MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY STATE UNIVERSITY
Academic and Research Institute of Business, Economics and Management
Department of International Economic Relations

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QUALIFICATION PAPER

on the topic "AGROVOLTAICS AS A PROMISING DIRECTION OF LAND USE FOR ENSURING GLOBAL ENERGY AND FOOD SECURITY"
Specialty 292 "International Economic Relations"

Student 4th course ______________ T.A. Perederii

group ME72 ан

It is submitted for the Bachelor's degree requirements fulfillment.

Qualifying Bachelor's paper contains the results of own research. The use of the ideas, results and texts of other authors has a link to the corresponding source

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ABSTRACT

on bachelor's degree qualification paper on the topic

"AGROVOLTAICS AS A PROMISING DIRECTION OF LAND USE FOR ENSURING GLOBAL ENERGY AND FOOD SECURITY"

Perederii Tetiana Anatoliivna

The main content of the bachelor's degree qualification paper is presented on 50 pages; including references consisted of 54 used sources, which are placed on 6 pages. The paper contains 8 tables, 17 figures.

Keywords: GLOBAL FOOD SECURITY, GLOBAL ENERGY SECURITY, AGROVOLTAICS, AGRICULTURE, SOLAR ENERGY.

The purpose of the bachelor's degree qualification paper is to research development prospects and evaluate the efficiency of agrovoltaic systems to ensure global energy and food security.

Object of the study is agrovoltaics.

Subject of the study is the dual-use of agricultural land based on agrovoltaic systems to ensure energy and food security.

Research methods: analytical-monographic, logical generalization, factor analysis, causal analysis, calculation-analytical, methods of investment analysis.

The information base of the paper is international databases, reporting data of Food and Agriculture Organization, International Energy Agency, the United Nations, official statistics of the State Statistics Service of Ukraine, the National Bank of Ukraine, public authorities regulating the agro-industrial complex and renewable energy sector, engineering companies with practical experience of implementing solar photovoltaic projects in Ukraine, scientific works of domestic and foreign scientists on the researched issues.

According to the results of the study, the following conclusions are formulated:

1) It is proved that global food and energy security challenges can be considered prerequisites for agrovoltaics development. It has been found that the

main problems in ensuring global food security include increasing the world's population, climate change, reduction of sown areas, and the use of food for industrial purposes. In turn, the main challenges of global energy security include the depletion of non-renewable energy resources and rising prices for them on world markets. The development of agrovoltaics can be considered a promising direction for solving the above problems and as the key to low-carbon growth.

2) Theoretical aspects of agrovoltaic systems, their advantages and disadvantages are investigated. Types of agrovoltaic systems are systematized according to such criteria as scope, type of system, type of placement of photovoltaic panels, and mobility. The foreign experience of agrovoltaics development is analyzed.

3) To assess the prospects for agrovoltaics development in Ukraine, the potential of agriculture and solar energy has been studied; state mechanisms for stimulating solar energy development have been analyzed. The main barriers that hinder the development of agrovoltaics in Ukraine are outlined, and proposals for their elimination are given.

4) The implementation of the agrovoltaic system project has been tested subject to appropriate amendments to the current legislation of Ukraine. The calculations show that the revenue from the sale of agricultural products, provided agrovoltaic systems, is lower due to the reduction in crop yields due to shading and the smaller area involved in their cultivation. At the same time, the decrease in revenue from the sale of agricultural products is offset by additional economic benefits from the sale of electricity generated by the agrovoltaic system at the feed-in tariff.

5) It is proved that the implementation of agrovoltaics systems has a synergistic effect. In addition to the economic benefits for the farms, the implementation of agrovoltaic systems can provide many other environmental and social benefits at the regional, national, and global levels.

Results of approbation of the basic provisions of the bachelor's degree qualification paper were considered at:

1) All-Ukrainian scientific-practical conference "Strategic prospects for the development of economic entities in an unstable economic environment" (Kremenchuk, March 13-15, 2020);

2) International scientific-practical conference "IEEE KhPI Week on Advanced Technology" (Kharkiv, October 5-10, 2020, *Scopus / Web of Science*);

3) International scientific-practical conference "Strategic and innovative development of economic system in the context of globalization" (Kremenchuk, November 6-8, 2020);

4) International scientific-practical conference "Socio-Economic Challenges" (Sumy, March 22-23, 2021).

The obtained results can be used by public authorities that regulate the agro-industrial complex and the renewable energy sector to formulate policies to stimulate agrovoltaics development.

The year of qualifying paper fulfillment is 2021.

The year of paper defense is 2021.

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY STATE UNIVERSITY
Academic and Research Institute of Business, Economics and Management
Department of International Economic Relations

APPROVED BY
Head of the International
Economic Relations Department
_________ Yu. M. Petrushenko

“___” ___________2021

TASKS FOR BACHELOR’S DEGREE QUALIFICATION PAPER

(specialty 292 “International Economic Relations”)
student 4 course, group МЕ 72 ан

Perederii Tetiana Anatoliivna

1. The theme of the paper is “Agrovoltaics as a promising direction of land use for ensuring of global energy and food security”.

approved by the order of the university from ____________________.

2. The term of completed paper submission by the student is 14.05.2021.

3. The purpose of the qualification paper is to research development prospects and evaluate the efficiency of agrovoltaic systems to ensure global energy and food security.

4. The object of the research is agrovoltaics.

5. The subject of research is the dual-use of agricultural land based on agrovoltaic systems to ensure energy and food security.

6. The qualification paper is carried out on materials of official statistics, legislative and normative acts, and scientific publications of domestic and foreign authors.

7. Approximate qualifying bachelor’s paper plan, terms for submitting chapters to the research advisor and the content of tasks for the accomplished purpose are as follows:

Chapter 1 Prerequisites for the development of agrovoltaics in the world.

Chapter 1 deals with analyzing precondition for agrovoltaics development, namely global food security issues, non-renewable energy resources depletion, and global environmental problems; till 10.04.2021.

Chapter 2 Agrovoltaics: symbiosis of solar energy and agriculture.

Chapter 2 deals with the investigation of theoretical aspects of agrovoltaic systems, their typology, and foreign experience in the development of agrovoltaics; till 27.04.2021.

Chapter 3 Economic justification of efficiency of agrovoltaic systems in Ukraine.

Chapter 3 deals with the investigation of prospects of agrovoltaics development in Ukraine, estimation of the cost of electricity generation and crop yields using agrovoltaic systems, justification of the synergetic effect of agrovoltaic system; till 14.05.2021.

8. Supervision on work:

Chapter	Full name and position of the advisor	Date, signature	
		task issued by	task accepted by
1	T.O. Kurbatova, Senior Lecturer of International Economic Relations Department	26.02.2021	26.02.2021
2	T.O. Kurbatova, Senior Lecturer of International Economic Relations Department	04.03.2021	04.03.2021
3	T.O. Kurbatova, Senior Lecturer of International Economic Relations Department	15.04.2021	15.04.2021

9. Date of issue of the task: 15.03.2021.

Research advisor ______________ T.O. Kurbatova

The tasks have been received ______________ T.A. Perederii

CONTENT

INTRODUCTION

Relevance of topic. Global challenges to food security in the face of energy and environmental challenges require the search for new technologies for the sustainable development of the agricultural sector. One such technology is agrovoltaics, which involves the simultaneous use of land for growing crops and generating electricity. The use of this technology will solve the problems of global energy and food security and have a positive impact on the low-carbon growth of countries' economies.

Today, agrovoltaics is in the formation stage, but in some countries, it has already become widespread. World experience shows that the key to the development of agrovoltaics is the state policy aimed at stimulating the installation of agrovoltaic systems to ensure the investment efficiency of such projects.

Given the above, the study of agrovoltaic technology, assessing economic, environmental, and social benefits from the implementation of agrovoltaic projects, becomes especially relevant

The purpose of the bachelor's degree qualification paper is to research development prospects and evaluate the efficiency of agrovoltaic systems to ensure global energy and food security.

In accordance with the aim of the qualification work, the following tasks were set:

– to determine the prerequisites for the development of agrovoltaics in the world;

– to study the theoretical aspects and typology of agrovoltaic systems;

– to analyze the potential of agriculture and solar energy for the development of agrovoltaics in Ukraine to systematize the main barriers that hinder its development;

– to estimate the cost of electricity generation based on agrovoltaic systems;

– to conduct a comparative assessment of crop yields with the use of agrovoltaic systems and without their use;

– to assess the economic, environmental, and social benefits from agrovoltaic projects implementation.

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4) International scientific-practical conference "Socio-Economic Challenges" (Sumy, March 22-23, 2021).

The obtained results can be used by public authorities that regulate the agro-industrial complex and the renewable energy sector to formulate policies to stimulate agrovoltaics development.

1 PREREQUISITES FOR THE DEVELOPMENT OF AGROVOLTAICS IN THE WORLD

1.1 Global food security issues as backgrounds for agrovoltaics development

Food security is a concept officially accepted in international practice, which is used to describe the state of the food market of a country or group of countries, as well as the world market. Experts from the Food and Agriculture Organization of the United Nations propose to consider food security as ensuring guaranteed access of all inhabitants of the planet, country, region to food at any time and to the extent necessary to ensure an active and healthy lifestyle [1].

The global food security is influenced by several factors (Fig.1.1).

