Energy efficiency and renewable energy sources in the agricultural area

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Abstract. The article highlights the methodology for quantifying energy efficiency and the principles of using renewable energy sources in the processes of production of final products of the agricultural sector. Domestic and foreign scientists carried out a large number of fundamental and applied research aimed at increasing energy efficiency and reducing the energy intensity of agricultural production and certain positive results have been achieved [3]. We have developed a scientific and methodological basis for increasing energy efficiency in agricultural production. Considering the energy technological process and the energy source in a single system, “energy resources-bio object” using the laws of conservation, movement, and absorption of energy [4] New indicators and criteria for evaluating the energy efficiency of agricultural products such as bioenergy efficiency coefficient and useful coefficient of energy use, taking into account the biological characteristics of agricultural energy consumers (technological facilities) [5, 6]. New electrical technologies for the processing and storage of agricultural materials and products, disinfection of water, and other biotechnological objects with the use of electrophysical and electrochemical effects [7, 8] were developed.

1. Introduction

In a market economy, the sustainable development of the agricultural sector is directly related to the efficiency of the final product. At present, more than 21% of electric energy produced in the Republic is rising in the production of agricultural products in Uzbekistan. In the energy balance of the agricultural sector of the country, more than 60% is thermal energy. The energy intensity of agricultural production is 2.0–2.5 times higher and the efficiency of invested capital is 1.5–2.0 times lower than in developed countries [1].

The introduction of market mechanisms has brought agricultural enterprises (producers) out of the tutelage of the state and new entities have appeared in their place: farmers, peasant agricultural clusters, and large private enterprises for processing, storage, and sale of agricultural products. As it turned out, most enterprises were not ready. On the other hand, this ward of the state was in many respects the reason for the continued growth in the energy intensity of agricultural products. In these situations, energy shortages and inaccessibility, more than 30% of agricultural products produced in the republic do not reach the consumer. Also, an increase in the price of organic fuel resources and a decrease in their reserves in the world, including Uzbekistan indicates the need to involve alternative sources of energy and fuel to meet the energy demand of agriculture. Such an approach to solving the energy problem not only increases the reliability of energy supply and energy efficiency of production industry products but also helps to improve the ecology and social standard of living of the population. Given the attractiveness of renewable energy as an environmentally friendly energy resource, in recent
years in the republic special attention has been paid to the development and expansion of its use in Uzbekistan. It is designated as a priority area for the development of science and technology of the republic. In 2019, the Law of Uzbekistan “On the Use of Renewable Energy Sources” was adopted, Presidential Decree PP-4422 of 08.22.2019, and many programs aimed at improving energy efficiency, energy conservation and the development of renewable energy were adopted [2].

The research of domestic and foreign authors was mainly devoted to the improvement of technological processes, the development of effective methods for introducing energy into technological materials, the automation and control of processes, and certain successes were achieved in reducing the energy intensity of agricultural production processes. A correct assessment of the efficiency of energy technological processes is an important factor in achieving the production efficiency of biological products. The existing methodology for assessing the energy efficiency of agricultural production by relative indicators: efficiency (efficiency) and power (Cos) of power plants, energy intensity and specific energy intensity, not quantitatively, does not fully meet the requirements of the laws of a market economy. Existing studies devoted to increasing the energy efficiency of energy technological processes in agriculture do not sufficiently cover the principles of the use of renewable energy sources as a factor in increasing the energy efficiency of the production of final agricultural products.

The world practice of using renewable energy sources shows that the technical implementation of the laws adopted, under legal acts and regulatory documents concerning the development of energy-generating power plants based on renewable energy sources or combined renewable energy sources with a traditional energy network or, to supply an individual or group of consumers, it is necessary to study the types and potentials (energy characteristics ) RES in a specific region, study energy consumers in a given region, their density required power, and geographical information data of the region. In the context of the transition of agricultural enterprises to new forms of management (farm, corporatization, agricultural clusters, etc.), the question of organizing and managing energy conservation to increase the efficiency of agricultural production, its competitiveness, and compliance with modern environmental requirements is becoming increasingly acute [25].

This work sets out a methodology for the quantitative assessment of energy efficiency and the principles of the use of renewable energy sources (RES), to increase the efficiency of production of the final products of the agricultural area, considering it in conjunction with the geographic information factors of the region.

Purpose and objective of the study. The aim of the study is to increase the energy efficiency of energy technology processes and the production of final products in the agricultural sector.

