UDC 621.311.24:005.2
DOI: https://doi.org/10.37320/2415-3583/14.13

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DEVELOPMENT OF A METHODOLOGY FOR MODELING ENERGY SUPPLY OF ENTERPRISES BASED ON RENEWABLE ENERGY SOURCES

We outline a potential scenario of energy consumption transition to renewables for the bakery industry of Ukraine where the total electricity demand is satisfied by solar energy. We simulate such a transition using parametric models combined with the Cobb-Douglas production function. We have selected 15 companies, which are ranked into three groups using cluster analysis. Geographically, the production facilities are located in Mykolaiv, Kherson and Zaporizhzhia regions, and the solar radiation in these territories is identical. For the three groups of bakeries in Southern Ukraine, the SAM program calculated the key projection feasibility indicators for the transition of enterprises to renewable sources, considering economic indices. This enabled us to calculate the positive effects of such transformation processes for both an enterprise and the industry as a whole.

Key words: *renewable energy sources, energy supply, photovoltaic solar power plant, factors of production, mechanism of energy supply, bakery enterprises.*

JEL classification: Q42, C12

Introduction. One of the global challenges the civilization faces is to provide energy supply for mankind's daily and industrial activities. This problem results from the limited availability and exhaustive nature of fossil fuels [1; 2]. At the present stage of technological development, it is impossible to imagine the existence of a society without the use of energy in production processes. Energy sources can be divided into two main groups: the first includes non-renewable energy – fossil fuels, the second one includes renewables (solar, wind, water, etc.) [3; 4; 5]. In their turn, state-of-the-art technologies enable significant reduction, and in some segments, complete abandonment of fossil fuels, replacing them with the renewables. The fact that energy sources are replaceable provides the opportunity to develop a theoretical justification for "structural transformation", which should result in a new energy model of an economic system, in which energy supply is based on the use of renewable energy sources.

The study of production factors and energy component, considering different economic theories, made it possible to consider energy as a separate factor of production, which is included in the production cycle.

On the basis of the models of P.A. Samuelson, Cobb-Douglas, M. Nerlov and taking into account the regularities arising between the factors of production, the price of energy, solar activity, adherence to the resource and energy saving mechanism targets and environmental efficiency of production, a parametric model of shift to renewable energy sources for enterprises have been developed [6].

In order to develop scenarios for the implementation of renewable energy systems in the production process at bakeries, a mathematical model was proposed, which involves changing the production method by switching to full or partial self-supply of energy for the production process.

The prediction of the main technological and economic indicators for the solar power plant launch at enterprises was performed using the proposed interdisciplinary mathematical model with the help of NREL – System Advisor Model software (SAM, Version 2017.9.5). This approach made it possible to calculate not only the economic effects, but also to forecast the reduction of greenhouse gas emissions.

For the three groups of bakeries in Southern Ukraine, the SAM program calculated the key projection feasibility indicators for the transition of enterprises to renewable sources, considering economic indices. This enabled us to calculate the positive effects of such transformation processes for both an enterprise and the industry as a whole.

The proposed calculation method can be applied to enterprises in other industries and various geographic regions, because it is universal.

Problem statement. The aim of the work is to develop a methodology for modeling the energy supply of enterprises on the basis of renewable energy sources, taking into account economic, technological and natural environmental components.

Materials and Methods We agree with Paul A. Samuelson's findings on the issue of different approaches to managing the efficiency of renewable and non-renewable resources: "The principles of effective management of these two classes of resources are quite different. Effective use of non-renewables means allocating the finite amount of these resources over time: should we use low-cost natural gas for this generation, or save it for the future? On the contrary, reasonable use of renewable resources aims at ensuring that the flow of services is efficiently maintained ...." [7]. And this, in our opinion, explains, and to some extend points to the further development path for both the economy as a whole and the enterprise itself as a structural unit of the economy.

Production functions allow to model production processes on the basis of elementary production factors, which makes it possible to carry out various analytical calculations, to measure the density of connections, to determine the efficiency of energy consumption, to predict operating results of the enterprise, to analyze the substitutability of elementary factors.

In 1970, scientists D. Georgenson and M. Bruno proposed a production function [8], which, together with components (*L, K*) – labor and capital costs, according to Douglas Solow, the cost of raw materials or energy E with a given price Pe may be considered:

$$q = f\left[E, L, K\right], \quad (1)$$

where q is the volume of output;

E, L, K are values of energy, labor and capital consumption in the production process of the enterprise [9].