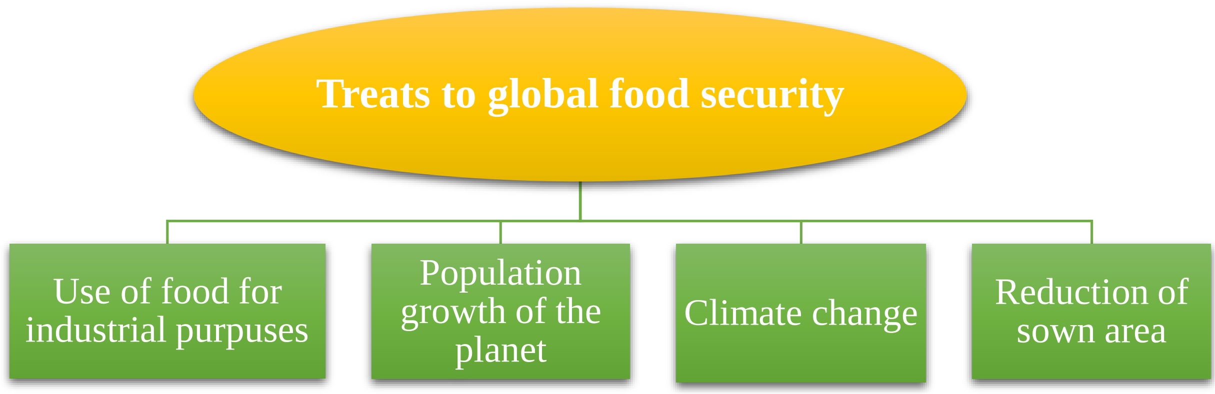

Figure 1.1 – Factors influencing the global food security [2]

One of the main threats to global food security is the growth of the world's population. At present there are more than 7,8 billion living humans on Earth, and according to the forecasts of the United Nations, population of our planet will grow up to 9.1 billion by 2050 (Fig.1.2).

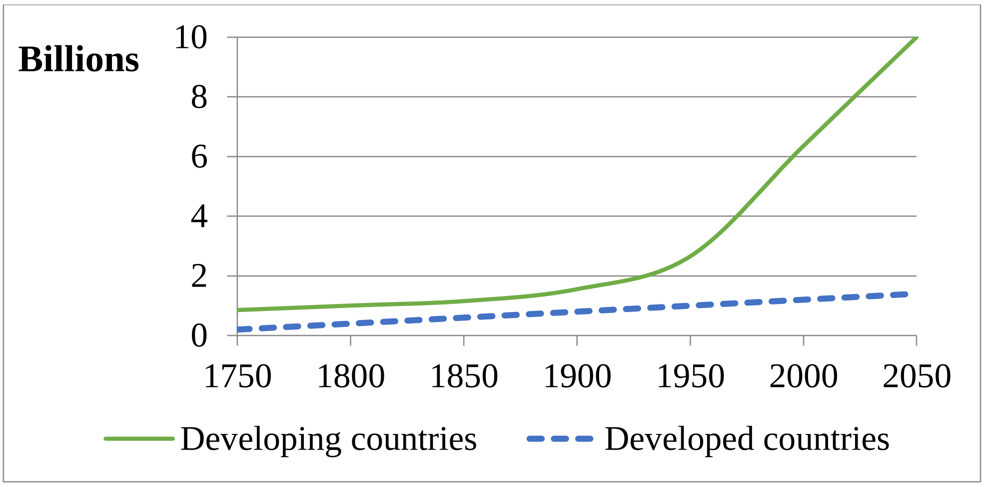

Figure 1.2 – World population development, billions [3]

To the problem of population growth is added the problem of increasing life expectancy (Fig.1.3). Over the past time, it is observed significant growth of humans' life expectancy, which in 2019 reached 72 years.

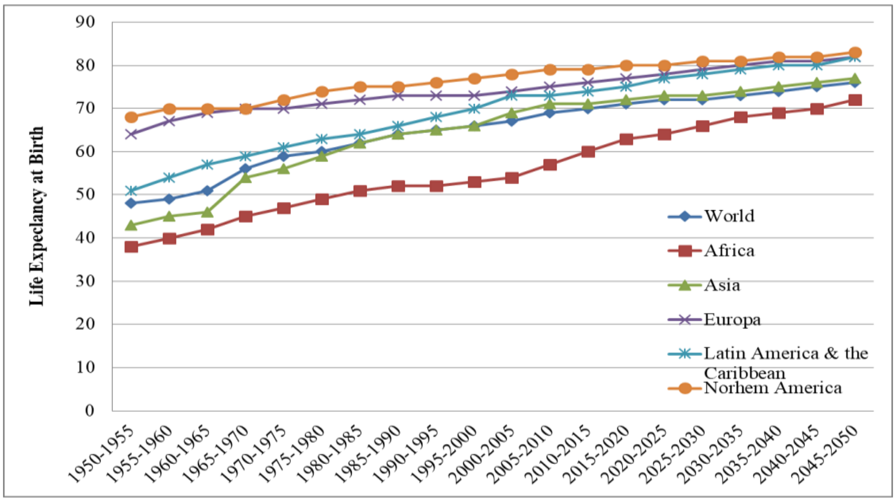

Figure 1.3 – Life expectancy by region, 1950-2050, years [4]

A significant challenge to global food security is global warming and climate change, which could reduce agricultural productivity by up to 30% by 2050. Researchers say climate change has reduced global rice yields by 0,3% and wheat yields by an average of 0,9% each year. Rising average annual temperature, uneven distribution of precipitation, abnormal weather phenomena, and land desertification has a comprehensive impact on reducing crop yields.

Climate change, in turn, causes the growth of natural disasters in the world (Fig. 1.4).

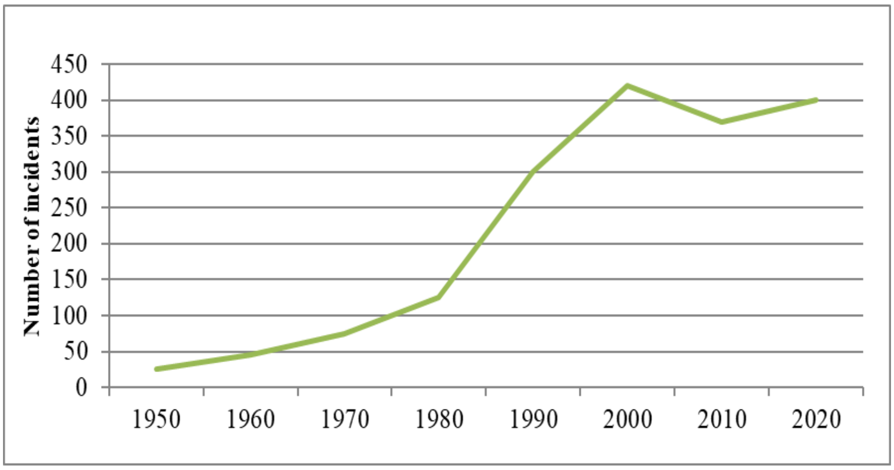

Figure 1.4 – Trend in the number of natural disasters, number of incidents [5]

Of all the threats associated with weather disasters, the greatest losses and damages are caused by tropical cyclones, floods, landslides. Food security is particularly affected by droughts, which exacerbate food insecurity in many places, particularly in Africa.

Another threat to food security is the reduction of arable land in the world due to the its degradation and the expansion of human settlements (Fig.1.5).

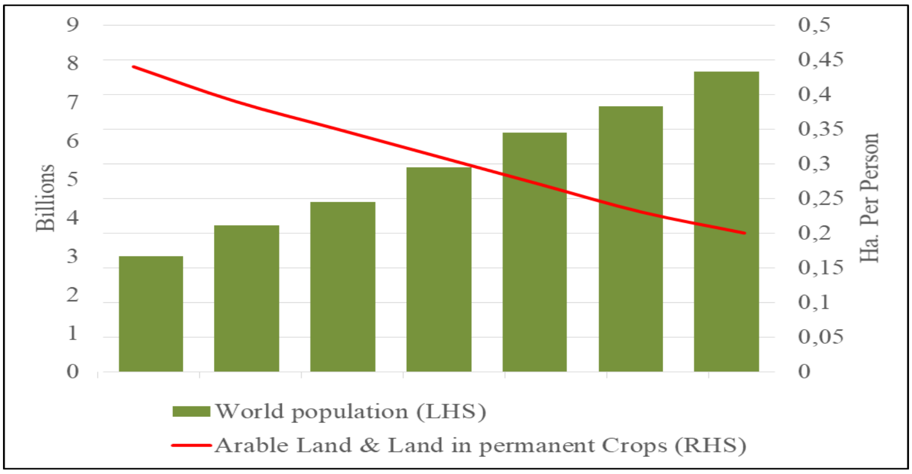

Figure 1.5 – World Population &Arable land, billions, ha per person [6]

Humanity already cultivates the most fertile soils. There is 4,810 mln ha of land under agricultural cultivation in the world. The United States owns the largest arable lands (185 mln ha), India (160 mln ha), Russia (134 mln ha), China (95 mln ha), Canada (46 mln ha), Kazakhstan (36 mln ha), and Ukraine (32 mln ha). At the same time, the Earth annually loses from 5 to 10 mln hectares of agricultural land due to environmental degradation, another 19.5 mln hectares are lost annually due to the rapid development of industry and the real estate market [7].

There is also an unfavorable tendency to increase the volume of crops for the production of biofuels. This direction is supported, for example, by the US government, which provides significant subsidies to its farming and agricultural companies to carry out such activities. The European Union provides for the allocation of 4% to 13% of agricultural land for the production of raw materials for biofuels in accordance with Directive 2003/30/EC, which emphasizes the need to replace 5.75% of diesel and gasoline with biofuels [7].

