

## Features of the Life Cycle Structuring of Renewable Energy Source Facilities\*

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The life cycle of renewable energy sources has been analyzed in the research paper. The differences and specific features of life cycles of traditional and renewable energy sources have been identified. A proprietary scheme of the life cycle of renewable energy sources has been proposed, which takes into account the identified features compare to traditional energy sources. The renewable energy life cycle consists of three stages and ten phases. The eco-destructive impact of renewable energy sources at each stage of the life cycle has been investigated and presented, which makes it possible to assess objectively and take into account the complex eco-destructive impact of the use of a specific object that uses renewable energy sources. The studies of Al-Mulali, Apergis, and Payne, Dogan and Turkekul, Menegaki, confirming the relationship between growth indicators (Gross Domestic Product) and the growth of energy produced by renewable energy sources were examined. The total electricity consumption in the world for the period 1973–2016 was considered. Comparisons of traditional and renewable energy sources by service life and life cycle are given, and the main stages and phases of the life cycle of renewable energy sources are examined in detail. The stages of development and creation of renewable energy technology, namely the stages of development and creation of renewable energy technology, the operation of renewable energy facilities and the utilization and recycling of renewable energy components were considered. The impact of renewable energy on the environment from reservoirs and the specific effects of the use of renewable energy facilities has been studied. To identify adverse factors of influence, from eco-destructive impact, the stages of the structural composition of the renewable energy life cycle were examined to find possible ways to eliminate them at each stage.

*Keywords:* renewable energy source, life cycle, energy, energy production, management of natural resource.

### *Abbreviations:*

RES – renewable energy sources;  
E – environment;  
LC – life cycle;  
SHPP – small hydro power plant;  
PSHPP – pontoon small HPPs.

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**Introduction.** The problem of meeting the needs for electric and other types of energy is not relevant. The energy sector of the economy has a strong connection with the destructive impact on the environment. There are 49 % of pollutant emissions in the world due to the activity of the energy sector [1]. Most of the electricity on Earth is generated through exhaustive resources. According to the Global Status Report REN21, in 2017, 79.7 % of the total final energy consumption was accounted for by exhaustive resources [2]. The modern world sees the solution to this problem in the mass use of renewable energy sources (hereinafter RES).

Comparing RES with traditional sources of energy, namely thermal (thermal and combined heat and power plants), nuclear (NPP) and hydro (HPP) power plants, one can note that the greatest load on the environment (hereinafter referred to as E) is at the stage of energy production. RES have less emissions of pollutants into the atmosphere, water pools and soils. However, during the analysis of the RES life cycle, certain destructive impact on the E were identified at all its stages [3, 4].

**Problem statement.** There are many publications that show the positive effects of increased energy production owing to RES. Most of these publications belong to foreign authors. This is due to the smaller number of RES facilities in Ukraine compared to the developed countries. According to the World Bank, RES generates about 4.14 % of the total energy production [1]. At the same time, the figure in Germany is 14.2 %, in the USA – 8.71 %, and in China – 12.41 %. The impact of RES on the economic development of countries attracts a great attention of the foreign researchers. The results of studies by Al-mulali [5], Apergis and Payne [6], Dogan, and Turkekul [7], Menegaki [8] confirm the hypothesis that there is a link between the growth in economic indicators (GDP) and increase in energy produced by RES.

The identification of the structural features of RES facilities life cycle is given attention by domestic scientists.

Thus, Kolohryvov researched the life cycle of enterprises from the point of view of the private sector [9]. Dereiko Kh. O. assessed the eco-destructive impact of solar power plants at all stages of the life cycle [10]. Havrysh O. A. drew attention to the need to evaluate different RES-based electricity generation technologies. [11]. Pryimenko S. A. explored the life cycle of the energy product derived from traditional energy sources [12].

**The purpose** is to analyze the life cycle of RES in order to identify differences and specific features in comparison to the life cycle of traditional energy sources.

**Results of the research.** The size of global electricity consumption has a growing trend. This can be confirmed by the dynamics of electricity consumption for the period of 1973–2016 (Figure 1). In this case, the phase of the life cycle “Development and creation of RES technologies” is characterized by the emergence of new technologies for electricity generation, including on the basis of RES [12, 13].

