Montenegrin Journal of Economics

Vol. 14, No. 4 (2018), 237-247

Criteria for Evaluation of Efficiency of Energy Transformation Based on Renewable Energy Sources

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ARTICLE INFO

Received August 12, 2018
Revised from September 14, 2018
Accepted November 17, 2018
Available online December 15, 2018

JEL classification:

Q1, Q20; Q48

DOI: 10.14254/1800-5845/2018.14-4.17

Keywords:

Efficiency,
energy consumption,
diversification of energy sources,
renewable energy sources,
energy potential.

ABSTRACT

In the context of shortage of natural resources in Ukraine, the problem of evaluating efficiency of the implementation of renewable energy sources (RES) becomes of particular importance and comes in first place, since its solution will reduce the energy dependence of the state. Theoretical, methodological and practical issues of diversification of energy sources and evaluation of their effectiveness have found their development in modern works of domestic and foreign scientists. However, methods proposed by the scientists for evaluating efficiency of the transformation of energy consumption based on RES are purely theoretical and do not fully allow to determine the current state and directions of diversification of energy sources. The research is aimed at improving methodological support and developing criteria for evaluating the efficiency of energy consumption transformation based on RES. The article considers the main methods of evaluating efficiency of involving RES in the energy consumption of the state, region and enterprise. Advantages, drawbacks and perspectives of diversifying energy sources based on RES are shown. The system of criteria for evaluating effectiveness of energy consumption transformation based on RES is proposed. It is based on economic, environmental and social efficiency.

INTRODUCTION

In times of the crisis of national economy it is impossible to reach a stable economic growth without implementing and using a complex of innovation techniques of using renewable and alternative energy sources; it makes it possible to reduce dependence of national economy on the world prices for energy resources, to avoid irretrievable loss of money for purchasing the imported energy sources, to provide with the reduction of energy intensity of output of industrial products and to increase competitiveness of national industrial products. It influences positively energy intensity of GDP and favours the increase of energy efficiency of national economy and, as a result, provides economic development of the state. At the same time, it is impossible to determine an appropriateness of using renewable or alternative sources of energy supply in the process of economic activity of any economic entity without implementation of an effective tool and methodological support for evaluating efficiency of energy consumption.

In the context of shortage of natural resources in Ukraine, the problem of evaluating the efficiency of implementation of renewable energy sources (RES) becomes of particular importance and comes in the first place, since its solution will reduce the energy dependence of the state.

1. LITERATURE REVIEW

Most of the present foreign studies in the field of diversification of energy resources supply is devoted to evaluation of technological, social and ecological changes in the field of energy generation and use, to identification of their influence on the social and ecological development and its stability (e.g. Jacobson, 2009; Carley et al. 2012; Markard et al., 2012; Negro et al, 2012; Terrapon-Pfaff et al., 2014). At the same time, as G. Mao et al. (2015), note, there is a significant geographical heterogeneity in the forming a range of research problems and their results. Besides, the literature analysis shows that a peak of interest was observed in different periods of time: at first there was an interest to solar and wind energy, and then – to the use of biofuel. Research in the field of incentives policy of alternative sources energy development and use of “green energy” (Schmalensee, 2011; Mundaca and Richter, 2015) was widely-spread.

There is a growing interest to the organizational and managerial aspects of implementation of diversification tools of energy sources supply, development of applied projects for certain types of renewable energy, as well as energy based on the use of recoverable resources, including the ways of solution of risks evaluation of implementation of such projects, approaches to integration of technologies of renewable and alternative power engineering and information control system etc. (e.g. Hitzeroth and Megerle, 2013; Chappin and Friege, 2014; Rasool, Ehsan and Shahbaz, 2015; Lee and Zhong et. al., 2015).

It should be noted, that although the present variety of scientific research in the field of alternative and renewable energy has certain methodological basis in the form of sustainable development concept (Meadows et al, 1972; Belousov, 2013), but the latter has a great number of transformations and variety of interpretations, that situationally appeared as a result of the necessity to solve specific and practical tasks, and which are characterized by the relative eclecticism and a lack of system. At the same time the mentioned groundworks are fragmentary and don’t have rather developed methodological apparatus for designing evaluation models of efficiency of energy supply transformation in terms of renewable energy sources and explanation of methodological approaches to the formation of organizational and economic supply of the efficiency of their use.