Research shows that today there is no state that does not care about food security. First of all, it concerns the production of food products. The food crisis in the modern world is undermining the health of more than 1 billion people and directly threatening a quarter of the population of developing countries, normal living and working conditions in these countries, and up to 5% of the population of developed countries. According to United Nations experts, about 50 million people have died each year from malnutrition and hunger over the past two decades [6]. The largest food deficit is in Africa: Zambia, Namibia, and the Central African Republic. To alleviate this situation, global food production should increase by 70% by 2050. Therefore, food security is second on the United Nations Global Sustainable Development Goals list.

According to international experts, in low- and middle-income countries have been a significant increase in performance over the past year, indicating a shift to more effective food security measures

The TOP-10 ranking of countries according to the Global Food Security Index in 2020 is given in Table 1.1 [8].

Table 1.1 – Ranking of countries according to the Global Food Security Index in 2020 [8]

Country	Rank	Points
Finland	1	85,3
Ireland	2	83,8
Netherlands	3	79,9
Austria	4	79,4
Czech Republic	5	78,6
United Kingdom	6	78,5
Sweden	7	78,1
Israel	8	78,0
Japan	9	77,9
Switzerland	10	77,7
Russia	*24*	*73,7*
Poland	*25*	*73,5*
Slovakia	*40*	*69,2*
Ukraine	*54*	*63,0*

It should be noted that the global food problem is based, first of all, on the uneven distribution of the results of scientific progress in agriculture, which prevents lower food prices, even when technical advances allow increasing yields in certain countries. Against this background, there is a decrease in agricultural land productivity, reduction of labor in the least developed countries, soil degradation, biodiversity loss, and more, which makes the task of finding the optimal way of agricultural planning increasingly difficult and knowledge-intensive. Some experts see the solution to this problem in using new alternative methods of agriculture, one of which is agrovoltaics.

1.2 World non-renewable energy resources depletion as precondition for agrovoltaics growth

At the present stage of development of the world economy there is an exacerbation of the problem of energy resources of national economies, which negatively affects the economic development of countries and their energy security.

The use of fuel and energy resources today is growing significantly (Fig. 1.6). Each inhabitant of the planet obtains 2 kW of energy, however, to ensure the generally accepted standards of quality of life requires 10 kW [9]. This figure is achieved only in developed countries.

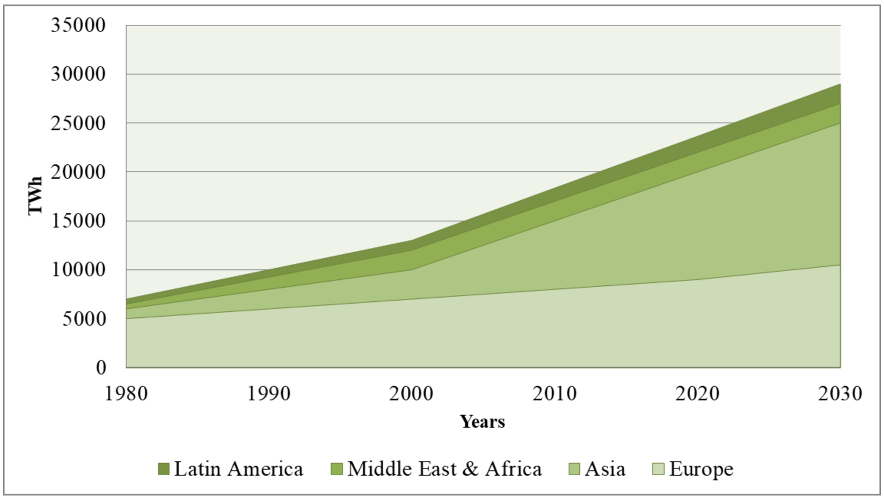

Figure 1.6 – World electricity consumption by region in 1980-2030, TWh [10]

Today, most reserves of fossil fuel and energy resources are in the process of depletion. According to average estimates, at the current production and consumption rate, oil in the world's explored fields will be enough for 15-25 years, natural gas – for 30-50 years, coal – for 100-200 years [11]. Another trend is a significant increase in prices for the use of additional fuel and energy resources on world markets due to increased demand for them. In addition, the shortage of fuel and energy resources contributes to the struggle for them, which is reflected in international conflicts.

One of the promising areas for solving the above problems is the development of renewable energy, the main advantages of which are:

• availability of renewable energy sources in all countries of the world, which allows to increase the level of energy independence of countries and helps to avoid energy crises;

• renewable energy sources are not depleted, which allows to store fossil fuel reserves for future generations and provides opportunities for their use outside the energy sector;

• renewable energy sources are environmentally friendly – energy production based on them is not accompanied by greenhouse gas emissions, which has a positive impact on the prevention of global warming and climate change;

• the possibility of using renewable energy sources near end-users, which allows to increase the reliability of energy supply, improve the quality of electricity and provide hard-to-reach areas with energy.

One of the most mature and affordable renewable energy technologies is solar energy. And the use of photovoltaic systems has become the most common way to use solar energy globally.

The use of solar energy in agriculture began in the 80th of the XX century. However, mass use in the agricultural sector intensified only a few years ago. It was made possible by the fact that solar energy technologies have not only significantly advanced in terms of efficiency over the past 15 years but have also become cheaper. Investing in energy assets makes the agribusiness less dependent on external suppliers and monopolies, which there are so many in the energy sector.

Another factor in the need to attract solar energy to the agricultural sector is cost predictability. Because of the construction of a solar power plant, the business receives a fully predicted price of one kilowatt-hour of electricity, which will not change for the better in contrast to suppliers' tariffs. Modern solar energy technologies are full of opportunities, similar to a designer, perfectly compatible with agriculture's business models. With solar energy, both small farms and large agricultural holdings are increasingly becoming drivers of innovation and become energy-independent entities.

One such innovative technology is agrovoltaics, which offers a new level of productivity and business sustainability for farmers. Installation of agrovoltaics systems on agricultural lands has several advantages. It allows increasing the share of renewable energy in the world energy balance, partially solving the depletion of non-renewable energy resources, protecting farm owners from fluctuations in energy prices, etc.

1.3 Agrovoltaic systems: towards solving global environmental problems

Global warming and climate change are one of the most important environmental problems of our time, the main cause of which is human activity, namely greenhouse gas emissions.

The main types of greenhouse gases are carbon dioxide, methane, nitrous oxide, and fluorinated gases. The main source of carbon dioxide emissions is the combustion of fossil fuels. Methane enters the atmosphere during fossil fuel extraction, waste decomposition in landfills, and animal husbandry. Emissions of nitric oxide accompany activities for the use of chemical fertilizers in agriculture. Fluorinated gases, which are formed as a result of various industrial processes and the destruction of the ozone layer, are also responsible for enhancing the greenhouse effect [12].

In terms of total greenhouse gas emissions, carbon dioxide ranks first – 76%, second is methane – 16%, third – nitrous oxide – 6%, the smallest contribution belongs to fluorinated gases – 2% [13].

With increasing greenhouse gas emissions by almost 1° C compared to 1950, global temperatures have risen. Scientists claim that raising the average global temperature to 2° C is critical for the planet and humanity [14]. The largest amounts of greenhouse gases are emitted by the energy sector during electricity and heat production (Fig. 1.7).

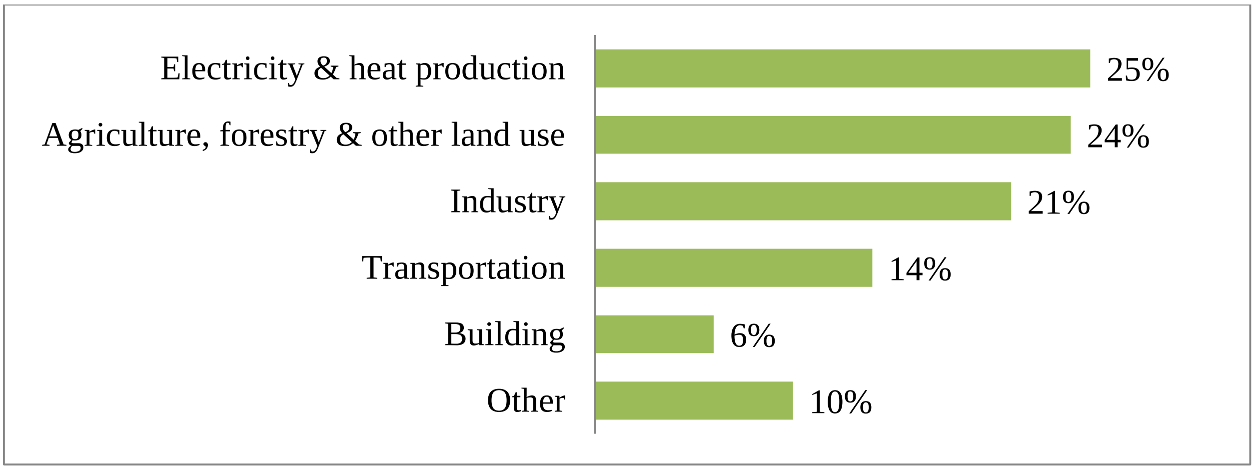

Figure 1.7 – Greenhouse gas emissions by sector in 2018, % [12]

Agriculture is an industry that also harms the environment and climate change in terms of greenhouse gas emissions. Total emissions from land cultivation, fertilizers, handling of manure, and livestock are almost 90 million tons of CO_2. At the same time, influencing the climate, the agro-industry is one of the most vulnerable to climate change. Therefore, there is a need to attract renewable energy to the agricultural sector. Enterprises reduce the negative impact of livestock waste by producing electricity from it. In addition to livestock waste, crop waste is also used to produce green heat and electricity [15].