Energy generation technology is constantly changing due to the energy of the sun, the earth and wind, which leads to a decrease in their cost. According to the theory of the product life cycle, electricity, as a product, goes through the first stages – introduction of the commodity into the market and recognition of the commodity by buyers, which are characterized by the increase in sales volumes. These stages last over 45 years for electricity as a product.

The world energy market consists of so-called traditional (oil products, natural gas, coal, fuel oil) and renewable energy sources. In order to provide the balance between the needs of today's and future generations (taking into account environmental, economic and social components), the question is of comparing traditional and RES based on their LCs, taking into account the impact of each energy source on the E.

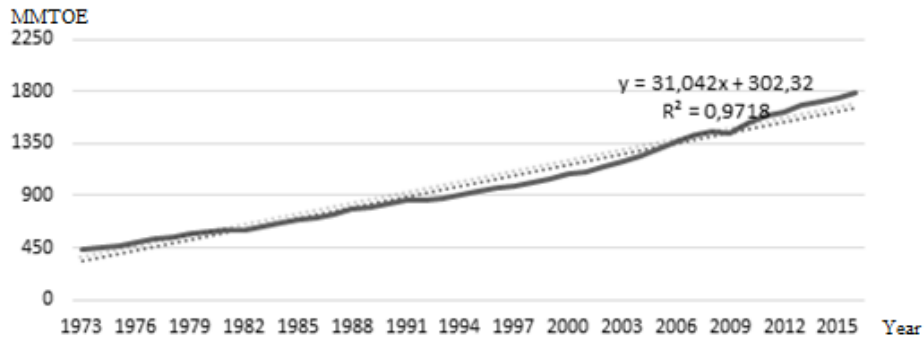


Figure 1. Total electricity consumption in the world for the period of 1973–2016, MMTOE [1, 14]

The first problem of comparing these energy sources is that each of them has its own lifetime and a particular eco-destructive impact. For example, the NPP has a service life of 55 years (RGM 1000) while wind power plants have a 20-year lifetime. If hydroelectric power plants are used, their service life reaches 100 years or more. Besides, the construction period and the minimum production capacity, which adds constraints to energy balance planning (Table 1), should be taken into account. That is, the period of time from the start of operation of the equipment to the moment of its utilization goes from 20 years for RES and 28 for TPP, and reaches 60 years in the case of nuclear power plants. Historical data show that over a 20-year period, energy structure, technologies and cost change significantly, leading to new optimal relationships between energy sources, taking into account environmental, resource and energy potentials.

Table 1  
The construction and operation period of electricity production facilities [15–19]

Electric power source	Construction period, years	Service life, years	Minimum size of new capacity, MW
<b>NPP</b>	4–6	55	1000
<b>TPS</b>	3–6	25	80
<b>TPP</b>	7–10	30–35	1.7
<b>HPP</b>	3–8	100 (30–40)*	<1 MW
<b>RES</b>			
<b>WPS (Wind power plant)</b>	<0.5	20	<1 MW
<b>SPP (Solar power plant)</b>	<0.5	30	<1 MW
<b>Mini Hydroelectric Power Plant (MHPP)</b>	<0.5	35	<1 MW

\* According to DSTU – 30–40 years, dam – 100 years

The life cycle period of a certain energy source from the moment of construction to utilization leads to a decrease in the level of energy independence and energy security of the country. This is due to the fact that long LC of one source complicates the transition to another or increases its cost. According to Pryimenko S. A., structurally, the LC of the energy product includes the following stages [12]: the invention of technology; obtaining the energy product; resource provision to which the exploration of the fields relates, their preparation for operation; transportation and processing of energy resources for their further use; energy production and transportation.

At all stages, the author identifies the process of waste utilization that occurs at each stage of the LC. This approach to the LC energy product only applies to traditional energy sources [12]. This view is shared by Martinez and Schlesner [20]. Martinez and Schlesner claim that RES is different from the LC of traditional energy sources and should be investigated separately. Both foreign scientists are researching the LC of RES starting from the stages of creation, transportation, processing and production of components of a future power plant based on primary resources. After the components of the power plant are manufactured, they are transported to the site of installation and further operation. After the operation phase, which is different for each type of RES, the elements of the power plants are dismantled and utilized.