2. RESEARCH METHODOLOGY

Methods proposed by scientists for evaluating efficiency of transformation of energy consumption based on RES are purely theoretical and do not fully allow to determine the current state and directions of diversification of energy sources. The research is aimed at improving methodological support and developing criteria for evaluating efficiency of energy consumption transformation based on RES. Presentation of baselines. Analysis of the scientific research relating to efficiency of energy supply transformation shows that there is a number of calculating methods and efficiency rate of energy production on the whole and based on renewable sources in particular. I. V. Belov (1983) points out in his research that when choosing an alternative from a number of presented engineering solutions with a single capital investment and little-changeable operating costs over the years, a minimum of annual unit expenditure is a choice criterion for project implementation and an indicator of comparative economic efficiency of capital investment. Besides, the scientist notes, that the comparison of alternatives should be done according to the unit expenditure over the calculating period.

In the opinion of some authors (Barabaner, Nikitin and Klokova, 1989), the recoupment ration for evaluating and choosing the project (supply system) is used as the unknown, which is calculated by the equation, linking up money flow of the whole term of the project and the unit capital investment for its implementation. So, a recoupment ratio is the indicator, which is set within a specific project. The value of the ratio for the person who makes a decision is not applied to other projects, as the proposed indicator is a maximum possible level of investment return for the specific project.

A group of scientists, H. Z. Barabaner, S. M. Nikitin and T. I. Klokova (1989) in their paper "Methodological issues of energy development of rural districts" consider the following indicators as production efficiency criteria: gross and net revenue, reduction of labour inputs and material resources, growth of funds supply, cost of a working place of fixed kilowatt, growth of output volume, reduction of unit expenditures. In our opinion, the most complete criteria systems of efficiency evaluation of energy transformation based on renewable energy sources (RES) are offered by the following scientists: V. S. Simankov, P. Yu. and Buchatsky (2012), and G. B. Osadchy (2014). V. S. Simankov, P. Yu. and Buchatsky (Ibid.) single out the following criteria among the main criteria of efficiency of RES involvement: resources significance; economic significance; social significance; non-energy significance; budgetary significance; environmental significance; energy significance; they make examples of their own indicators of efficiency.

3. RESEARCH RESULTS

Depending on the purposes and tasks of efficiency evaluation of energy supply transformation based on renewable energy sources, one or another indicator given above may be used. Nevertheless, considered methods have a significant drawback – they are theoretical and overburdened with indicators. To our mind, the model of efficiency evaluation of energy supply transformation based on renewable energy sources should include three components: economic, environmental and social efficiency.

Choice of stated components is explained by the following. Facilities of renewable power engineering have different economic features, which determine in turn an economic significance of the facility. Economic evaluation makes it possible to determine profitability of construction of renewable power engineering facility as for society on the whole so for specific economic entities implementing the projects. It also enables to compare efficiency of investments expenditures for construction of traditional and renewable power engineering facilities. Taking into account the constant growth of energy cost, understanding of reasonability and economic efficiency of use of renewable energy sources by the households is not less important thing.

Considering the incomplete electrification of the state and large problems with connection of distant sectors to electrical supply network, the problem of efficiency of renewable power engineering technologies in case of full lack of electrical supply network is urgent.

Power engineering facilities influence the environment in different ways. Different ecological compatibility is determined by environmental damage, which its construction and operation makes. Comparison of the influence of different type power stations on the environment makes it possible to determine expenditures necessary for maintaining the environment in acceptable state.

Energy production based on renewable sources takes place without hydrocarbon raw material burning and, as a result, without the release of greenhouse gases and other atmosphere pollutants. So, we may assert so-called *"the effect of zero CO_2 emission"*. However, the study of the whole life cycle of production, beginning with the preparatory stage, makes it possible to reveal side effects in the process of energy production.

It is necessary for energy generation to manufacture and to install energy equipment, to create infrastructure and to provide its working conditions, to prepare raw materials, to utilize used materials and equipment after expiration date. It needs operation of metallurgical, engineering, agricultural and other plats, use of extractive sources of energy and means "nonzero emission". Transition to renewable power engineering doesn't always lead to the decrease of the environmental pollution, including decrease of CO_2 emission and other greenhouse gases. So, it needs more detailed and thorough study.

Comparing the alternatives of development of renewable energy facilities, important features defining their social significance are not considered enough. A number of unemployed for 9 months of 2016 was 1 662.2 persons, compared to the appropriate period in 2015 it went 24.6 thousand up. Unemployment rate increased from 9.0% to 9.2% of economically active population. Development of mechanical engineering and scientific and technical potential of renewable power engineering may result in the increase of working places in Ukraine and provide the economic growth. So, the social effect of the development of renewable energy sources is beyond any doubt and needs further study.