Therefore, one of the promising ways to reduce emissions is to replace traditional energy production technologies with renewable energy resources, including solar energy based on agrovoltaic systems. The practice of agrovoltaics shows that agrovoltaic systems do not harm nature but, on the contrary, contribute to agriculture becoming more organic and nature-oriented by helping to reduce greenhouse gas emissions into the atmosphere.

It is worth noting that global warming and climate change are serious environmental problems, the solution of which requires consolidated action by the international community, primarily through the conclusion and implementation of global climate agreements. Under the Paris Climate Agreement, which regulates measures to reduce carbon dioxide in the atmosphere, all countries, regardless of their level of economic development, have committed themselves to reducing greenhouse gas emissions to prevent global temperatures above 2°C.

Different countries emit different amounts of greenhouse gases, thus making different contributions to global warming (Fig. 1.8).

Such counties as China, the USA, Russia, India, and Japan emit together more than half of the world's emissions. Therefore, along with countries that have limited land resources and shortages of their own energy resources, these countries should also pay special attention to agrovoltaics technology, the use of which can make a significant contribution to reducing greenhouse gas emissions.

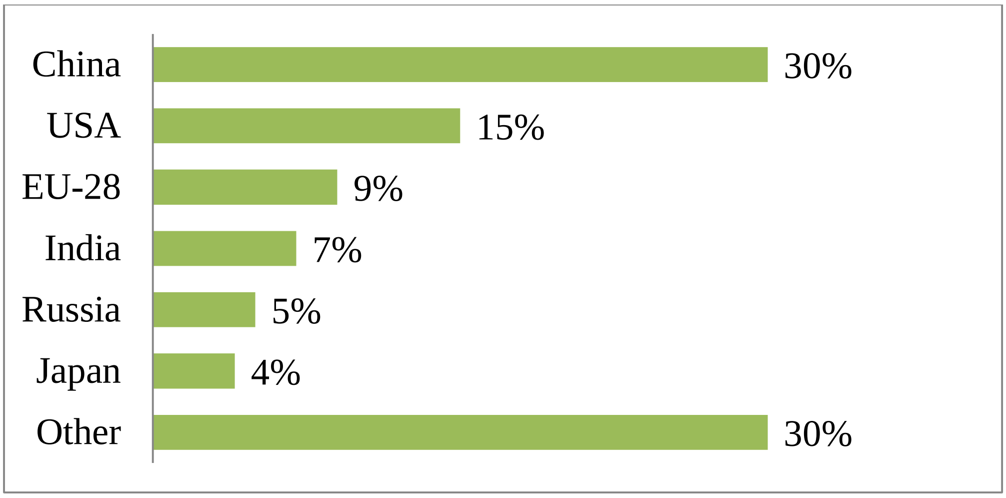

Figure 1.8 – Greenhouse gas emissions by country in 2018, % [12]

Thus, given the above, the development of agrovoltaics can be considered by countries as one of the effective tools to achieve carbon-neutral economies.

2. AGROVOLTAICS: SYMBIOSIS OF SOLAR ENERGY AND AGRICULTURE

2.1 Theoretical aspects of agrovoltaic systems

For a long time, the sun has been a source of free and clean energy in the world of agribusiness, providing crops with everything they need to grow. Today, the prospects for using solar energy in the agricultural sector are expanding to generate electricity based on agrovoltaic systems.

Agrovoltaics is a relatively new technology that allows the simultaneous use of agricultural land for energy and food purposes. Solar power plants can generate significant amounts of electricity and require large areas for their location [16].The amount of land resources of the planet is limited, and a significant part of them falls on agricultural land, so it makes sense to double their purpose by using agrovoltaics technologies (Fig. 2.1).

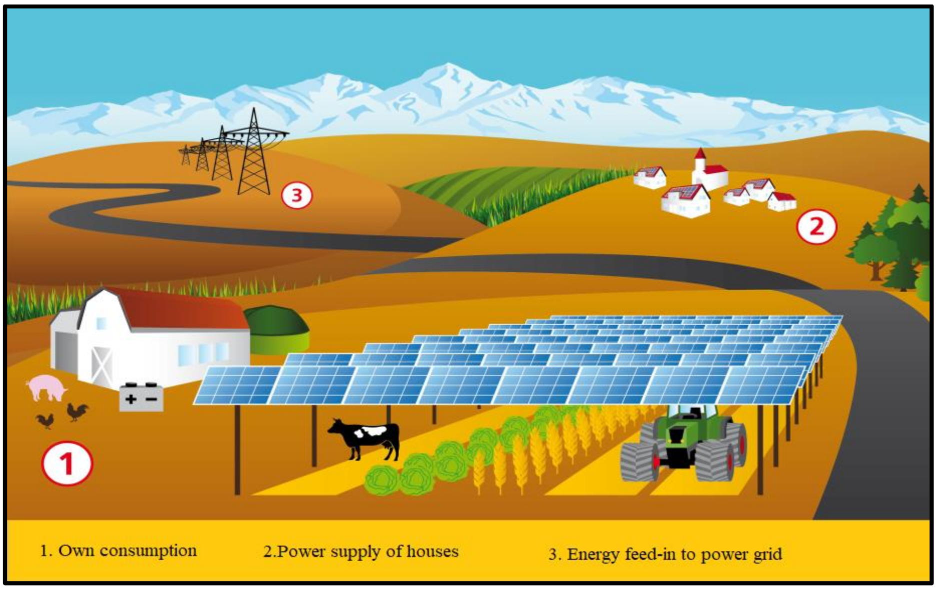

Figure 2.1 – The principle of operation of the agrovoltaics system [17]

The latest agrovoltaic systems have the ability to track sunlight and are installed on special structures. Horizontal bases are mounted on the supports, on which the secondary axis holding the solar panels is hinged. The axles can be rotated by electric motors using innovative control systems. Unlike traditional ground-based photovoltaic systems, agrovoltaics systems allow agricultural work to be performed using standard agricultural machinery.

Today, two main methods of designing photovoltaic panels for agrovoltaic systems are used. The first is based on the installation of tape types of crystalline silicon photovoltaic panels placed above the surface of the plantings. They allow sunlight to hit the ground, but most of it hits photovoltaic panels to generate electricity. The second method is based on the application of thin-film photovoltaic panels, which are translucent and have the ability to transmit some light [18].

The main advantages of agrovoltaics include: [17,18]:

– the possibility of providing farm households with their own electricity, which can be used for production needs;

– receiving income from the sale of electricity at a feed-in tariff or under other mechanisms to stimulate the development of solar energy;

– controlling of the level of solar radiation in crops;

– controlling and adjustment of moisture and nutrient content in the soil, reduction of groundwater evaporation;

– the possibility of using solar tunnels, the service life of which is 25-30 years, instead of film, which must be replaced every 5-6 years;

– the ability to harvest, avoiding the peak of its maturation in a period of low cost.

However, in addition to the above advantages, agrovoltaic systems have certain disadvantages. One of the problems with this technology is that solar panel supports are installed on concrete platforms, thus reducing the area of land that can be used to grow crops. Another disadvantage is the shading formed by photovoltaic panels. This negatively affects the yield of most crops. For example, the yield of vegetables such as peppers, broccoli is only 60% of the amount that can be obtained under normal conditions of their cultivation [19]. In addition, some problems may occur in the processing of agricultural crops. This concerns the limitation of the size and efficiency of agricultural machinery that can be placed under and between agrovoltaic systems [20].

However, agrovoltaics is one of the most promising technologies that allows farms to combine energy and agricultural business effectively despite these disadvantages.

2.2 Typology of agrovoltaic systems

The rapid spread of agrovoltaics in recent years has led to some variations of agrovoltaic systems. Criteria such as scope, type of system, type of placement of photovoltaic panels, and mobility can be used to classify them [21].

The first logical step is the classification of agrovoltaic systems based on their application. According to this criterion, they are divided into those used in the crop sector and those used in the livestock sector. In addition, this criterion can also be used to classify agrovoltaic systems used for field cultivation of crops (wheat, corn, sunflower, potatoes, etc.) and those used in gardening for growing fruit and berry crops.

The second stage of classification is based on the type of system, which can be open or closed. Closed agrovoltaic systems are greenhouses on the roof of which photovoltaic modules are placed (Fig. 2.2).

Figure 2.2 – Closed agrovoltaic system [19]

Such greenhouses have a fully controlled and closed microclimate (temperature, humidity, etc.), which is completely different from the uncontrolled meteorological conditions of the open agrovoltaic system (Fig. 2.3).

Figure 2.3 – Open agrovoltaic system [18]

The next criterion for the classification of agrovoltaic systems concerns the placement of photovoltaic panels. They can be placed in straight rows, in a checkerboard pattern, at an angle and vertically (Fig. 2.4).