Study of existing scientific solutions to improve the energy efficiency of energy-technological processes production of final products in the agricultural area; Development of a methodology for the quantitative assessment of energy efficiency of energy technological processes in agricultural production; Definition of analytical expression indicator of a quantitative assessment of energy efficiency “Relative energy intensity of the process”

\[ Q_e = 1 + \Delta Q^* \]  

(1)

Studying the laws of the influence of natural climatic and geographical information data of a particular region on the energy characteristics of a photovoltaic battery; Formation of the principles of the use of renewable energy sources in processes ensuring the increase in efficiency of production of final products of the agricultural sector.

The object of study. The artificial energy system of the consumer and energy technology processes. The subject of study formation of a methodology for assessing energy efficiency, production of final products in the agricultural sector in the system, “Energy source, including renewable energy –Energy technological process” Studies of the patterns of the influence of natural, climatic and geographical information data of a specific region on energy characteristics were carried out experimentally using mathematical statistics.
2. Research Methodologies
Studies of the data on the types and potentials of renewable energy in the regions and in general on the territory of Uzbekistan were carried out according to statistical data and according to the data of hydro meteorological and actinometric stations and selectively direct measurement. In developing the principles of the formation of an energy system based on renewable energy sources (RES) that increase the efficiency of production of the final products of the agricultural sector, they were based on system analysis methods, on the laws of movement and absorption of energy in the environment, the law of conservation of energy, and the method of finite respect.

3. Results and Discussion
Domestic and foreign scientists carried out a large number of fundamental and applied research aimed at increasing energy efficiency and reducing the energy intensity of agricultural production and certain positive results have been achieved [3]. We have developed a scientific and methodological basis for increasing energy efficiency in agricultural production, considering the energy technological process and the energy source in a single system, “energy resources-bio object" using the laws of conservation, movement, and absorption of energy [4] New indicators and criteria for evaluating the energy efficiency of agricultural products such as bioenergy efficiency coefficient and useful coefficient of energy use, taking into account the biological characteristics of agricultural energy consumers (technological facilities) [5, 6]. New electrical technologies for the processing and storage of agricultural materials and products, disinfection of water, and other biotechnological objects with the use of electrophysical and electrochemical effects [7, 8] were developed.

The fundamentals of electrophysical and electrochemical treatment of drinking water and irrigation system water have been developed to create energy-saving electrical technologies [9].

We have developed the methodological foundations of energy conservation and energy efficiency assessment of agricultural production, considering the energy source and the consumer as a single artificial energy system (IES) of the consumer (Figure 1).

The proposed artificial energy system of the consumer more fully reflects the principles of market attitudes in addressing the issues of increasing the energy efficiency of production. The amount of energy, energy equipment, including equipment based on renewable energy sources, materials, and raw materials, technologies, and equipment, is recorded on the left border of the system. And, on the right border of the system, products are produced that are sold to the external and domestic markets. In the system under consideration, the supplied energy passing through the elements of the line of the system enters the input of the ETP-I, ETP-II, ETP-III, and, consuming the technological environment, performs a certain work. Each element of the system has an input and an output where you can install devices for metering energy moving along the line of the system and evaluate the efficiency of energy use for each element of the line and in the electronic circuit [24].

For a quantitative assessment of the energy use efficiency of each element of the line and in the electronic occurring of the final product, in previous studies, we adopted the relative energy of the process in the element \(Q_e\) determined by the ratio supplied to the input of the energy element \(Q_{in}\) on the energy at the output of the element (on the required energy) \(Q_{out}\)

\[
Q_e = \frac{Q_{in}}{Q_{out}} = \frac{Q_{start}}{Q_{end}}
\]  

Taking into account energy losses through the elements of the system \(\Delta Q\), the energy balance equation of the system can be written in the following form.
Figure 1. Consumer Artificial Energy System (IESP):
ETP I is an energy-technological process producing products for the consumer market; ETP II is auxiliary energy-technological processes ensuring the flow of the main ETP (pre-treatment of heating, grinding, etc.); ETP III is an energy-technological process providing the necessary production conditions, conditions for the life of people and animals (heating, lighting, vent, air conditioning).

\[ Q_{\text{start}} = Q_{\text{end}} + \Delta Q \]  
(3)

Separating the left and right sides of equation (2) by \( Q_{\text{end}} \) we get:

\[ \frac{Q_{\text{start}}}{Q_{\text{end}}} = \frac{Q_{\text{end}} + \Delta Q}{Q_{\text{end}}} \quad \text{or} \quad Q_{\text{e}} = 1 + \Delta Q^* \]  
(4)

where:
- \( Q_{\text{e}} \) is the relative energy intensity of the process;
- \( Q_{\text{start}} \) and \( Q_{\text{end}} \) are the amount of energy brought to the beginning of the element.

\[ \Delta Q^* = \frac{\Delta Q}{Q_{\text{end}}} \]  
is the relative energy loss.