3.1 Economic Efficiency

It is reasonable to consider economic efficiency from four standpoints: efficiency of investments expenditures, fixed cost of electricity, technology efficiency of the households, and technology efficiency in case of full lack of electrical supply network. To give an example, we calculate measure of effectiveness of investments expenditures for three types of power stations: gas thermal power plant (TPP), wind-driven power station (WPS) and solar power-station (SPS). The following data are used:

- Rated capacity, MW – 620 MW (for TPP), 100 MW (for WPS), 150 MW (for SPS).
- Ratio of rated capacity use (RRCU), % – 87% (for TPP), 35% (for WPS), 25% (for SPS).
- Investments expenditures, $/1 kW – 917 $/1 kW (for TPP), 2213 $/1 kW (for WPS), 3873 $/1 kW (for SPS).
- Fixed operating costs, $/kW – 13.20 $/kW (for TPP), 39.55 $/kW (for WPS), 24.69 $/kW (for SPS).
- Variable operating costs, $/kW·h – 0.05 $/kW·h (for TPP), 0 $/kW·h (for WPS), 0 $/kW·h (for SPS).

It should be noted that power stations must generate an equal amount of electricity. Calculation of the main factors and their comparison are given in the Table 1.

Table 1. Calculation and comparison of the main economic factors of TPP, WPS and SPS

Factor	*Gas TPP*	*WPS*	*SPS*
RRCU, %	87%	35%	25%
Rated capacity, MW	620	1541 620 MW × 87 % / 35 % = 1541 MW	2158 620 MW × 87 % / 25 % = 2157 MW
Electricity generation per year, MW·h	4725144 620 MW × 8760 h × 87 % = 4725 GW·h	4725144 1541 MW × 8760 h × 35 % = 4725 GW·h	4725144 2158 MW × 8760 h × 25 % = 4725 GW·h
Investments expenditures, $ / 1 kW	917	2213	3873
Investments expenditures, mil $, total	569 620 MW × $ 917 thousand / 1 MW = $ 569 mil	3411 1541 MW · $ 2213 thousand / 1 MW = $ 3411 mil	8356 2157 MW · $ 3873 thousand / 1MW = $ 8356 mil
Fixed operating costs, $ / kW	13,20	39,55	24,69
Fixed operating costs, mil $	8 $ 13,2 × 620 000 kW = $ 8 mil	61 $ 39,55 × 1541000 kW = $ 61 mil	53 $ 24,69 × 2158000kW = $ 53 mil
Variable operating costs, $ / kW·h	0,05	0	0
Variable operating costs, mil $	236 $ 0,05 × 4725 GW·h = $ 236 mil per year	0	0
Operating costs, mil $, total	244 $ 8 + $ 236 = $ 244 mil per year	61	53
Exceeding the investments expenditures relative to gas TPP, mil $	-	2842 $ 3411 mil – $ 569 mil = $ 2842 mil	7788 $ 8356 mil – $ 569 mil = $ 7788 mil
Saving in operating costs relative to gas TPP, mil $ per year	-	183 $ 244mil – $ 61 mil = $ 183 mil	191 $ 244 mil – $ 53 mil = $ 191 mil
Common term of recoupment for gas TPP, years	-	15,5 $ 2842 mil / $ 183 mil per year = 15.5 times	40,7 $ 7788 mil / $ 191 mil per year = 40.7 times