The structural composition of the LC of RES proposed by us is fundamentally different from the LC of traditional energy products. The LC of RES is divided into three main stages and ten phases (Figure 2), which include the following components.

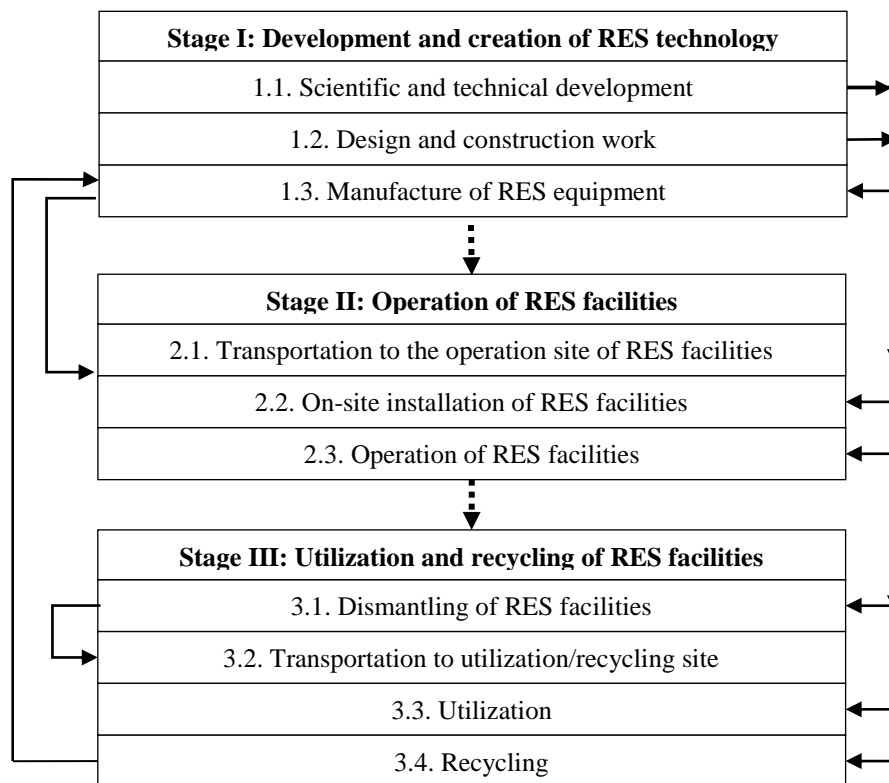


Figure 2. Main stages and phases of the life cycle of renewable energy sources

**Stage 1. Development and creation of RES technology.** The first stage consists of three phases: scientific and technological development (1.1); design and construction works (1.2); production of RES equipment (1.3). Scientific researches are carried out on the phases 1.1 and 1.2. in the field of new technologies of transformation of energy of the sun, air, water into electric (thermal or other); extraction and processing of primary resources for the production of components of RES equipment; new opportunities to reuse expired equipment components. The process of research on the phases 1.1 and 1.2 takes place independently of other components of the LC, but it should be taken into account that the results of the research affect the other stages and phases of the RES LC. An example of the implications of scientific research is the reduction of the cost of solar panels by 51 %, and their add-on components and installations by 37 % (for the period of 1998–2010) [21].

When analyzing research papers in this field, the difference in time between new technologies (the result of research) and their implementation in the processes of energy resources extraction and their processing for energy production should be taken into account. The stage of development and creation of RES technologies should aim to reduce the use of resources for the production of equipment, their cost and load on the E, to increase the efficiency of equipment and to enable the re-operation of components of RES equipment.

During the production phase of RES equipment, available technologies are used, which can vary greatly depending on the enterprises or countries. The difference in production technologies leads to different indicators of efficiency and resource intensity of energy production; the economic component and environmental damage are changed due to the production of a particular equipment. The environmental damage on this phase is due to the processing and preparation of the primary resources that are a part of the RES facilities.

