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Development of Energy Enterprises in the Context of Green Transformation

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Abstract. The article argues that the search for effective tools to ensure the economically secure future of energy companies and their development in the context of green transformation is necessary due to the speed of global transformations, the priority of reducing dependence on fuel and energy imports, the development of renewable energy sources, the instability of the environment for the functioning of energy companies (as a result of russia’s full-scale invasion of Ukraine) and their position both on the Ukrainian and European energy markets. The reality of the energy sector in the country and the steps for the recovery of the energy companies determined by the Economic Recovery Plan of Ukraine were analyzed. The evidence shows that the legislative amendments aimed at stabilizing the energy sector and solving key issues lack efficiency and cannot ensure the vital activity of energy enterprises and their development in the conditions of climate-neutral transformation. A methodology was proposed to assess the progress of the carbon-neutral development of energy companies, which should become the basis for attracting ESG investing. The vectors for creating a favorable environment for environmental, social, and governance (ESG) investing were identified as a unique opportunity to ensure the economically secure future of energy companies and their development in the context of green transformation.

Keywords: energy neutrality, decarbonization, sustainability reporting, green tariff, transitional payment mechanism, ESG investing, energy efficiency.

1 Introduction

The challenges associated with environmental degradation and climate change have emerged rapidly in recent years, raising serious concerns among the international community and policymakers seeking sustainable development. At the recent COP27 (Conference of the Parties) summit on environmental governance and climate change, countries that have ratified the United Nations Framework Convention on Climate Change (UNFCCC) decided to achieve net-zero carbon emissions, primarily through the reduction of fossil fuel power plants [1].

Ukraine did not stay on the sidelines either. As a result, the Government adopted the National Plan for the Reduction of Emissions (NPRE) from Large Combustion Plants (LCP) – Thermal Power Plants (TPP) and Combined Heat and Power Plants (CHP) [2], the second nationally determined contribution of Ukraine to the Paris Agreement [3], adopted the National Energy and Climate Change Plan for the period up to 2030 [4], approved the Strategy for Environmental Security and Climate Change Adaptation for the period up to 2030 [5] and developed the Operational Plan for its implementation for the period 2022-2024 [6]. With their introduction, the volume of electricity generation by TPPs and CHPs in Ukraine gradually decreases. However, we consider it inappropriate to completely abandon TPP/CHP for the following four main reasons.

First, Ukraine does not have enough capacity for substations for receiving, distributing, and transforming electricity.

Second, the units of the nuclear power plants (NPPs) cannot increase their load during the day, as they work with a constant load and provide basic electricity consumption. Therefore, there needs to be an additional source of generation that can be used to meet the electricity demand generated during peak hours. This is what TPPs and CHPs do. Therefore, their importance in the energy system of Ukraine lies primarily in regulating the volume of power generation during the day, thus ensuring the stability of the country of the Economic Cooperation Organization (ECO).

Third, as the main driver for developing renewable energy sources (RES), solar energy is a low-efficiency and unstable type of energy with an average conversion efficiency not exceeding 20 %. In addition, it requires large areas to house the equipment in the face of an ever-increasing scarcity of agricultural land. It is, therefore, unlikely that solar energy and other types of renewable energy will be able to replace fossil fuels 100%, even in the long term. An energy model that combines the development of RES, hydroelectric power plants (HEPS), combined heat and power (CHP), and innovative, safe nuclear technologies (in particular small modular reactors (SMR) and fast neutron reactors) could be a more realistic scenario for achieving climate goals [7].

Fourth, TPP simultaneously generates both electricity and heat, meeting the needs of consumers in heat supply.