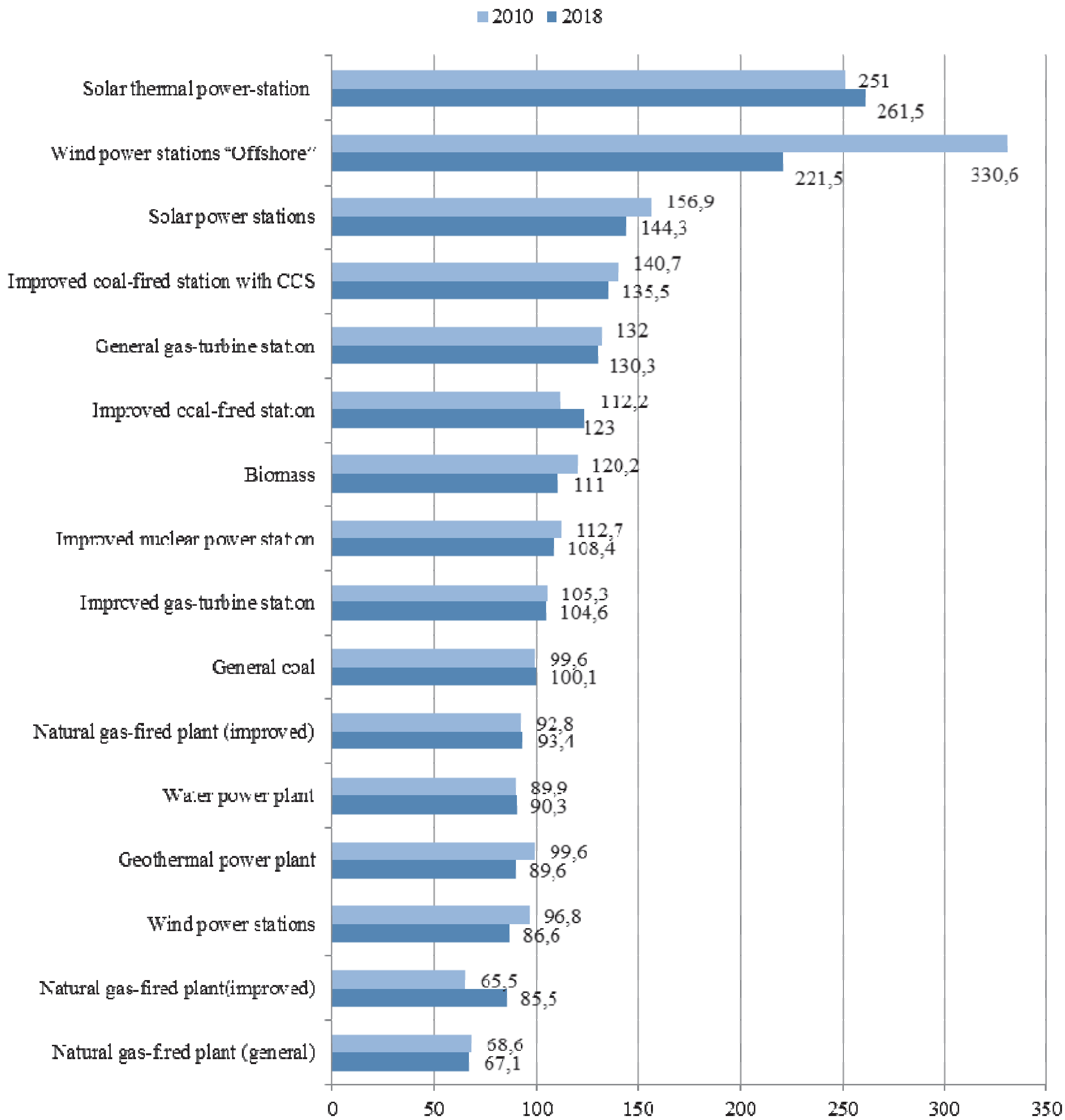
Source: The study was performed by the authors on the base of source Degtyarev (2015, 2017.

According to the results of calculations we can conclude that power stations using the renewable energy sources still need more sizable investments than power stations using traditional sources of energy. But too high term of recoupment of power stations using RES in comparison to the traditional ones is unattractive for investors. When comparing the cost price of electricity, generated at the expense of RES to the electricity, generated at the expense of extractive fuel, such indicator as fixed cost of electricity is used (FCOE).

Fixed cost of electricity is such cost for kW·h during the whole period of power station operating, which equates the unit cost of proceeds from the energy generation and sale with the unit cost of expenditures for construction and operation of the power station.

As for the components of the given above factor for investment projects in Ukraine, it is unfortunately possible to get only the common volume of expenditures for construction of power stations and their capacity. Herewith, it is usually impossible to understand what the expenditures for construction consist of: whether the delivery and equipment installation was included, or the expenditures for the whole equipment or only crucial components were taken into account. In the available sources, there is also lack of data about equipment used at RES power stations; it additionally makes worse the comparison of the received results. So, to carry out further study and comparison, we use calculated fixed cost price of electricity in the USA, the EU and China (Figure 1).

Figure 1. Evaluation of the average fixed cost price of electricity of power stations in 2010 and power stations being put into operation in 2018, $/MW·h.



Source: Bezrukikh,2010; 2015.

As we see, power stations using wind energy yield only to natural gas-fired plants in the fixed cost, leaving behind only coal and nuclear power stations. According to the trends of 2018 wind power stations also leave behind water power plants as opposed to 2010. However, in spite of positive trends most of power stations using RER are outsiders – solar power stations, "Offshore" wind power stations.