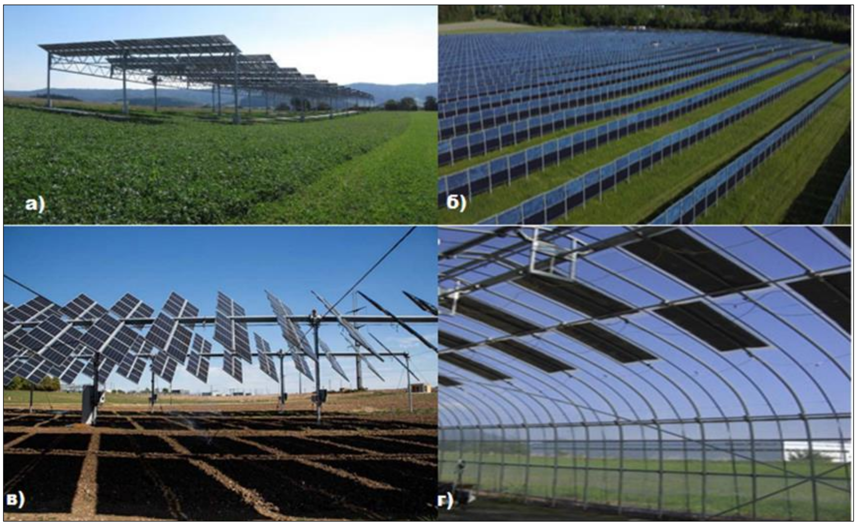

Figure 2.4 – Possible types of placement of photovoltaic panels
a) straight rows, b) in a checkerboard pattern, c) at an angle, d) vertical [22, 23, 24]

Different designs create different spatial boundaries and shading. The choice of construction type depends on the type of crops that are planned to be grown. From the point of view of more uniform distribution of solar radiation, agrovoltaic systems with photovoltaic panels in a checkerboard pattern are the most effective. This arrangement allows creating variable shadows under the system, which can change depending on the time of day and the sun's position. Therefore, all plants under the panel receive a uniform light effect..

The last stage of classification is based on the mobility of agrovoltaic systems. Large-capacity and high-capacity agrovoltaic systems are usually fixed (means do not move from one field to another). In contrast, small-scale agrovoltaic systems can be mobile and temporarily used in different areas. A separate type of agrovoltaic systems is designed with an additional function for collecting rainwater, which is collected from the surface of the modules in a corresponding channel at the bottom of the panel. It makes possibility to use it for watering plants (Fig. 2.5).

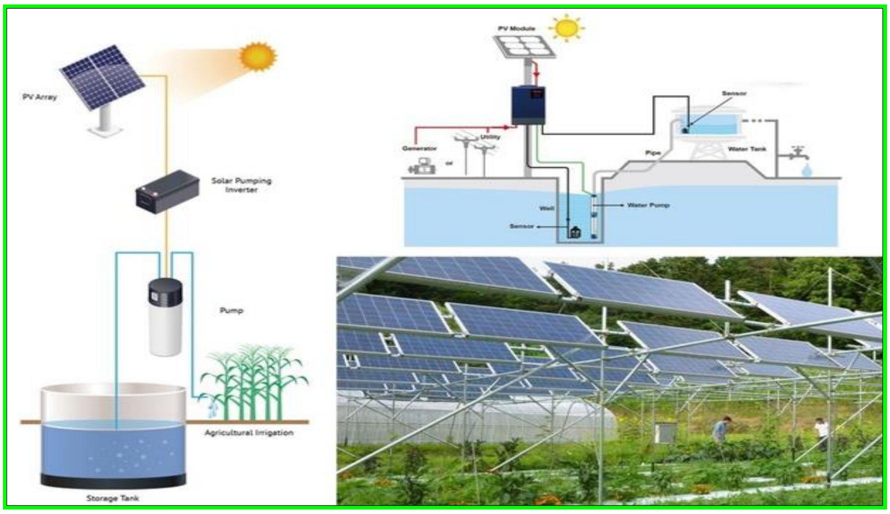

Figure 2.5 – Agrovoltaic system with additional function for collection rainwater [25]

In addition, the accumulated rainwater can be used to clean photovoltaic panels from dust (especially in arid regions), as dust reduces the transparency of the panels, thereby reducing the amount of electricity generated.

Thus, the rapid increase in the types of agrovoltaic systems emphasizes the growing potential of their use and outlines the diversity of their application in different areas of agriculture.

2.3 Foreign experience in the development of agrovoltaics

Today, agrovoltaics projects have become widespread in a number of countries. Some of them are pilot and being implemented for conducting scientific research on the dual use of agricultural land, while others have been exploited long for food and energy purposes [26].

The first country where agrovoltaics began to develop was Germany. The pioneer of this direction was Adolf Gotzerberger, who founded the Fraunhofer Institute for Solar Energy Systems. The institute installed a "dual farm" on an area of one-third of a hectare, where the solar panels were located high enough for agricultural machinery to pass under them. Wheat, potatoes, celery, and clover were grown under photovoltaic panels. Electricity generated by the agrovoltaic system has increased the economic efficiency of agricultural land use by 60% [25].

In the United States, a pilot agrovoltaic system is installed at the University of Massachusetts. Peppers, beans, coriander, tomatoes, lettuce, and broccoli, are grown under solar panels. These crops are harvested by hand. The gaps between the solar panels of this system are 1–1.2 m wide, which allows obtaining almost the same crop yield as in the open sun. At the same time, state farms hardly use agro-volt systems in practice. To stimulate the development of this area, the local has introduced a program of special grants, the amount of which reaches 100 thousand dollars [24].

Arizona has some experience growing peppers, tomatoes, avocados, and mangoes using agrovoltaic systems. Studies on farms in this state have shown that plants need half as much water as in the open sun. Solar panels protected them from frost, smoothed temperature fluctuations, extended the growing season, and the temperature in the shade of photovoltaic panels allowed workers to work in more comfortable conditions [24].

India is a particularly promising region for agrovoltaics, as it has an economy that focuses on agriculture, and is rapidly expanding energy services, as up to 21.3% of India’s population does not have access to any form of electricity.

In addition to the installation of agrovoltaic systems, the installation on the panels of solar steam generators – portable devices that purify and desalinate water in the process of evaporation. Such devices, according to scientists, can have a positive impact on the sanitary and epidemiological situation in regions with a shortage of drinking water, reduction of diseases caused by lack of safe drinking water [27].

While in Europe and America mainly small-scale research and a few medium-scale commercial agrovoltaic facilities have so far been established, China is already implementing this technology on a large scale. More and more attention is being paid to expanding domestic demand to address China’s photovoltaic overcapacity. The combination of photovoltaic energy and agricultural activities is a natural response to the supply of clean and sustainable electricity for agriculture. Various agricultural crops including rice and forage grasses are cultivated. In recent years, photovoltaic agriculture has grown rapidly in China thanks to a strong state support policy, thriving controlled organic agriculture, a focus on rural electrification policy etc [28].

Thus, agrovoltaics as relatively new technology is becoming increasingly popular in the world, and it has become a practice in the most developed countries.

Moreover, all pilot projects and practices prove that agrovoltaics undoubtedly increases in commodity production, both in the form of agricultural products and in the form of clean renewable energy.

3 ECONOMIC JUSTIFICATION OF EFFICIENCY OF AGROVOLTAIC SYSTEMS IN UKRAINE

3.1 Prospects of agrovoltaics development in Ukraine

Agriculture and energy are one of the main components of Ukraine's successful development. Their symbiosis in the agrovoltaic direction has significant potential for development in the near future.

The climate and geographical location of Ukraine are favorable for the operation of photovoltaic systems. For the most part, the potential of solar energy is concentrated in the southern regions of the country, declining as it moves north (Fig.3.1).

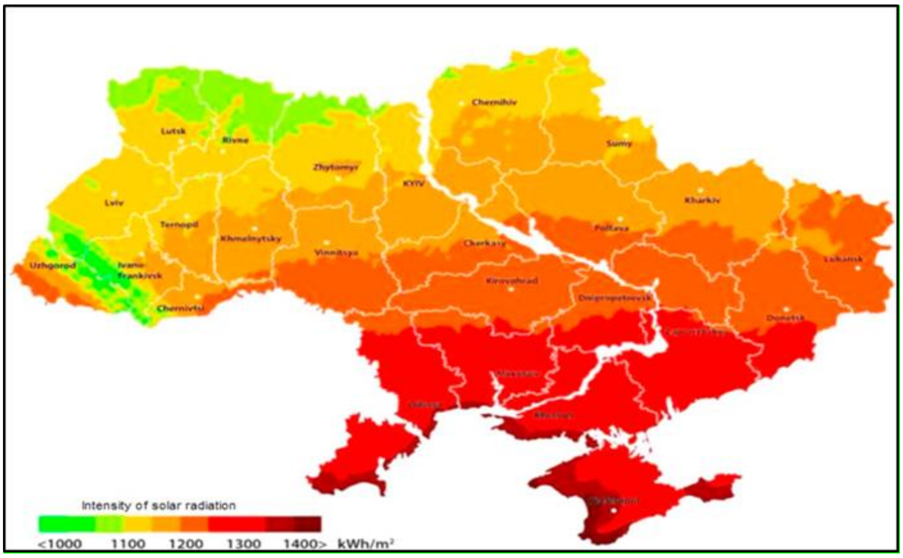

Figure 3.1 – Intensity of solar radiation in Ukraine, kWh/m^2 [29]

Solar generating capacity can be operated efficiently throughout the year, but most efficiently for seven months a year (April to October) in the southern regions and five months a year in the northern regions (May to September).

Ukraine also has significant potential for agricultural development, due to favorable natural conditions: fertile soils and temperate climate in most parts of the country provide Ukrainian farmers with significant competitive advantages.

Ukraine’s agriculture is a leader in the export of crop and livestock products to world markets. In addition, it is the main driving force for the development of the country’s economy and ensuring the welfare of the population [30].

The land fund of Ukraine has approximately 43 million hectares of agricultural land, 32 million hectares of which are arable land. The latter is equal to one-third of the arable land in the European Union [30].