The relative minimum value of the relative energy intensity of the processes is 1, with the ideal case if \( \Delta Q = 0 \)
From equation 3 we can conclude that in the ideal case when \( \Delta Q^* = 0 \) the minimum relative energy intensity of the process will be \( Q_e = 1 \). With increasing \( \Delta Q^* \) the relative energy intensity of the process will also increase. From the energy balance equation \( Q_{\text{start}} = Q_{\text{end}} + \Delta Q \) it can be seen that with an increase in the number of elements, the right and the left side of the equation

\[
nQ_e = n(1 + \Delta Q^*)
\]

(5)

Will simultaneously increase relative energy intensity shows how many times more energy is spent on the process compared to the specific (theoretical) energy consumption.

The proposed assessment methodology and the adopted energy efficiency indicator make it possible to establish the minimum and maximum energy intensity of the process, which corresponds to the principles of a market economy [23].

The left side of the consumer’s intelligent energy system (IES) provides the possibility of using renewable energy sources as energy quality.

The energy efficiency in the production of final products (goods) is estimated by the combination of energy, economic, environmental, and social effects (Fig. 2).

![Figure 2. Components of energy efficiency in agricultural production.](image)

The participation of one or another component in the formation of the overall efficiency of energy use depends on the type of energy used (excited, non-renewable, or their combination). Economic and energy efficiency of production of the final product. Using renewable energy sources, with the existing cost of energy, the energy they generate is not always higher than when using renewable energy sources. The attractiveness of the use of renewable energy lies in the fact that it always helps to alleviate the environmental situation and improve the social condition of the population. In this regard, it is of particular interest to expand the use of renewable energy sources as a factor in increasing the energy, economic, environmental, and social effects in the agricultural sector.

A large number of scientific works of Uzbek and foreign scientists have been devoted to studying the energy characteristics of renewable energy sources, the possibility of using them for energy supply purposes of consumers, and directly for technological purposes. J.Twidell, Sheryazov S.K., Ptashkina-Girina O.S., Nizamutdinova N.S., Acosta-Silva Y.D.J., Torres-Pacheco I., Matsumoto Y., Toledano-Ayala M., Soto-Zarazúa G.M., Zelaya-Angel O., Méndez-López A., Hassanien R.H.E., Li M., Dong Lin W., Kobelev A.V., Saplin L.A., Elistratov V.V., Strebkov D.S., and others developed a large number of theoretical and practical recommendations served as the development of renewable energy and technology and their use [10-18].

However, some of the features inherent in this type of energy are such as the probabilistic nature of the change in their energy characteristics, the different density of their flow across regions from one country and their non-persistence, taking into account the climatic and geoinformation data, requires the formation of the principles of the rational combination of energy source and consumer and their functioning in a particular region with certain climatic and geoinformation data [22].
Below we present some results of our research on the formation of the principles of using renewable energy sources (for example, solar energy in the agricultural sector), which envisages increasing the efficiency of the production of final products of the agricultural sector.

The technical potential of solar energy in Uzbekistan is 179.0 million tons of oil equivalent. 3 times more potentials of primary resources produced by the present in the republic (51 million tons of oil equivalent).

The data of long-term observations on the network of actinometric stations in Uzbekistan show that the duration of sunshine in various regions of the republic varies from 2410 to 3090 hours a year.

The total solar radiation in summer is 27 MJ/m$^2$ per day, and in winter about 7 MJ/m$^2$. These data show that the technical potential of solar energy in the republic is sufficient for the operation of photovoltaic stations [19].

Table 1. The daily movements of the hourly average values (in the numerator) and total (in the denominator) under average cloud cover in Bektemir region

| Month | 1     | 2     | 3     | 4     | 5     | 6     |
|-------|-------|-------|-------|-------|-------|-------|
| Amount for daylight hours, MJ/m$^2$ | 3.55  | 4.46  | 5.54  | 7.40  | 9.65  | 11.43 |
| Total for Month MJ/m$^2$          | 110.26| 125.07| 171.78| 221.73| 289.73| 343.00|
| Month MJ/m$^2$                    | 160.73| 198.36| 275.82| 351.16| 434.54| 461.47|
| Amount for daylight hours, MJ/m$^2$ | 7     | 8     | 9     | 10    | 11    | 12    |
| Total for Month MJ/m$^2$          | 382.18| 388.85| 333.30| 235.65| 142.65| 95.98 |
| Month MJ/m$^2$                    | 493.10| 491.90| 431.45| 313.98| 202.98| 145.12|

When developing the energy complex “Energy-generating source-consumer” based on renewable energy sources, we recommend 2 options.