Efficiency of the technology for household defines position of the customer, who chooses between energy purchasing at retail price (in a number of cases with the expenses for technological connection to the network) and installing private autonomous system enabling to turn off the system or to reduce expenses for energy purchasing.

In this case we also make calculations of efficiency. So, a solar power station of low capacity (5 kW) being assembled, which includes solar cell panel, accumulator, inverting element, is proposed, according to online shop data (https://alteco.in.ua), at the price of about 188270 UAH (or $6 724) (without installation), the generation per year is 5348 kW. With RRCU 17.0%, electricity generation per year is: 5348-(5348×17.0%) = 4438 kW·h.

With retail prices for electricity at the level 1.68 UAH/kW·h (for volume used above 100 kW·h electricity per month), the use of the complex enables the customer to save 4438×1.68=7455.84 UAH per year (or $266.3 per year). Thus, a common recoupment period for it is 188270/7456 = 25 years. There is no point for user from the standpoint of economic effect, because it exceeds a predicted lifetime of the complex.

One of the most influential factors of competitiveness of autonomous power stations based on RES is lack of electricity network. In such case a consumer has additional expenditures for technological connection to the network. It is especially urgent for rural areas and distant economies. Cost of manufacturing equipment is often lower than the cost of connection, particularly subject to the laying the power lines (PL).

According to our own calculations cost of laying 1 km of PL is 5.0-6.0 mil UAH (or $178 571-$214 286) (without the cost of transformer substation); incidental cost at the rate of about 20.0%, i.e. 1.0-1.2 mil UAH (or $35 715-$42 857) are additionally expected. So, total investments expenditures, without the cost of transformer substation, for 1 km of PL constitute 6.0-7.2 mil UAH (or $214 286-$257 143). Cost of solar power station with the capacity of 32 kW is 726 000 UAH (or $25 929). If the average RRCU is equal to 17.0%, the power station can generate 26 500 kW·h of electricity. It can be compared with the yearly electricity consumption by 10-12 households.

Besides, further economic effect is reached at the account of lack of payment for electricity. From the mentioned above we can conclude the following: the more the distance of the consumer from the central electricity supply, the more the economic effect of the use of autonomous power stations based on RES.

3.2 Environmental Efficiency

Power stations using traditional sources of energy emit yearly sulphur dioxide, carbon dioxide, nitrogen oxide, solid particles of ash, and also toxic heavy metals. Comparison of the influence of different types of power stations on the environment is given in the Table 2.

As it is seen from the table, renewable sources of energy are more environmentally friendly than traditional sources according to all indicators.

Table 2: Comparative characteristic of the influence of different types of power stations on the environment

Types of influence	*RES*	*Atom*	*Coal*	*Natural gas*
Global warming	–	–	+	+
Water pollution by the thermal or harmful emissions	–	+	+	+
Air pollution	–	–	+	limited
Mercury emissions	–	–	+	–
Mining activity, fuel output	–	+	+	+
Solid waste	–	+	+	–
Habitation environment	limited	limited	+	+

Source: Annual Energy Outlook, 2017.

However, as the opponents of the development of renewable power engineering note, CO_2 emission occurs during the production process of components for "green power engineering". Main indicator, from the standpoint of greenhouse gases emission, is connected with energy generation – an amount of CO_2 gram-equivalent for the unit of generated energy, namely, kW·h for power engineering, i.e. $gCO_2eq/kW \cdot h$. It is obviously that distribution of greenhouse gases emission according to the stages of production life cycle is different for different types of energy. It also concerns power stations using RES. Life cycle analysis gives the following emission indicators for different types of electricity generation [$gCO_2eq/kW \cdot h$]: wind – 10 (according to the life cycle stages: preparation – 8.6; production – 0.5; finishing – 0.9); tidal – 15.0; water – 20.0; ocean wave – 22.0; geothermal – 35.0; solar batteries – 40.0; solar concentrators – 10.0; bioenergetics – 230. However, it is significantly less than the values given for power stations using traditional sources of energy: coal – 1000 (according to the life cycle: preparation – 10; production – 980; finishing – 10); gas – 490.

One of the most important features of environmental efficiency is irretrievable water consumption at the power stations. Irretrievable water consumption at different types of power stations is given in the Table 3.