The main crops that make Ukraine one of the world leaders in agriculture are cereals and oilseeds. Most land is concentrated under cereals – 54%, industrial crops – 32%, feed crops – 6,2%, vegetables – 6.5%, fruits and berries – 0,8%, viticulture – 0,2%, hop growing – less than 0,1% [31].

Due to the favorable geographical location, climate, and soil fertility, Ukraine has great prospects to intensify agriculture by using solar energy, optimizing the use of space, and getting the most out of it.

The development of renewable energy is one of the key areas of reforming Ukraine’s energy sector. Guidelines for the development of renewable energy are declared in the Energy Strategy of Ukraine for the period up to 2035. It provides an increase in the share of green energy in the country’s final energy consumption to 12% and 25% in 2025 and 2035, respectively [32].

To achieve these goals, the government has implemented economic mechanisms to encourage the generation of electricity from renewable energy sources, including solar energy. Such mechanisms include: 1) feed-in tariff; 2) tax and customs benefits. It should be noted that the introduced mechanisms are the same for all renewable energy technologies. Consider them from the point of stimulating the development of solar energy in this study.

1. Feed-in tariff. According to the Law of Ukraine “On the electricity market”[33], the feed-in tariff is a tariff at which electricity generated from renewable energy resources, including solar energy, is purchased.

The feed-in tariff is calculated for each generating object separately based on special coefficients, which depend on the solar power plant's location, capacity, and year of commissioning.

The state guarantees the purchase of the entire amount of electricity generated by solar power plants at the feed-in tariff until December 29, 2030. In the event of changes in the legislation governing the procedure for stimulating the generation of electricity from solar radiation, businesses may choose a new procedure for stimulation.

The Law “On Alternative Energy Sources” [34] provides for a fixed surcharge to the feed-in tariff for the using equipment and components of domestic production in the construction of solar power plants. Thus, for solar power plants commissioned from July 1, 2015 to December 31, 2024, when using Ukrainian-made equipment at the level of 30% and 50%, the size of the surcharge to the feed-in tariff is 5% and 10%, respectively.

The purpose of this legislation is to stimulate the development of domestic equipment and components for the solar energy sector, which will help modernize the production capacity of Ukrainian machine-building enterprises, reduce imports of such equipment and increase its exports in the future.

2. Tax and customs benefits. The Tax and Customs Codes of Ukraine [35, 36] provide for exemption from value added tax and customs duties for the purchase of materials, equipment, components used to generate electricity from solar radiation.

It should be noted that these tax and customs benefits can be used only if identical goods with similar quality characteristics are not produced in Ukraine.

Favorable climatic conditions and implemented state support mechanisms have contributed to the rapid increase in solar energy capacity in both the industrial sector (business sector) and the private household sector. Thus, as of the end of 2019, there were 820 solar energy facilities in Ukraine in the industrial sector.

As of the end of 2019, their number has increased almost 10 times compared to 2015 (Fig. 3.2).

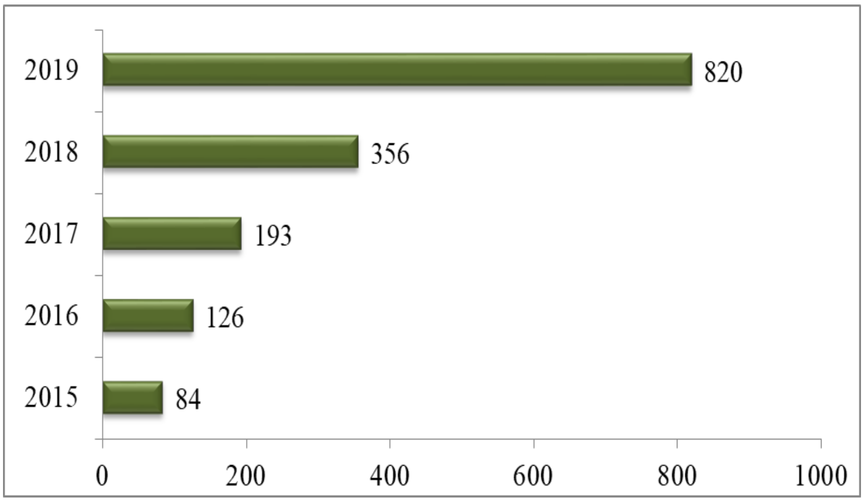

Figure 3.2 – Number of solar power plants in the industrial sector in 2015-2019, units [37, 38, 39, 40, 41]

The total installed capacity of solar power plants in the industrial sector as of the end of 2019 was 4934,6 MW, which is 11,4 times higher than in 2015 (Fig. 3.3).

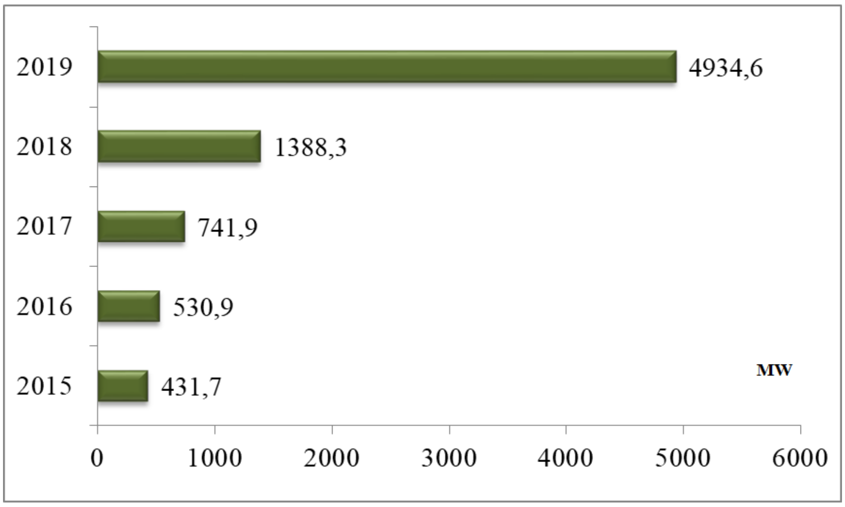

Figure 3.3 – Installed capacity of solar power plants in Ukraine in 2015-2019, MW [37, 38, 39, 40, 41]

The amount of electricity generated by solar power plants in the industrial sector in 2019 amounted to 2932 million kWh, which is 6 times higher than in 2015 (Fig. 3.4).

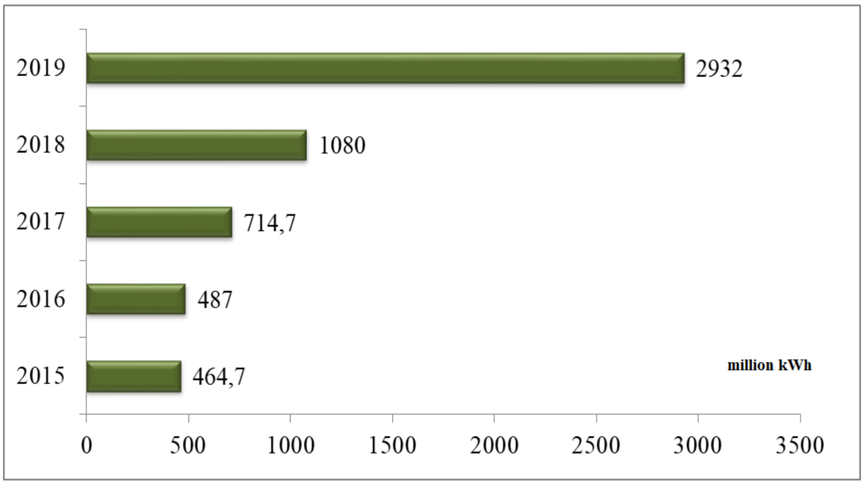

Figure 3.4 – The amount of electricity generated by solar power plants in the industrial sector in 2015-2019, million kWh [37, 38, 39, 40, 41]

In addition to the industrial sector, significant positive dynamics in terms of the number of solar energy facilities, their installed capacity and the amount of electricity generated by them was observed in the private household sector (Table 3.1).

Table 3.1 – The main indicators of solar energy development in the private household sector [37, 38, 39, 40, 41]

Indicators of solar energy development in the private household sector	2015	2016	2017	2018	2019
Number, units	224	1109	3010	7450	21968
Installed capacity, MW	2,2	16,7	51	157	553
Volume of generated electricity, million kWh	0,25	2,91	18,92	76,12	303

Given the above, we can conclude that the main reason for solar energy development was the state incentive policy. It should be noted that in Ukraine, it applies only to the electricity sector. This is the main reason why this technology has not developed in other sectors: heat, transport, and agrovoltaics.

Despite some advantages of agrovoltaic systems, the available potential of solar energy and agriculture for its development, today in Ukraine no agrovoltaic system is installed. Let us consider the main obstacles to the dual use of agricultural land for energy and food purposes in Ukraine.

The main obstacle to the installation of agrovoltaic systems in Ukraine is the peculiarities of the legislation governing the development of renewable energy in Ukraine. Thus, in accordance with Article 14 of the Law of Ukraine “On Energy Lands and the Legal Regime of Special Zones of Energy Facilities” solar power plants can be located only on land unsuitable for agricultural use [42] with difficult relief, high level of waterlogging, etc. Today, this legal norm is the main barrier to the development of agrovoltaics in Ukraine.

Subject to changes in current legislation and permission to install agrovoltaic systems on agricultural land, the development of this area may face other barriers.

First, it is the need for significant start-up investments for the implementation of agrovoltaic projects. It should be noted that the implementation of projects of solar photovoltaic power plants is quite expensive. In turn, capital costs for agro-voltaic systems in comparison with usual photovoltaic installations are higher [43]. It is due to the presence of a frame system, which requires applying a denser layer of anti-corrosion coating. Due to the humidity in the areas where agrovoltaic systems are located, there is increased corrosion activity.