**Option 1.** Designing a power complex based on a power plant with a photovoltaic battery (PVB) of industrial production.

In this case, based on studying the natural-climatic and geo-information data of a particular region, the real energy characteristics of the PVB are determined and the energy complex is formed by the required power and operating modes of consumers.

**Option 2.** The design of the energy complex is carried out according to the required capacity and the consumers’ work modes, taking into account the climatic and geographical information data of the specific region, it provides for the selection of a photovoltaic element (converter) for determining the total power of a photovoltaic battery in a power plant and on its basis to form an energy complex.

When using industrial-type photovoltaic plants manufactured in other countries in Uzbekistan, it is necessary to study the following factors and use their results when designing an energy complex based on a photovoltaic (PVB) power plant: - the influence of temperature conditions, which will reduce the efficiency of conversion of PVB to the summer months of the year [21]:

- the influence of the region's dustiness on the efficiency of the conversion of the PV;
- energy losses in a photoelectric battery (PVB) depending on its orientation to the Sun (The technique for determining energy losses is based on measuring the short-circuit currents of the PVB);
- to certify solar cells (SC) and PVB using simulators of solar radiation (SR) following International Standards in the conditions of AM 1;
- Loss of energy of the PV from temperature. The energy conversion efficiency of solar radiation in solar cells is 17–20%. The specific figures are determined by the climatic conditions of the area where the SC is installed.
Figure 3 shows the dependence of the voltage $U_v$ on the PVB on the temperature difference between the back surface of the PVB and the environment $(T_{B.S.} - T_E)$.

![Figure 3. Dependence of voltage $U_v$ on the PVB on the temperature difference between the back surface of the PVB and the environment $(T_{B.S.} - T_E)$.

It can be seen from Figure 3 that an increase in the ambient temperature above 30 °C leads to an intensive decrease in the voltage of the PVB.

A study of the influence of air temperature on the efficiency of using solar energy in the hot climate of Central Asia shows that the efficiency of the crystalline silicon-based photomultiplier decreases by more than 40%. In summer the air temperature in the shade reaches 45 °C and on the surface of the PVB 65 °C. The reflection coefficient from the protective glass and the surface of the solar cell in the PVB is less than 8%. Up to 20% of the absorbed radiation is converted into electrical energy, the remaining part into heat, and heats the structure of solar cells.

In rural areas of the second half of May to the first half of September, the decrease in the efficiency of PVB is up to 45% of the passport value. Thus, when using PVB in a hot climate, the conversion efficiency is not more than 9-11%. The rest (80-85%), absorbed by the energy of solar radiation, turns into heat, leading to a deterioration in the parameters of the PVB installation.

The effect of pollution on the parameters of PVB. The main sources of dust and salt on the territory of the republic are the dried-up part of the Aral Sea, the surface of saline dump lakes and salt marshes.

Figure 4 the change in the degree of air pollution in June, October, and December is given. Pollution of the surface of the photomultiplier with atmospheric dust leads to a decrease in power by 30% or more. The dust has particles, the sizes of which vary from fractions to hundreds of micrometers. Not only has the size of the dust changed, but also the chemical composition. Dust concentration increases sharply in the second half of May and does not decrease until the end of November.
Figure 4. Change in the degree of air pollution in June, October, and December.

From the picture, it can be seen that the high dustiness of the air is observed in summer and autumn (before the start of the rainy season).

4. Conclusion

Based on the results of our and other researchers, we can draw the following conclusions

1. The proposed artificial energy system (IES) of the consumer (Fig. 1), which considers the energy source and the consumer as a single system, more fully reflects the principles of market attitudes in addressing issues of increasing energy efficiency of production.

2. The proposed assessment methodology and energy efficiency indicator for the relative energy intensity of the process in the element \( Q_e \) allows you to set the margins of the minimum and maximum energy intensity of the process, which corresponds to the principles of a market economy.

3. When using PVB in hot climates, the conversion efficiency is not more than 8-10%. The rest (80-85%) of the absorbed SR energy is converted into heat, leading to deterioration in the parameters of the PVB installation.

4. Decrease in efficiency in the summertime due to pollution of the surface of the PVB is 30 percent or more, therefore, annual monitoring of the amount and composition of precipitation in areas promising for the construction of photovoltaic stations (PVB) is required.

5. The results of annual monitoring are extremely important in the design of PVB, because. The project will include possible methods for cleaning the surface of the solar cell and real economic indicators will be determined.

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