For each type of RES, primary resources are significantly different, for example, the traditional design of the wind generator is a metal mast, on top of which are the blades. The mast and generator components require metal, the support requires concrete, plastic and metal – for the blades. At the same time, solar power plants require the structure on which it is located (the roof of buildings or metal structures to provide the necessary angle of inclination relative to the sun), the materials used to make the panels and the accumulating station (lead, cobalt, lithium and others).

**Stage 2. Operation of RES facilities.** The second stage consists of three phases: transportation to the place of operation of RES facilities (2.1); on-site installation of RES facilities (2.2); operation of RES facilities (2.3). Phase 2.1 results in a load on the E in emissions of harmful substances to the atmosphere from vehicles. Phase 2.2 has an impact on soil and landscape; the use of heavy equipment leads to additional emissions of harmful substances into the atmosphere.

The phase of operation of RES facilities is fundamentally different from the operation of traditional energy sources. RES do not use exhaustive energy resources for electricity generation, while traditional energy sources use energy and primary resources during the construction, operation and production stages of electricity.

**Stage 3. Utilization and recycling of RES facilities.** This stage consists of four phases: dismantling of RES facilities (3.1); transportation of RES facilities to the place of utilization or recycling (3.2); utilization of equipment (3.3); recycling of equipment components (3.4). The disassembly phase (3.1) may be affected by phase 2.2 (equipment installation), the size of which depends on the type of RES. Recycling of RES facilities (3.3) depends on the types of RES and the operating period of the resource (from 20 to 30 years). After the end of the operating period, only utilization is traditionally offered, however, to reduce the load on the E, it is possible to reuse or recycle (in Eng. recycling – the process of converting waste into new materials and

objects). We propose to use utilization only for RES components that cannot be reused or their use is economically and environmentally impractical and associated with increased risk at RES facilities. The annexes that can be reused (recycling 3.4) are “transferred” to the scheme of the LC of the energy product at the stage of production of the RES equipment (1.3). This approach can reduce the production of primary energy resources and reduce the load on the E.

As an example, a study by Begon Guezurag [22], according to which 84.4 % of energy costs from all the LC of the wind turbines are at the production stage, of which 55 % is in the central tower. It can be concluded that the tower can be reused or recycled for future use. Similar results apply to MHPP. Research on recycling solar panels has shown that, under present conditions, most parts of a solar panel are cheaper to recycle than reuse. WPP is another example of recycling. Using the data of the 2011 research report [23], the resources used were determined per 1 MW of capacity based on WPP (Table 2).

*Table 2*

Material content used per 1 MW of WPP capacity [23]

	Construct ional steel, alloy steel	Concrete	Fiberglass	Other*	Copper	Magnets	Cast iron	<b>Total weight</b>
Modern WPPs	115.0	590	9.8	8.05	2.5	0	23.9	750.0
WPPs of the following generations	103.0	402	6.8	9.3	3.0	43.2	20.0	540.0
% change	-10	-32	-31	+16	+20	--	-16	-28

\* “other” column includes aluminum, plastic, epoxide resins, polymer foam and wood.

The materials listed below are steel, copper, magnets and cast iron that can be reused. In the material mass, 141.4 of 750 kg/MW (or 18.85 %) for modern WPPs and 169.2 of 540 kg/MW (or 31.3 %) for WPPs of future generations can be reused. Such components as concrete, fiberglass, and most other materials cannot be reused.

The similar structure of the materials is peculiar to MHPP, but it depends on the type of hydroelectric power plants. In one case, the bulk of the materials is made of structural steel and alloy steel (80–95 % of the total mass), when it comes to floating structures without the construction of dams. At the same time, the category of MHPP includes equipment that needs a concrete foundation, which changes the ratio of materials. In this case, the relative proportion of steel in the structure of the materials varies up to 40–60 % of the total mass. In both cases, the part made of steel can be reused. However, studies by foreign scientists point to the low cost-effectiveness of the materials reusing [23], while at the same time, taking into account the environmental component, the recycling process becomes more efficient.

Solar panels are almost non-recyclable with modern technology. This is due to the peculiarities of the materials and the high cost of their processing.