It is important to understand that it is necessary to distinguish in modeling the three major groups of technical and economic indicators, where each group characterizes the main stages of the solar power launch process at enterprises, specifically:

– a group of technical and economic indicators that characterize and describe the enterprise prior to the launch of solar technology;

– a group of technical and economic indicators relevant to the moment of this technology launch, which belong to the period of time, in which the organizational and economic mechanism of implementation is in effect;

– a group of technical and economic indicators of the enterprise at the stage upon the launch of a solar power plant.

Thus, the analysis of relationships by the above three groups will enable to identify and determine the key quantitative and qualitative indicators, as well as the characteristics of each stage in the implementation process, which will enable to offer the economic mechanism that will lead to the achievement of the goal – by impact on certain group factors described by technical and economic indicators – that is: cost-effective implementation of solar technology at enterprises.

Generation of Wpv electricity is a result of the two groups of factors: the first includes the technological characteristics of the equipment Ti (technological factor), and the second – the total insolation intensity on the surface of an installed solar power plant Ee (natural-climatic factor), which can be expressed as follows:

$$Wpv = f\left[T_i, E_e\right], \quad (2)$$

The method to calculate the total intensity of insolation includes the whole array of knowledge from different disciplines: physics, geometry, astronomy, meteorology [10].

In general, power generation by a solar power plant can be expressed by the following functional dependence:

$$Wpv = f\left[T_i, N, S, \alpha_t, \Delta K\right], \quad (3)$$

where T_i is the technological factors;

N is the natural and climatic factors;

S is the surface area of the PV modules;

α_t is the tilt of the PV modules to the Earth's surface, depends on a season;

ΔK is the capital invested in solar technology.

Each functional indicator (5) individually requires separate consideration and analysis, which is possible only using the tools from different disciplines: engineering, physics, the nature of knowledge and economics.

It should be noted that the enterprise's shift to solar energy may bring various economic results, which is directly related to many factors: firstly, the ratio of consumed power to generated power, secondly, the sales of the in-house generated electricity by the company at the "green" tariff – τ_z. These options are considered in the second section of our study.

As a rule, an enterprise purchases three types of energy: power, heat and fuel, and for each type there is a price p_i equal to the tariffs in effect or the cost of energy – τ_i. Hence the energy consumption of the enterprise is:

$$E = \sum E_i \tau_i, \quad (4)$$

where E is the energy consumption of the enterprise in terms of value;

E_i is the quantitative indicator i of energy type.

We use the concept of environmental performance proposed in the research work [11]. The authors of this paper define eco-efficiency as the ratio of two components: the cost of production, that is the monetary expression of the production output one desires to increase, and the environmental impact indicators to be decreased. The production costs are formed by the products and services manufactured. So, to determine eco-efficiency, we can use the indicator – the ratio of the production costs to environmental impact:

$$Ecol.Ef = \frac{Y_p}{GHG} \quad (5)$$

where Y_p is the volume of production;

Ecol.Ef is eco-efficiency;

GHG is the amount of greenhouse gas generated for manufacturing of input resources used in the production process.

Given the formulas (1–5), taking into account the costs, the economic mechanism of enterprise's energy supply from renewable energy sources may be simulated as two simplified functional systems, where (6) is the model prior to PV introduction, and (7) is the model after PV launch:

$$\begin{cases} Y_p = \left[K, L, E\right] \\ E = \sum E_i \tau \\ Ecol.Ef = \dfrac{Y_p}{GHG} \end{cases}, \quad (6)$$

$$\begin{cases} Y_p^{/} = \left[K^{/}, L^{/}, E^{/}\right] \\ E^{/} = \sum E_i^{/} \tau \\ Wpv = f\left[Ti, N, S, \alpha_t, \Delta K\right] \\ Ecol.Ef^{/} = \dfrac{Y_p}{GHG^{/}} \end{cases}, \quad (7)$$

where Y_p is the production output;

K, L, E is the capital, labor and energy costs in the production process;

E is the energy costs;

E_i is the amount of energy of the i-th type;

τ_i is the tariff;

Ecol.Ef is eco-efficiency;

GHG is the amount of greenhouse gas generated during the manufacturing of input resources required for the production process

Y'_p is the product output upon the PV power plant launch;

K', L', E' is the costs of capital, labor and energy upon the PV power plant launch;

E' is the energy costs upon the PV power plant launch;

E'_i is the amount of energy of the *i*-type;

τ_i is the tariff;

E_{pv} is the amount of PV energy generated;

T_{hi} is the technological factors;

N is the natural and climatic factors;

S is the surface area of the PV module placement;

αt is the tilt of PV modules to the Earth's surface, depending on the season;

ΔK is the capital invested in PV;

Ecol.Ef is the ecological efficiency after introduction of PV;

GHG' is the amount of greenhouse gases generated in the production of input resources required for the production process after the PV launch [12].