Perhaps the only way to reduce carbon emissions from thermal power plants is to gasify them. However, this requires the implementation of large-scale and capital-intensive projects to reconstruct TPP/CHP equipment and construct flue gas cleaning plants from sulfur dioxide (CO_2) and nitrogen oxides (NO_x) emissions. However, unfortunately, NPRE [4] mechanisms and sources of their financing are not defined. The same mechanisms for financing projects for reconstruction/modernization of power generation facilities that were in effect before the introduction of the new electricity market have lost their relevance, and new ones have not been developed or implemented in national legislation. Therefore, it is evident that TPP/CHP do not have the necessary resources to finance the modernization of their equipment [8] since the marginal prices for electricity set by the national regulator do not provide the creation of funds necessary for implementing TPP/CHP gasification projects. On the contrary, they make it more and more difficult for the Ukrainian power industry to fulfill the tasks defined by the NPRE [4], the Nationally Determined Contribution (NDC) 2 to the Paris Climate Agreement [3], and the Association Agreement between Ukraine and the EU. The decommissioning of a part of the TPP/CHP units and/or their shutdown due to non-compliance with the provisions of the NPRE may lead to a shortage of generating capacities and, consequently, to a violation of the country's energy security [8, p. 11], which is in a rather critical state as a result of russia's full-scale invasion of Ukraine.

As a result of missile attacks alone, as of the end of March 2023, up to 5 GW of generating capacity remains damaged in the United Energy System (UES) of Ukraine, including 19 TPP units with a total capacity of 3.3 GW, four CHP units with a capacity of 1.1 GW, and eight HEPS hydroelectric units with a capacity of 0.54 GW. Part of the generating capacity is still under occupation. These are five TPPs with a total capacity of 10 GW and the largest, Zaporizhzhia NPP, with a total capacity of 6 GW [9].

The experience of foreign countries after the post-war reconstruction shows that the main source of financing for the modernization of TPP/CHP generating equipment should be foreign financial assistance. However, against the backdrop of a large number of statements and declarations of Western partners on financial support for the modernization of TPP / CHP generating equipment in Ukraine in the post-war years, the institutional mechanism and financial instruments for restoring the energy industry have not yet been determined. In particular, in May 2022, the European Commission announced the creation of a special financial mechanism, "Rebuild Ukraine", designed to provide financial support to Ukraine through grants and loans, but so far, such a mechanism has not been launched [1]. Therefore, understanding the complexity of this issue, there is an urgent need to find avant-garde ways to ensure the development of energy enterprises in the post-war years in the context of green transformation.

2 Literature Review

It is not only the complexity of the "green transformation" and the lack of funds for its financing but also the constant shifting of the attention of politics, business, and science to this area. This is evidenced by numerous speeches of government representatives and public organizations, publications of foreign and domestic researchers in scientific journals, and publications of experts and practitioners in mass media and blogs.

The existing climate threats and environmental pollution require humanity to reflect on the actual value of nature, UN Secretary-General António Guterres [10] emphasizes. Humanity will only ensure the well-being of the planet, and thus the well-being of present and future generations, if we understand its value and direct our ingenuity towards the transition to low-carbon production [11]. R. Flavio, M. Arroyo, and L. J. Miguel [12] emphasize that adequate financial support is critical for achieving carbon emission reductions, especially in the energy sector, under any of the energy-growth-environment nexus scenarios. In addition, government regulation plays an essential role in its formation by creating a favorable environment for attracting investment.

Mara Madaleno and Manuel Carlos Nogueira [13, p.33] emphasize that since energy is an essential source of economic growth in the world economy, sustainable economic growth can only be achieved by first creating the conditions necessary for expanding the production and consumption of "green" energy sources. Only in a sustainable way will it be possible to ensure the necessary reduction of CO2 emissions while increasing the amount of electricity generation, the demand for which is constantly growing.

They are fully supported by Hongyi Zhang, Hsing Hung Chen, Kunseng Lao, and Zhengyu Ren [14], as well as Zhuohang Li, Tao Shen, Yifen Yin, and Hsing Hung Chen [15], as well as Zahoor Ahmed, Michael Cary, Muhammad Shahbaz, Xuan Vinh Vo [16], which in the example of the United States is the second largest emitter of CO_2 environmental pollutant, where nearly 16 % of the world's energy production is consumed with only 4.3 % of the world's population (for comparison, China and India together consume about 28 % of the world's energy production, despite being home to 36 % of the world's population) have proven that public investment in renewable energy research and development and thermal power plant modernization is a helpful strategy for achieving better economic performance and environmental sustainability. As part of its efforts to combat climate change, the United States has increased its share of renewable electricity generation over the past two decades. However, the United States still generates most of its energy from fossil fuels, primarily due to a history of government subsidies that were put in place to artificially support domestic fossil fuel production. Whether these subsidies will continue is one of the most critical issues in US political discourse [16].