For further analysis, the environmental impact of RES in terms of soils, reservoirs and the specific effects of the use of RES facilities has been considered. We have studied WPPs, SPPs and SHPPs (without dam construction) as the most widespread in Ukraine and those entitled to a “green tariff”. The stages of the structural composition of the LC are considered in terms of eco-destructive impact in order to identify adverse environmental factors and find possible ways to eliminate them at each phase of the LC. The common environmental impact of all phases of LC

for all types of RES is divided by the total (Table 3) and the specific, which differs depending on RES facility (Table 4).

*Table 3*

Total eco-destructive impact by energy product life cycle stages for all types of RES

Phase	Eco-destructive impact
<b>Overall impact for all RES</b>	
1.1.-1.2.	Absent
1.3.	Emissions of pollutants into the atmosphere, soil and water in the process of manufacturing RES equipment
2.1.	Emissions of pollutants into the atmosphere from transport used at the stage of manufacturing and transporting the equipment to the place of operation
2.2.-3.1.	It has features for each type of RES
3.2.	Emissions of pollutants into the atmosphere from transport used during the operation phase of RES facilities
3.3.	Emissions of harmful substances into the atmosphere from RES facilities in the course of utilization; disposal of individual items of RES equipment
3.4.	N/A

*Table 4*

Eco-destructive impact of RES on the phases of the life cycle of the energy product

Phase	Eco-destructive impact
<b>Roof Solar Power Plants (SPP)</b>	
2.2	Relatively low eco-destructive impact from equipment installation
2.3	There is additional electromagnetic pollution affecting the dwellers of the house; causes heat pollution; has a negative impact on the biota
3.1	Relatively low eco-destructive impact of dismantling of RES equipment
<b>Ground-based Solar Power Plants (SPP)</b>	
2.2	In the case of the installation of small and medium-sized SPP facilities, frame structures are used which have a relatively small eco-destructive impact on the installation stage; in the case of large SPP, structures are being constructed, resulting in significant environmental impact; remote location of the SPP from the power grid requires additional costs for electrical supports or underground cable laying in order to connect to the overall power grid
2.3	Reduces sunlight; causes heat pollution; used washing water penetrates into the soil and water pool; affects the biota
3.1	Dismantling of structures of large SPP sites can lead to additional environmental pollution
<b>Wind Power Plants (WPP)</b>	
2.2	Small WPPs have relatively little environmental damage due to the use of small frames and roofs of buildings; medium and large WPPs use a rigid platform for fixing the mast. There is an environmental damage associated with its construction
2.3	Noise pollution, electromagnetic pollution; impact on wild animals
3.1	The platform for fixing the mast of the WPP remains after the end of the WPP operation
<b>Mini-Hydro Power Plants (HPPP) and Pontoon Small Hydroelectric Power Plants (PSHPP)</b>	
2.2	The PMHPP uses a built-up shoreline, which does not cause additional environmental load; SHPPs that require construction of dams or other structures having an impact on the flow, affecting natural evaporation and biota
2.3	A large concentration of PMHPPs can lead to a decrease in the flow velocity and has negative environmental effects; all SHPPs have an impact on the animal life
3.1	Skeleton PMHPPs have relatively little environmental impact; Small Hydroelectric Power Plant with a dam or with other structures has a significant eco-destructive effect at the dismantling stage

The analysis of the LC of RES provides an opportunity to assess the environmental impact of RES and to compare it with other energy sources. To do this, it is necessary to estimate the

amount of environmental and economic damage caused to each of the sources per unit of energy produced. This will allow you to calculate the amount of losses in terms of the cost of each energy source per unit of energy produced.

**Conclusions and prospects of further research.** The structural composition of the LC of RES facilities is significantly different from LC of traditional energy sources. For the objective analysis of RES, it is necessary to take into account the eco-destructive impact on the stage and phase of the LC of each RES. The study of each type of RES is based on the theory of the LC of the energy product. The comparison of energy sources with each other involves taking into account eco-destructive effects and assessment of the ecological and economic damage from the use of RES facilities at each stage of the LC. The issue of loss assessment of different energy sources needs further research in theoretical and methodical directions.