For the study of the transition to renewable energy sources, the bread and bakery production sector – KVED 10.71 – was selected. This choice was made upon analyzing the industries and is based on the following.

This industry – out of the processing industries considered by us – demonstrates the lowest energy intensity, which means that, if the shift to renewable energy sources is feasible for this economic segment, it will be feasible for other industries with higher energy intensity (power intensity) of productions.

In the period under review (2012–2016), this industry has the largest drop in the number of enterprises in operation and in terms of output.

The energy intensity of this industry over the period considered was stable as compared to other industries.

The share of electricity in the energy mix supplied for the bread production is approx. 15%, which allows to change the production process and to switch to in-house generated electricity with the use of renewable energy sources.

The economic analysis into the key technical and economic indicators was carried out for the bakeries, and the statistical data were considered according to the following scheme:

– Marketable products in physical terms.
– Number of enterprises.
– Electricity consumption.
– Electricity intensity.
– Energy consumption by types of energy sources.
– Energy intensity.

We have selected 15 companies. Geographically, their production facilities are based in Mykolaiv, Kherson and Zaporizhzhia regions. The required annual solar insolation is available in these territories. The data were obtained from the State Statistics Service of Ukraine [13], therefore, it is impossible to indicate the names of these enterprises, and therefore, all the enterprises in our study were assigned relevant sequential numbers from 1 to 15.

Since the quantitative indicator of electricity consumption by the enterprises for 2013–2017 is necessary for the calculation of the solar power plant for further research, we enter this indicator for 2017 in table 1 along with *L, K, T* indicators.

Table 1. Actual electricity costs for the entire output (work performed) during the reporting period, thousand kWh with indicators *L, K, T* in 2017.

After previous analysis of endogenous Y parameter and exogenous *K, L, E* parameters, Statistica software revealed that the relationship between the variables is nonlinear. We believe that it is advisable to use a multiplicative model in the form of a log-linear functional regression model, which can be presented in general in the form of equations (8) and (9).

$$y = \alpha \prod_k X_k^{\beta k} e^{\varepsilon}, \quad (8)$$

or

$$\ln y = \ln \alpha + \sum_k \beta_k \ln X_k + \varepsilon, \quad (9)$$

where y is the endogenous value;

α is the linear parameter of the static function;

X_k is the endogenous (independent) variables

β_k is the coefficient of elasticity;

e is the fundamental mathematical constant;

ϵ is the vector of random variable.

In this model, the coefficients are interpreted as the coefficients of elasticity, formula (10).

Table 1 – Actual electricity costs for the entire output (work performed) during the reporting period, thousand kWh with indicators L, K, T in 2017

Grouping enterprises into subsets			2017			
			L	K	E	Y
No.	Group number	Company name	number of employees	ths. UAH	ths. kWh	t
1	I	Zaporizhzhia region 2	120	62,117	408	9,222
2		Mykolaiv region 4	19	5,334.5	304	3,364
3		Zaporizhzhia region 1	120	4,741	660	2,738
4		Mykolaiv region 1	42	8,360	264	2,222
5		Kherson region 3	4	1,616	0	0
6		Mykolaiv region 5	1	2,928.3	–	0
7		Mykolaiv region 3	0	898	–	0
8	II	Zaporizhzhia region 3	10	203.6	49	448
9		Kherson region 4	10	199.6	110	280
10		Mykolaiv region 6	7	232.8	92	42
11		Kherson region 1	10	540.3	64	588
12	III	Kherson region 6	5	399	32	274
13		Kherson region 2	3	73.2	35	9
14		Kherson region 5	0	1.7	10	0
15		Mykolaiv region 2	1	259	0	0

Source: calculated by the author

$$\left(\frac{dy}{dx_k}\right)\left(\frac{x_k}{y}\right)=\frac{\partial \ln y}{\partial \ln x_k}=\beta_{k'}, \qquad (10)$$

It is necessary to comment that function Y = f [K, L, E] under study is twice differentiated, and in addition it meets all the requirements for this class of such production functions. We present it in the mathematical form corresponding to formula (10), writing down explicitly in equation 11 for the factors investigated.

$$Y=\alpha K^{\beta_1}L^{\beta_2}E^{\beta_3}+\varepsilon, \qquad (11)$$

where Y is the volume of bakery products (t.);

α is the linear parameter of a static function;

β_k is the coefficients of elasticity;

K is the capital, total value (UAH thousand);

L is the labor (average number of employees);

E is the energy (toe).