The need for significant financial resources is exacerbated by the lack of affordable lending for such projects. Thus, rates on long-term loans in the national currency for green energy projects range from 12-18% per annum, which does not allow to attract financial resources to investors on acceptable terms [44, 45].

Given the high cost of installation and the lack of affordable lending, the payback period of investment projects for constructing agro-volt systems is approaching 20-22 years, which is unacceptable from an economic point of view. Therefore, the best option to stimulate the development of this area is to extend the feed-in tariff for electricity generated from agrovoltaic systems. An additional impetus for the development of agrovoltaics may also be improving legislation regarding the formation of energy cooperatives. It will create favorable organizational and economic conditions for the pooling of financial resources of local communities for the joint implementation of agrovoltaic projects.

Secondly, the development of agrovoltaics in Ukraine is faced with resistance to legislation and farmers themselves, who are reluctant to take any initiatives. Farmers are accustomed to working according to a certain scheme of rapid rates of income, which was formed over the years in agriculture in Ukraine. Therefore, it is important to inform farm owners about the economic, social, and environmental benefits of implementing agro-voltaic projects.

Summing up, in our opinion, the improvement of current legislation to stimulate the development of agrovoltaics, in the first place, should address two points: 1) granting permission for the use of agricultural land for the construction of agro-voltaic systems. First of all, such permits should be obtained by small farms, which will help increase their competitiveness compared to large agricultural holdings. In the initial stages, the state may issue permits for the installation of agrovoltaic systems in limited areas (for example, not more than 5 hectares for each farm); 2) extension of the feed-in tariff for electricity generated based on agrovoltaic systems. This will guarantee investors a quick return on start-up investment and promote the competitiveness of agro-volt systems compared to other renewable energy technologies on the Ukrainian market.

Next, we will test the implementation of the agrovoltaic project, subject to the above changes in current legislation. The approbation will be carried out for the farm “Palun”, located in the Khomyntsi village, Romensky district, Sumy region.

3.2 Estimation of the cost of electricity generation and crop yields using agrovoltaic systems in Ukraine

Estimating the cost of electricity generation based on agrovoltaic systems and payback period are key factors influencing decisions on the implementation of such investment projects.

We will estimate the cost of electricity generation by the agrovoltaic system based on the Levelized Cost of Electricity (LCOE) method. Levelized Cost of Electricit method reflects the fixed cost of electricity throughout the life cycle of the generating facility, which equates the total discounted costs of its construction and operation to the total discounted revenue from the sale of electricity [46].

To estimate the cost of electricity generation based on agrovoltaic system in this study will take into account the following indicators: investment costs, operating costs, the amount of electricity generated, the cost of decommissioning of agrovoltaic system and the discount rate.

Thus, the formula for calculating the LCOE will look like:

$$LCOE = \frac{\sum_{t=0}^{n} ((I_t + Q_t + F_t + D_t) \cdot (1+r)^{-t})}{\sum_{t=0}^{n} (E_t \cdot (1+r)^{-t})}, \quad (3.1)$$

where *LCOE* – fixed cost of electricity generation during the lifecycle of the agrovoltaic system, UAH/kWh; *Et* – the amount of electricity generated in the t year, kWh/year; *It* – investment costs in the t year, UAH; *Qt* – operating expenses in the t year, UAH; *Dt* – costs for decommissioning of agrovoltaic system in t year, UAH; *n* – service life of agrovoltaic system, years; *r* – the discount rate; *t* – year of investment project implementation.

Discount rate, calculated on the basis of the Weight Average Cost of Capital [47]. Its calculation will be based on the assumption that the farm “Palun” will not attract credit resources for the construction of the agrovoltaic system, as it has its own financial resources for the project. Given this, the cost of borrowed capital and its share of the balance sheet in this study will be zero. Valuation of equity is defined as the sum of alternative investments in deposit accounts.

For this purpose, we will analyze the rates on deposits in the national currency in the 5 most reliable banks in Ukraine. In 2020, such banks were Ukrsibbank, Credit Agricole, Kredobank, Pravex Bank, Raiffeisen Bank Aval [48]. Annual rates on deposits in these banks are given in Table 3.2.

Table 3.2 – Annual rates on deposits in national currency in 5 most reliable banks of Ukraine as of March 1, 2021 [49]

Name of the bank	Annual rate on deposits in national currency, %
Ukrsibbank	5,75
Credit Agricole	5,50
Kredobank	9,00
Pravex Bank	8,00
Raiffeisen Bank Aval	5,75

The data in Table 3.2 shows that the highest interest rate on deposits in national currency is offered by Kredobank, which will be used to calculate the discount rate. Given that the equity share on the balance sheet is 100%, the discount rate will be 9%.

Next, we consider the technical and economic characteristics of the agrovoltaic system that will be used for calculations [50; 51]:

- installed capacity of agrovoltaic system – 1,2 MW;
- the area involved in the agrovoltaic system – 2,3 ha;
- the area involved under the frame part – 0,3 ha;
- area available for crops – 2 ha;
- the service life of the agrovoltaic system – 25 years;
- annual electricity production – 1780000 kWh/year.
- investment costs – 28700000 UAH;
- operating costs and maintenance costs – 620000 UAH/year;
- costs for decommissioning of the agrovoltaic system – 1375000 UAH.

Based on the above technical and economic data, the cost of generating electricity generated based on agrovoltaic system, calculated by Formula (3.1), is 1,86 UAH/kWh.

We calculate the value of the feed-in tariff at which the farm could sell electricity, subject to changes in current legislation, proposed by us in advance. According to the current legislation, businesses can sell at a green rate only the excess electricity not consumed for their own purposes. Note that the amount of electricity consumed by the farm "Palun" in 2020 was 429387 kWh.

The National Energy and Utilities Regulatory Commission calculates the feed-in tariff in accordance with the algorithms specified in Resolution № 1817 of 30.08.2019 [52].

The fixed minimum size of the feed-in tariff (Φ_{min}, EUR per 1 kWh without VAT) is calculated according to the formula:

$$FT_{min} = \frac{\mathrm{T}_{consr.II\ cl.01.01.2009} \cdot \mathrm{K}_{gr.t}}{E_{01.01.2009}}, \tag{3.2}$$

where $\mathrm{T}_{cons.II\ cl.01.01.2009}$ – retail tariff for consumers of the second voltage class as of January 2009 (0,58 UAH per 1 kWh without VAT); $\mathrm{K}_{f.t}$ – coefficient of feed-in tariff, determined by the Law of Ukraine "On the electricity market" [33] (for electricity generated from solar radiation, the installed capacity of which does not exceed 10 MW, put into operation from 01.01.2020 to 31.12.2024, the coefficient of the feed-in tariff is 2,51); $E_{01.01.2009}$ – the exchange rate of UAH to the EUR, officially set by the National Bank of Ukraine on January 1, 2009 (1085,55 UAH per 100 EUR).

Based on the fixed minimum tariff size, the value of feed-in tariff is calculated, according to which electricity is sold, according to the formula:

$$\mathrm{T}_{ft.} = FT_{min} \cdot E_{avg30}, \tag{3.3}$$

where T_{fr} – feed-in tariff at which electricity is sold (UAH per 1 kWh without VAT); E_{avg30} – the average exchange rate of UAH to EUR for the last 30 calendar days preceding the date of feed-in tariff calculation (UAH per 100 EUR), determined by the formula:

$$E_{avg30} = \frac{\sum_{\mathrm{i=d-1}}^{d-1} €E_{\mathrm{i}}}{30}, \tag{3.4}$$

where E_{i}– exchange rate of UAH to EUR, officially set by the National Bank of Ukraine on the *i*-date, UAH per 100 EUR; d – the date of the feed-in tariff calculation.

Calculated according to formulas (3.2-3.4), the feed-in tariff for the agrovoltaic system is 4,51 UAH/kWh, which is 2,3 times higher than the cost of electricity generation, calculated according to the Levelized Cost of Electricity method.

Based on the above data, we will calculate the payback period of the investment project by the formula:

$$PP = \sum_{t=1}^{n} CF_t \geq II_{0,} \tag{3.5}$$

where *PP* – the payback period of the investment project; II_0 – initial investment in the zero period (year), UAH; CF_t – net cash flow in the t year, UAH; *n* – duration of the project life cycle, years; *t* – year of project implementation.

The results of calculating the payback period of the agrovoltaic system show that at the current level of the feed-in tariff, start-up investments will pay off in 7,1 years, which is quite attractive for investors.

One of the features of agrovoltaic systems is the effect of shading created by photovoltaic modules on the development of crops and their yields (Table 3.3).

Table 3.3 – Influence of agrovoltaic systems on agricultural crops [21]

Name of agricultural culture	Impact on yield	Further effects
Sunflower	Decrease in a set of seeds and its number	Changed the composition of fatty acids
Potato	Decreased yield and its number	Increasing plant height and leafage area
Wheat	Decrease in grain yield and grain size	Increased yield for some varieties in conditions of moderate shading; increased protein content
Corn	Decrease in grain yield due to decrease in its weight; increasing the yield of the stem	Increased fat and protein content; reducing the starch content
Rise	Reduced grain yield due to shading at the stages of reproduction and ripening	Shading at the vegetative stage had no effect
Tomato	Increased fruit yield under moderate shading conditions. Increasing the height of plants with increasing shade	Reduced content of ascorbic acid, carotenoids and phenolic substances. Reduced number of fruits with sunburn.
Sweet pepper	The highest yield under moderate shading conditions	Reduced number of fruits with sunburn

The data in Table 3.3 show that, depending on the type of crop and the intensity of shading, it can have both positive and negative effects on crop yields and other crop characteristics.

