of the Agro voltaic system, Scilab [25] develops a software platform combining the radiation and shading model with the universal plant growth simulator GECROS [26]. The GECROS agricultural crop model predicts the biomass and yield depending on climatic factors (radiation, temperature, wind speed and humidity) and available water and nitrogen amount in the soil.

We propose using the solar concentrators in the fields of Mexico and Azerbaijan. For Mexico, these can be systems together with common crops such as beans, corn, and agave. For Azerbaijan, these can be plantations of early vegetables, fields of potatoes or beets. The spaces between plant rows can be used to install solar concentrators. Moreover, the parabolic surface dimensions do not affect the plants at all.

Global demand for energy leads to an increase in the need for the use of green energy for irrigation, domestic purposes, etc. The studies [2–4], [18–20] describe the solar concentrators installing in combination with an agricultural field infrastructure. They show economic feasibility of these systems in some rural areas and their opportunities for the electrification of the latter, while stimulating their economic growth.

The first problem required to be solved for combining solar energy with agriculture is the choice of solar concentrators and the most suitable crops for such concentrators. The need for solar energy varies for different crops depending on their metabolism and the timing of sunlight use. The design of solar concentrators and the mounting methods (distance and height of frames) can generate different amounts of energy according to the requirements of selected crops.

One of the motivating options can be obtained using parabolic dish solar concentrators covered with flat triangular or square mirrors. For example, the studies [27–31] present the development of such concentrators. The cost of such solar concentrator is low due to modeling of a parabolic surface by flat mirrors, and small dimensions (from 2 to 3 meters in diameter). Such a concentrator operates in two modes: 1) capturing solar energy, when the parabolic dish axis is directed towards the sun; 2) in the minimum shadow, when the parabolic dish axis is fixed perpendicular to the sun direction. The hypothesis is based on the idea of placing solar devices in areas occupied by crops, so that the interaction between them is minimal, thus, benefitting from solar devices for crops.

Solar concentrators can also be used to preserve rainwater for irrigation, building rainwater collecting systems nearby or around them. These devices can be designed as inverted umbrellas opening when it rains and closing when it doesn’t, enabling the preserved water to be used for solar-powered irrigation.

4. MATHEMATICAL MODEL FOR EVALUATION OF SOLAR CONCENTRATORS AND AGRICULTURAL PLANTS

The main goal of this study is to develop a methodology for evaluating the effectiveness of possible models for combining solar concentrators with a certain type of plant. The first step implies the development of an analytical model with the parameters characterizing agricultural fields. The second step is to evaluate the characteristics of the solar concentrator.

The parameters taken into account in the fields include the field area, its slope, soil type, humidity, spacing between the rows, crop type, crop density, maximum plant width, and plant height. Irritability of plants to external agents (light, temperature, humidity, etc.) and plant development are determinable by the timing of sowing, germination, growth and harvesting.

The key function may include all of these parameters or some of most important in a particular situation. The simplest model is the linear model. In this case, the key function has the following form:

$$f_1(x) = a_1x_1 + a_2x_2 + a_3x_3 + ... + a_nx_n \qquad (1)$$

where x_1, x_2,..., x_n are the selected parameters for the field and plants, whereas a_1, a_2, …, a_n are the coefficients obtained by calculation or experiment for a specific task.

The characteristics taken into account in solar concentrators include their dimensions, weight, plate width or dish diameter, shade produced, mounting structure, material of construction, quantity and distribution of solar concentrators. The type of key function is selected depending on the specific task. In this case, the key function can be presented as follows:

$$f_2(y) = b_1y_1 + b_2y_2 + b_3y_3 + ... + b_my_m \, , \qquad (2)$$

where y_1, y_2,..., y_m are the selected parameters of the characteristics of solar concentrators, whereas b_1, b_2, …, b_m are the coefficients obtained by calculation or experiment.

Some of these parameters can be obtained from various statistical tables, for example, the yield rate of certain crops. Certain parameters require additional mathematical calculations, for example, how many concentrators can be placed on a field with a predetermined distance between the poles (supports), etc. Some values can be obtained during the operation of the first real prototype of combined system. Based on these key functions, new functions will be defined to determine the relationship between field parameters and concentrators' characteristics. For example, determination of the stability of solar concentrator support on the ground or the amount of shadow by solar concentrators on plants throughout the day. The computer system can be developed by model developers, or available software systems can be used, for example, software modules described in [30].

5. DISCUSSION OF POSSIBLE OPTIONS FOR THE MODEL IMPLEMENTATION

A holistic system combining renewable energy sources and agricultural fields may use new designs of solar concentrators. Fig. 1 shows several prototypes of solar concentrators developed and patented in Mexico, Spain and the United States of America [2], [27–31]. Micro Equipment technology (MET) has been developed over the past few years [32]. The task of solar concentrators manufacturing was chosen as an application of MET. Various types of solar concentrators with flat mirrors and their prototypes have been developed so far. These concentrators can be installed on the horizontal roofs of buildings, as are in many cities and towns in Mexico. Installing solar concentrators in agricultural fields is a new trend.

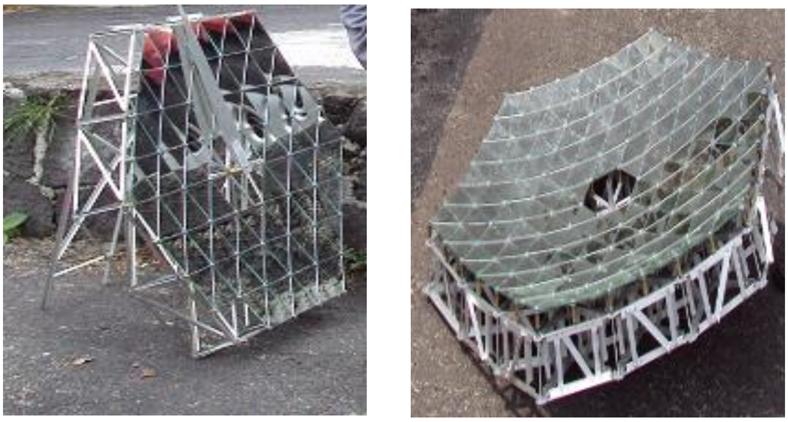

Figure 1. Prototypes of flat mirror solar concentrators

In Azerbaijan, the period of active agricultural activity, for example, for planting potatoes or beets, depending on the region, starts from late February to April. Potato varieties are distinguished depending on how many days after planting the tuber are dug out: early - after 50–65 days; medium early - after 65–80 days; mid-season - after 80-95 days; medium-late - after 95-110 days; late - after 110 or more days. Planting rows are often wide enough to install solar concentrators.

In Mexico, cultivation starts in April and ends in October or November [24]. Solar concentrators can be used during this 7-month period. In early May, plants do not consume much solar energy, and during this period, the solar concentrators can be placed easily. In the period from November to April, concentrators can be installed throughout the field.

6. CONCLUSION

We proposed the creation of integrated systems for electricity generation and agricultural products on one field through the use of solar energy. The proposed models made it possible to evaluate the distribution of solar concentrators, and to obtain results without conducting experiments on real sowing and harvesting cycles.

The next stage of the study includes the development of a strategy for placing solar concentrators among crops, the development of new prototypes of solar concentrators. The proposed system includes a dual source of income for farmers, rural electrification, and the availability of electricity for local agricultural processing. Due to geospatial positions of Azerbaijan and Mexico located in privileged regions of solar radiation, they have many opportunities for the practical use of solar energy.

Acknowledgments

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