It is known that there are different econometric approaches for estimating unknown values of α and β_k for function 3.5. We believe that in this case it is advisable to use Statistica 10.0 software, directly embedded modules: "Nonlinear estimation" and "Multiple nonlinear regression". We will create in Statistica 10.0 software application a data table for the first group of enterprises and carry out "Nonlinear estimation" for function (11), entering it in the data-entry window "User Model" in the form: Y = A0 * (L^a) * (K^b) * (E^c). Upon evaluation of the model parameters, the production function will be as follows:

$$Y=8{,}188K^{0{,}162}L^{0{,}061}E^{0{,}785}, \qquad (12)$$

The estimation of the production function parameters for the group II of enterprises showed that this method of finding unknown quantities is incorrect for this sample, which may be due to the number of factors. Firstly, inaccuracies in statistical information are possible. Secondly, production output "*Y"* at medium and small enterprises, as compared to large productions, may have other functional relationships between the factors of production *"K", "L", "E"*. In our opinion, in this case, there may be an increase in the work performance related to personal entrepreneurial abilities of the individual, which can affect both the organization of production and its final results.

There is great likelihood that the production function for this group of enterprises is more complex and more statistic data are needed to determine it. Therefore, in order to find the energy consumption indicator E for Group II enterprises, we have chosen an approach based on the average specific energy consumption per unit of output, formula 13.

$$E_{sr}=\frac{\sum_i^n E_i}{\sum_i^n Y_i}, \qquad (13)$$

where Es_r is the specific energy consumption per ton of production;

E_i is the energy consumed by the i-th enterprise;

Y_i is the product output of the i-th enterprise.

As a result of the calculations for the second group of enterprises, the enterprises of the second group use on average 145 kg oil equivalent, which is 101.5 kg o.e. to produce one ton of products.

As a result of the analysis for the three groups of enterprises, we can draw the following conclusions:

– for large enterprises of the bakery industry of Ukraine it is permissible to describe the production process with the help of a production function, which in turn makes it possible to find energy consumption figures with the use of the following indicators: labor, capital and output;

– it is advisable to calculate specific energy consumption of products for medium-sized enterprises of the bakery industry of Ukraine using the average data for the studied time interval;

– small enterprises of the bakery industry of Ukraine require an ad hoc approach in every case, taking into consideration their technological and organizational specific features (Table 2).

Calculations of the key technical and economic indicators for the potential solar power plants will be performed using NREL – SAM software.

Figure 1 shows the results of energy flows, taking into account in-house consumption and production.

Conclusions. The research has developed the economic mechanism of ensuring efficient use of renewable energy sources at enterprises and scientifically substantiated the feasibility of enterprise transition to energy from renewable energy sources. The study findings enable us to draw the following conclusions:

On the basis of the models of P.A. Samuelson, Koba-Douglas, M. Nerlov and the regularities arising between the factors of production, price for energy sources and ecological efficiency of production, we have developed a parametric model for enterprise transition to renewable energy sources

Table 2 – Determination of energy consumption by groups of bakeries in Ukraine

Groups of enterprises	Volume of commercial output *Y, t* per year	Method	Correspondence	Calculation of energy consumption, *E*
I	from 950	Production function	$Y=8{,}188K^{0{,}162}L^{0{,}061}E^{0{,}785}$	$E=\left(\frac{Y}{\alpha K^{\beta_1}L^{\beta_2}}\right)^{\frac{1}{\beta_3}}+\varepsilon$
II	from 350 to 950	Statistical average figures	Not defined	$E_{sr}=\frac{\sum_i^n E_i}{\sum_i^n Y_i}$
III	from 350 to 0	Ad hoc approach	Unlikely	individual approach