Next, we will focus on crops, the cultivation of which is typical for the Sumy region. Comparison of their yields without the use and with the use of agrovoltaic systems are given in Table 3.4. As can be seen from the data in Table 3.4, a decrease in yield is observed for most of the study's crops. The only exception is winter wheat, the yield of which increases insignificantly.

Table 3.4 – Comparison of crop yields without using and with using of agrovoltaic systems [53, 54]

Name of agricultural crop	Yield without using of agrovoltaic systems, centner / ha	Yield without with using of agrovoltaic systems, centner / ha
Spring wheat	53,70	42,96
Winter wheat	53,80	55,41
Barley	43,00	34,40
Corn	87,10	69,68
Sunflower	32,30	28,84
Potato	161,50	129,20

It is worth noting that the farm “Palun” specializes in growing three types of crops: spring wheat, corn, and sunflower. Using the data in Table 3.4, we will calculate the revenue from the sale of these agricultural products by the farm without using agrovoltaic system, considering that the area of land allocated for the construction of agrovoltaic system is 2,3 hectares (Table 3.5).

Table 3.5 – Revenue from the sale of agricultural products by the farm without using of agrovoltaic system *(calculated by the author)*

Name of agricultural crop	Area used for growing crops, ha	Yield without using of agrovoltaic systems, centner / ha	Sales price in the domestic market of Ukraine, UAH / centner	Sales revenue, UAH
Spring wheat	2,3	53,70	483,93	59770,19
Corn	2,3	87,10	467,94	93742,42

Next, we calculate the revenue from the sale of agricultural products by the farm using the agrovoltaic system. In this case, 0,3 ha will be used for frame systems for mounting photovoltaic modules; respectively, the area for growing crops will be only 2 ha (Table 3.6).

Table 3.6 – Revenue from the sale of agricultural products by the farm with using of agrovoltaic system *(calculated by the author)*

Name of agricultural crop	Area used for growing crops, ha	Yield with using of agrovoltaic systems, centner / ha	Sales price in the domestic market of Ukraine, UAH / centner	Sales revenue, UAH
Spring wheat	2,0	42,96	483,93	41579,27
Corn	2,0	69,68	467,94	65212,12

The tables show that the revenue from the sale of agricultural products, provided agrovoltaic systems, is lower than without their use, due to both reduced yields due to shading and the smaller area used for growing crops.

However, the main advantage of agrovoltaic systems is the maximum efficiency of dual-use of agricultural land for energy and food purposes, which allows the farm to receive income from two components: the sale of agricultural products and electricity.

3.3 Synergetic effect of agrovoltaic system

With effective state regulation of agrovoltaic development, namely the spread of the feed-in tariff for electricity generated by agrovoltaic systems, the reduction of revenues from the sale of agricultural products will be offset by additional economic benefits from the sale of green electricity. Calculate the total economic benefits of the farm from the dual use of agricultural land.

As mentioned above, according to the current legislation, businesses can sell at the feed-in tariff rate only the excess electricity that is not consumed for their own purposes. Given that the amount of electricity consumed by the farm “Palun” in 2020 was 429387 kWh, and the annual generation of electricity by agrovoltaic system capacity of 1 MW is 1780000 kWh, so the annual amount of electricity that the farm can sell at the feed-in tariff will be 1350613 kWh. Considering the above and the data in Table 3.6, we calculate the annual economic benefits from the dual-use of land by the farm for energy and food purposes (Table 3.7).

Table 3.7 – Economic benefits of dual use of agricultural land by farms for energy and food purposes *(calculated by the author)*

Name of products sold for the year	The volume of products sold	Sales price	Sales revenue, UAH
1 variant			
Electricity	1350613 kWh	4,51 UAH / kWh	6132843,89
Spring wheat	85,92 centner	483,93 UAH / centner	
2 variant			
Electricity	1350613 kWh	4,51 UAH / kWh	6142970,62
Corn	139,36 centner	467,94 UAH / centner	

Based on the data given in Table 3.7, it can be concluded that the implementation of the agrovoltaic system project (subject to the sale of electricity at a feed-in tariff) guarantees significant economic benefits to the farm, regardless of the type of crop grown.

It is worth noting that farming has many risk factors: weather conditions, low yields, fluctuations in prices for products and fuel, etc. The agrovoltaic system will allow the farm to diversify its activities, thereby reducing risks for business.

In addition to the economic benefits to the farm, the implementation of the agrovoltaic project can provide some other benefits.

The farm, through the operation of the agrovoltaic system, can provide: 1) its own electricity needs; 2) pumping water into water supply tanks, carry out drip and metered watering; 3) water heating by means of solar collectors; 4) control of the level of solar radiation entering the plants and soil moisture [17].

For local communities, the construction and operation of agrovoltaic systems will help create new jobs, partially solving employment in rural areas. Payment of taxes to local budgets will contribute to the development of infrastructure that will have a positive impact on the quality and well-being of the rural population. For the state, large-scale agrovoltaics development will contribute to:

– increasing the share of renewable energy sources in the country's overall energy balance, which will have a positive impact on achieving the goals for the development of renewable energy set out in the Energy Strategy of Ukraine until 2035 and fulfilling Ukraine's commitments within the European Energy Society;

– reducing dependence on imports of fossil fuels and energy resources and increasing the level of energy security of the country;

– reducing greenhouse gas emissions into the atmosphere, which will positively impact the environment and fulfil Ukraine’s commitments under the Paris Climate Agreement.

Thus, it can be argued that the implementation of agrovoltaic projects has a synergistic effect and can provide many economic, environmental, and social benefits for the farm, local communities, and the state as a whole.

CONCLUSIONS

The bachelor's thesis considers the challenges of global food and energy security as a prerequisite for the development of agrovoltaics. It is proved that global food and energy security challenges can be considered prerequisites for agrovoltaics development. It has been found that the main problems in ensuring global food security include increasing the world's population, climate change, reduction of sown areas, and the use of food for industrial purposes. In turn, the main challenges of global energy security include the depletion of non-renewable energy resources and rising prices for them on world markets. The development of agrovoltaics can be considered a promising direction for solving the above problems and as the key to low-carbon growth.

Theoretical aspects of agrovoltaic systems, their advantages and disadvantages are investigated. Types of agrovoltaic systems are systematized according to such criteria as scope, type of system, type of placement of photovoltaic panels, and mobility. The foreign experience of agrovoltaics development is analyzed.

To assess the prospects for agrovoltaics development in Ukraine, the potential of agriculture and solar energy has been studied; state mechanisms for stimulating solar energy development have been analyzed. The main barriers that hinder the development of agrovoltaics in Ukraine are outlined, and proposals for their elimination are given.

The implementation of the agrovoltaic system project has been tested subject to appropriate amendments to the current legislation of Ukraine. The calculations show that the revenue from the sale of agricultural products, provided agrovoltaic systems, is lower due to the reduction in crop yields due to shading and the smaller area involved in their cultivation. At the same time, the decrease in revenue from the sale of agricultural products is offset by additional economic benefits from the sale of electricity generated by the agrovoltaic system at the feed-in tariff.

It is proved that the implementation of agrovoltaics systems has a synergistic effect. In addition to the economic benefits for the farms, the implementation of agrovoltaic systems can provide many other environmental and social benefits at the regional, national, and global levels.

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SUMMARY

Perederii T.A. Agrovoltaics as a promising direction of land use for ensuring of global energy and food security. – Bachelor’s qualification paper. Sumy State University, Sumy, 2021.

The final paper is devoted to the study of the prospects of using agrovoltaic systems in order to solve the problems of global energy and food security. The preconditions of agrovoltaics development in the world, theoretical aspects of agrovoltaic systems are considered, the foreign experience of dual use of agricultural lands for food and energy purposes is analyzed. In order to assess the prospects for the development of agrovoltaics in Ukraine, the potential of agriculture and solar energy is studied, the state mechanisms of stimulating the development of solar energy are analyzed. The implementation of the agrovoltaic system project has been tested. The economic, social and environmental benefits from the implementation of agro-volt systems at the regional, national and global levels are assessed.

Keywords: global food security, global energy security, agrovoltaics, agriculture, solar energy.

АНОТАЦІЯ

Передерій Т.А. Агровольтаїка як перспективний напрям забезпечення глобальної енергетичної та продовольчої безпеки. – Кваліфікаційна бакалаврська робота. Сумський державний університет, Суми, 2021.

Кваліфікаційна бакалаврська робота присвячена дослідженню перспектив використання агровольтаїчних систем з метою вирішення проблем забезпечення глобальної енергетичної та продовольчої безпеки. Розглянуто передумови розвитку агровольтаїки в світі, теоретичні аспекти агровольтаїчних систем, проаналізовано закордонний досвід дуального використання сільськогосподарських земель в продовольчих та енергетичних цілях. З метою оцінки перспектив розвитку агровольтаїки в Україні досліджено потенціал сільського господарства та сонячної енергетики, проаналізовано державні механізми стимулювання розвитку сонячної енергетики. Апробовано реалізацію проєкту агровольтаїчної системи. Оцінено економічні, соціальні та екологічні вигоди від реалізації агровольтаїчних систем на регіональному національному та глобальному рівнях.

Ключові слова: глобальна продовольча безпека, глобальна енергетична безпека, агровольтаїка, сільське господарство, сонячна енергетика.