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**Особенности структуризации жизненного цикла  
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В современном мире вопрос удовлетворения потребности людей в энергии и экодеструктивное влияние энергетического сектора на экологию планеты стоит очень остро. Существуют методы оценки ущерба, который наносится от традиционных источников энергии, в то время как использование данной методики к возобновляемым источникам энергии не объективно. Причина состоит в том, что основной ущерб окружающей среде от традиционных источников энергии наносится во время производства электричества, за счет использования энергетических ресурсов. В то же время, возобновляемые источники энергии не используют энергетических ресурсов для производства электричества, поэтому для оценки ущерба возобновляемых источников энергии необходимо анализировать их жизненный цикл. Были рассмотрены исследования Al-mulali, Apergis and Payne, Dogan и Turkekul, Menegaki подтверждающие наличия взаимосвязи между ростом экономических показателей (валовый внутренний продукт) и ростом в энергии, производимой возобновляемыми источниками энергии. В статье изложено экодеструктивное влияние возобновляемых источников энергии на этапах и фазах жизненного цикла для возобновляемых источников энергии. Было рассмотрено суммарное потребление электроэнергии в мире за период 1973–2016 гг. Приведены сравнения традиционных и возобновляемых источников энергии по сроку службы и жизненному циклу, а также подробно рассмотрены основные этапы и фазы жизненного цикла возобновляемых источников энергии. Показаны этапы разработки, создания технологии, эксплуатация объектов, утилизация и переработка компонентов возобновляемых источников энергии. Было рассмотрено влияние возобновляемых источников энергии на окружающую среду с точки зрения резервуаров, водохранилищ и конкретные эффекты последствия использования объектов возобновляемых источников энергии. С целью выявления неблагоприятных факторов влияния, с точки зрения экодеструктивного воздействия, были рассмотрены этапы структурного состава жизненного цикла возобновляемых источников энергии для поиска возможных путей их устранения на каждом этапе.

*Ключевые слова:* возобновляемый источник энергии, жизненный цикл, энергия, энергетика, природопользование.

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#### **Формування організаційно-економічного механізму залучення інвестицій до регіону**

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У сучасному світі питання задоволення потреби людей в енергії та екодеструктивності вплив енергетичного сектора на екологію планети стоїть дуже гостро. Існують методи оцінки збитку, який наноситься від традиційних джерел енергії, в той час як використання даної методики до поновлюваних джерел енергії не об'єктивно. Причина полягає в тому, що основний збиток навколишньому середовищу від традиційних джерел енергії наноситься під час виробництва електрики, за рахунок використання енергетичних ресурсів. У той же час, поновлювані джерела енергії не використовують енергетичних ресурсів для виробництва електрики, тому для оцінки збитку поновлюваних джерел енергії необхідно аналізувати їх життєвий цикл. Були розглянуті дослідження Al-mulali, Apergis and Payne, Dogan і Turkekul, Menegak які підтверджують наявності взаємозв'язку між зростанням економічних показників (валовий внутрішній продукт) і зростанням в енергії, виробленої поновлюваними джерелами енергії. У статті викладено екодеструктивний вплив поновлюваних джерел енергії на етапах і фазах життєвого циклу для поновлюваних джерел енергії. Було розглянуто сумарне споживання електроенергії в світі за період 1973-2016 рр. Наведено порівняння традиційних і поновлюваних джерел енергії за термінами служби і життєвого циклу, а також детально розглянуті основні етапи і фази життєвого циклу поновлюваних джерел енергії. Показані етапи розробки, створення технології, експлуатації об'єктів, утилізації та переробки компонентів поновлюваних джерел енергії. Було розглянуто вплив поновлюваних джерел енергії на навколишнє середовище з точки зору резервуарів, водоймищ та конкретні ефекти наслідків використання об'єктів поновлюваних джерел енергії. З метою виявлення несприятливих факторів впливу, з точки зору екодеструктивного впливу, були розглянуті етапи структурного складу життєвого циклу поновлюваних джерел енергії для пошуку можливих шляхів їх усунення на кожному етапі.

*Ключові слова:* відновлювальне джерело енергії, життєвий цикл, енергія, енергетика, природокористування.

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