With the rapid development of renewable energy, regulating the load of the electric power system has become an important issue, and much research has been conducted on regulating the load using TPP [17]. Challenges related to environmental sustainability, security of energy supply, economic stability, and social aspects are identified on the way to a decarbonized energy sector [18]. Elisa Papadis and George Tsatsaronis [18] argues that a global carbon tax is the most promising instrument to accelerate the process of decarbonization. However, this process will be very challenging for humankind due to the high capital requirements.

I. P. Hayuduky [19] argues the need to form a global and national motivation system for sustainable low-carbon development of the country's economy and industries. The author emphasizes that achieving ambitious goals requires large amounts of investment. Nevertheless, the formation of such an investment potential is complicated by contradictions in the global anti-carbon policy when negative environmental consequences are global, and the financing of measures to reduce greenhouse gas emissions is sectoral [11].

Investments prioritizing environmental, social, and corporate responsibility are replacing the conventional investment paradigm, and the energy sector is one of the sectors most affected by this trend [20].

Thus, the European-Ukrainian Energy Agency director K. Polyakova [21] emphasizes that the energy industry has continued to fight for survival for more than a year. RES producers ended 2022 with a "green" tariff payment rate of 54 %. Debts for imbalances and debts under the "green" tariff for the current and previous years remain the key issues important for the survival of the industry's enterprises. The analyzed sample in [22] includes over 500 publicly reported companies from different energy sectors, and the research methodology embeds robust regression models. The main results provide new insights into the modeling of firm performance through environmental, social, and governance (ESG) practices and entail that the environmental pillar of ESG negatively affects energy companies' financial performance.

Experts of the Razumkov Center [7] emphasize the complexity of the process of decarbonization of the energy industry of Ukraine and dwell in detail on the problems of attracting investments in the development of energy infrastructure to ensure the transition to carbon-neutral energy. It proposed a set of recommendations for energy decarbonization to ensure sustainable electricity production, energy security, and economic recovery of Ukraine [7]. The set is based on European experience in combating climate change and the "green" transition, as well as considering external challenges – the Carbon Border Adjustment Mechanism (CBAM) and the impact on the energy sector of military operations.

The work [23] presents the possibility of ensuring economic security by transforming the energy system towards renewable energy sources, including solar, wind, hydropower, and biofuels. This process is linked to the transition of economies to a less carbon-intensive and more sustainable energy system. The study [23] examines economic and policy incentives for clean energies, both direct and indirect.

Proposals are also coming from government officials, in particular with the submission to the Verkhovna Rada of 02.05.2023 for consideration of the draft law No. 3056-IX, which is aimed at improving the conditions for supporting the production of electricity from alternative energy sources by generating plants of consumers, taking into account the best global practices. And also a whole circle of scientists. In particular, the scientists of the IEPr of the National Academy of Sciences of Ukraine, in the Report "Economically justified approach to the introduction of the National Plan for the reduction of emissions in Ukraine based on the experience of reducing emissions of harmful pollutants into the air by large combustion plants in Europe" considered the European experience of state support for TPPs/CHPs. It was emphasized that among the mechanisms that were used and continue to be used to support coal generation, the most significant in terms of financing is the transitional payment mechanism, which is currently used in Poland, Germany, Portugal, the Czech Republic, Greece, Italy, and contracts for difference, which are still used in Austria, Denmark, the Netherlands, and Great Britain.

O. V. Borysiak [24], based on the results of a study of the potential of energy enterprises under martial law, proposes to apply an integrated segmental approach to the development of a conceptual model for positioning "green" energy on the European energy market as a carbon-neutral product, which will contribute to the formation of additional resources for the modernization of energy enterprises thanks to its export, in particular TPP and/or CHP.

There are also proposals regarding the replacement of the "green tariff" in Ukraine with a new model of Net billing, to which K. Bilousova [25] calls for discussion on the pages of "Ecopolitics".