Table 3. Irretrievable water consumption at the power stations of different types

Type of the power station	*WPS*	*SPS*	*APS*	*TPS*		
				oil prod-ucts	*gas*	*coal*
Unit water loss, l/kW·h	0,004 575 times < than APS; 400 times < than TPS using oil products; 238 times < than TPS using gas; 475 times < than TPS using coal	0,11 21 times < than APS; 15 times < than TPS using oil products; 9 times < than TPS using gas; 17 times < than TPS using coal.	2,3	1,6	0,95	1,9

Source: Annual Energy Outlook, 2017.

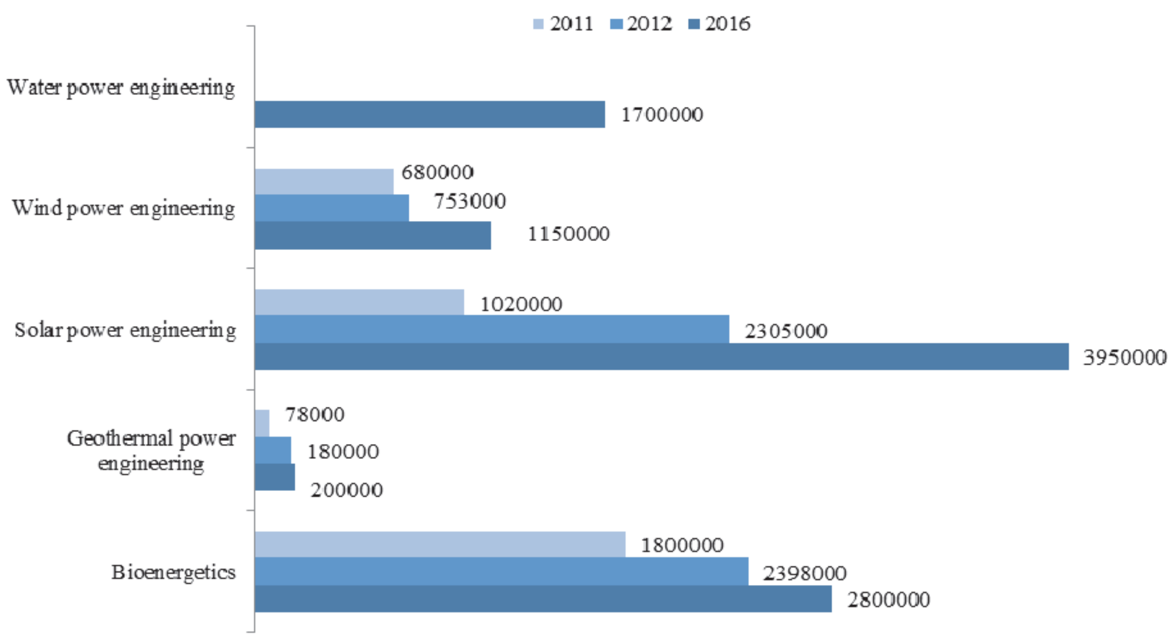
Minimal irretrievable water loss at the wind and solar power stations is shown in the table above.

3.3 Social efficiency

Except the reduction of harmful emissions, which influence negatively the health of population, job creation in the region of production of equipment for renewable power engineering and operation of RES facilities is considered to be a significant social effect. Working places connected with renewable power engineering (direct) and related fields (indirect) are considered as well.

According to the results of the previous year there were 9.8 mil of working places in renewable power engineering of the world (Fig. 2). Solar photoelectric technologies provided the greatest number of working places (3950000), bioenergetics took the second place (2800000), big and small water power engineering took the third place (1700000).

Figure 2. Working places in renewable power engineering



Source: REN 21 (2012, 2013, 2017)

So, positive dynamics of the growth of the number of people working in the field of renewable power engineering is observed at present. According to IRENA predictions, doubling of the part of renewable energy sources in the world energy balance results in more than 24 mil of working places all over the world by 2030. It may be the chance for employment growth and development of scientific and technical potential of Ukraine. In addition to production capacities, scientific and research, technical secondary and higher educational institutions will be developed.

CONCLUSIONS

The system of criteria developed and tested by the authors allows to cover the main areas that receive a positive effect due to the transformation of the structure of energy supply sources based on renewable energy sources, namely: economic, environmental and social. At the same time, the calculation of the economic efficiency of the diversification of energy supply sources is complicated by the unreliability of data on the average normed cost of electricity produced by various types of energy supply sources and the efficiency of renewable energy sources based technology for households, especially in the absence of complete network power supply. These directions of further research should be considered promising, their results will increase the validity of managerial decisions on the transformation of the structure of energy supply sources in Ukraine with the use of renewable energy sources.

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