Source: calculated by the author

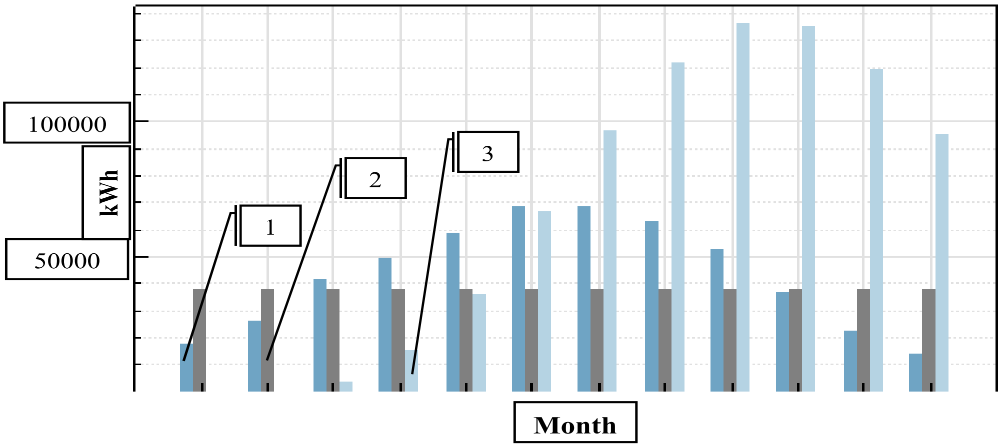

Figure 1 – Monthly consumption and total power generation by PV solar power plant and the resultant, developed by the author using SAM software: 1 – System AC energy; 2 – Electricity Load; 3 – Excess generation kWh credit earr

with adhering to the resource- and energy-saving goals and taking into account the environmental component.

On the basis of a comprehensive analysis, the energy consumption and energy saving status have been examined for KVED 10.71 enterprises; the energy potential of renewable energy sources in Ukraine has been determined. The theoretical and methodological grounds underlying the establishment of energy supply mechanism at the enterprises have been reviewed based on the use of renewable energy sources are considered.

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РОЗРОБКА МЕТОДИКИ МОДЕЛЮВАННЯ ЕНЕРГОЗАБЕЗПЕЧЕННЯ ПІДПРИЄМСТВ НА ОСНОВІ ВІДНОВЛЮВАНИХ ДЖЕРЕЛ ЕНЕРГІЇ

Намічено потенційний сценарій переходу споживання енергії до відновлюваних джерел енергії для хлібопекарської промисловості України, де загальна потреба в електроенергії задовольняється за рахунок сонячної енергії. Ми моделюємо такий перехід, використовуючи параметричні моделі в поєднанні з виробничою функцією Кобба-Дугласа. Запропоновані методичні підходи до виявлення взаємозв'язків між факторами виробництва та джерелами енергії, які ґрунтуються на обчисленні ключових показників для аналізу енергоефективного енергопостачання та стохастичних зв'язків між факторами виробництва, що дозволяє побудувати більш точну модель перехід до поновлюваних джерел енергії. Запропоновано формування механізму енергопостачання з використанням відновлюваних джерел енергії на підприємствах. Дослідження переходу до відновлюваних джерел енергії було проведено на прикладі підприємств, які підпадають під категорію 10.71 відповідно до Класифікації господарської діяльності (виробництво хліба та хлібобулочних виробів з коротким терміном зберігання). На цих підприємствах енергоємність стабільна протягом розглянутого періоду порівняно з іншими галузями. Частка електроенергії в суміші енергії в хлібопекарських виробництвах становить приблизно 15%, що дозволяє змінити процес виробництва та перейти до споживання електроенергії, що виробляється вдома, з відновлюваних джерел енергії. Ця галузь має велике соціальне значення для населення, оскільки виготовлений продукт є необхідним для життя людини. Ми вибрали 15 компаній, які класифікуються у три групи за допомогою кластерного аналізу. Географічно виробничі потужності розташовані у Миколаївській, Херсонській та Запорізькій областях, а сонячна радіація на цих територіях однакова. Для трьох груп хлібозаводів на півдні України за допомогою програми SAM розраховувано ключові показники доцільності прогнозування переходу підприємств на відновлювані джерела, враховуючи економічні показники. Це дозволило нам обчислити позитивні ефекти таких процесів трансформації як для підприємства, так і для галузі в цілому.

Ключові слова: *відновлювані джерела енергії, енергопостачання, фотоелектричні сонячні електростанції, фактори виробництва, механізм енергопостачання, хлібобулочні підприємства.*