Therefore, we are convinced that the issue of the development of energy enterprises in the context of "green transformations" does not lose its relevance, and with the damage to energy infrastructure facilities as a result of russia's full-scale invasion of the territory of Ukraine, they become even more relevant.

The goal is to determine the optimal path for the formation of Ukraine's energy portfolio in the post-war years, taking into account the characteristics of the country's energy mix, the consequences of russia's full-scale invasion of Ukraine, and the possibility of attracting investments in the development of energy enterprises in the context of "green transformations".

3 Research Methodology

The theoretical and methodological basis for realizing the research goal became the fundamental provisions of the modern science of public administration. In the research process, general scientific methods were used. In particular, methods of abstraction, induction and deduction, analysis and synthesis, abstract-logical, and graphic.

Among the special methods in the research process, the following were used: the method of sectoral mapping – when assessing the state of electric power enterprises, the decoupling analysis method – when determining the dynamism of the gap between the capital invested in the development of DTEK Group's TPP/CHP and the number of carbon emissions; the method of harmonization – when searching for sources of financing for the "green" development of energy enterprises according to the decarbonization tasks set. Correlation regression analysis and the least square method were used for mathematical model construction, and scenario forecasts were found.

Sharing the values of the "European Green Deal" [26], with the adoption of which Europe declared its intention to become the first climate-neutral continent in the world by 2050, Ukraine announced its intention to cooperate with the EU in the direction of "greening" energy.

Currently, the EU is moving dynamically in this direction, as evidenced by the data in Table 1.

Ukraine is moving much more dynamically in this trend. During the analyzed period, it reduced GHG emissions (from the power industry) to 167.9 million tons, or in other words by 44 %. However, such positive indicators were achieved not due to the implementation of projects for the modernization of energy enterprises, but due to the reduction of production volumes and, therefore, the volumes of electricity consumption by industrial enterprises.

Table 1 – Dynamics of reduction of greenhouse gas emissions in EU countries and Ukraine during 2012-2021

Countries	Years									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
EU countries	3218.7	3146.0	2980.8	3043.7	3075.7	3095.7	3069.0	2931.5	2564.2	2728.2
Ukraine	299.1	286.5	246.8	195.1	215.6	187.9	196.7	185.5	172.9	167.9

There is no doubt that it is challenging to implement projects for modernizing power plants and, in particular, combined heat and power plants with investment needs above 4 billion EUR (Table 2) in the absence of the sources and mechanisms for their financing defined in the NRP [8], even if there is agreement on the issue of extending the terms of their implementation [1].

However, having received the status of a candidate for EU accession, Ukraine will continue to move in the direction of achieving the goals of the European Green Agreement, continuing the implementation of the principles and standards of European legislation, focusing on the future obligations of EU membership in cooperation with European partners.

In order to achieve the goals of decarbonization, a comprehensive approach and an effective recovery plan with an effective program for attracting investments, creating the basis for "green" modernization, and stimulating the development of renewable energy is necessary [7].

Table 2 – The need for capital investments for the reconstruction/modernization/technical re-equipment of power plants, considering the changes ensuring the implementation of the NPRE [8]

Years	Desulfuri-zation	Denitrifi-cation	Dust cleaning	Amount
2020	97	42	15	154
2021	396	18	87	501
2022	193	18	135	346
2023	171	18	56	245
2024	135	185	75	395
2025	158	307	57	522
2026	138	102	51	291
2027	153	88	36	277
2028	203	78	31	312
2029	170	46	–	216
2030	156	69	–	225
2031	170	108	–	278
2032	143	114	–	257
2033	26	86	–	112
Total	2311	1 276	543	4130

Undoubtedly, one of the sources of financing the modernization of TPPs and CHPs should be the investment component of the electricity price. However, the electricity market has been liberalized, and wholesale and retail electricity markets have been created by analogy with European countries, namely: the market of bilateral contracts, the market of bilateral contracts at free prices, the day-ahead market, the balancing, and intraday market, did not bring the expected result. In addition, in connection with the state of war in the country, the CMU Resolution No. 838 of 22.07.2022 [27] extended the operation of the mechanism for ensuring the public interests in the process of functioning of the electric energy market, i.e., the operation of forced price restrictions.

Using this mechanism shows that price regulation measures on the electricity market should be limited and gradually phased out in the post-war years, ensuring generating companies' gradual financial recovery [28].

In order to accelerate the "greening" of the energy industry and stimulate the development of RES in Ukraine, the "green" tariff model has been introduced for many years. On the one hand, this has allowed a significant push for creating a new industry and the rapid development of small-scale generations. Thus, from 2018 to 2022, the total capacity of household installations for producing energy from solar radiation will increase more than fivefold and, by the beginning of 2022, will amount to 1205 MW (about 45 thousand units) [29].

On the other hand, this model has a number of limitations and shortcomings that have led to abuses and do not allow to ensure the stability and sustainability of the development of "green" generation:

firstly, the introduction of the "green" tariff did not promote self-sufficiency and energy independence, but rather the targeted sale of electric energy at a higher tariff;

secondly, such a model leads to a number of technical challenges and distorts the ideology of support for small-scale generation from renewable energy sources in order to bring clean "green" energy closer to consumers;

thirdly, the mechanism for supporting RES generation is currently regulated only for households (up to 30 kW) and energy cooperatives (up to 150 kW) [29].

For this reason, the issues of modernization of coal-fired power plants have so far been of secondary importance.

Among the models of "greening" of coal-fired power generation, which have been used for many years in foreign practice, in particular in Poland, Germany, Portugal, the Czech Republic, Greece, Italy, and are still used in Austria, Denmark, the Netherlands, Great Britain, etc., there is a transitional payment model [8, p.88].

The results of calculations of transitional payment volumes carried out by IEPr of NASU are summarized in Table 3.

Table 3 – Calculations of transitional payment volumes for three options for the distribution of charges between household and non-household consumers [8, pp. 156-164].

Years	Household consumers (permanent payment per month, UAH)			Non-household consumers (transitional payment rate per 1 kW, UAH)		
	Alternative options for charging a transitional fee					
	30/70	50/50	70/30	30/70	50/50	70/30
1	0.662006	1.103343	1.544680	0.003704	0.002645	0.001587
2	2.871502	4.785837	6.700171	0.016065	0.011475	0.006885
3	4.828002	8.046671	11.265339	0.027010	0.019293	0.011576
4	6.873052	11.455086	16.037120	0.038451	0.027465	0.016479
5	9.166880	15.278133	21.389386	0.051284	0.036632	0.021979
6	11.848635	19.747725	27.646815	0.066287	0.047348	0.028409
7	13.404559	22.340931	31.277304	0.074992	0.053566	0.032139
8	14.964699	24.941166	34.917632	0.083720	0.059800	0.035880
9	15.635138	26.058564	36.481989	0.087471	0.062479	0.037488
10	15.829102	26.381836	36.934570	0.088556	0.063254	0.037953
11	15.458041	25.763402	36.068763	0.086480	0.061772	0.037063
12	13.703937	22.839895	31.975853	0.076667	0.054762	0.032857
13	12.228129	20.380214	28.532300	0.068410	0.048865	0.029319
14	10.545707	17.576178	24.606649	0.058998	0.042141	0.025285
15	8.251878	13.753131	19.254383	0.046165	0.032975	0.019785
16	5.570123	9.283539	12.996955	0.031162	0.022259	0.013355
17	4.014199	6.690332	9.366465	0.022457	0.016041	0.009625
18	2.454059	4.090098	5.726137	0.013729	0.009807	0.005884
19	1.783620	2.972700	4.161780	0.009978	0.007127	0.004276
20	1.589657	2.649428	3.709199	0.008893	0.006352	0.003811
21	1.298712	2.164519	3.030327	0.007266	0.005190	0.003114
22	0.843319	1.405532	1.967745	0.004718	0.003370	0.002022
23	0.362627	0.604379	0.846130	0.002029	0.001449	0.000869

Its difference lies in the fact that when the TPP/CHP receives bank loans to implement modernization projects, a clear schedule of fixed income for the entire project life cycle is established. Therefore, researchers from the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine recommended implementing this model in Ukraine. In the report [8], they provide calculations of the amount of transitional payment for three options for the distribution of charges between household and non-household consumers:

– option 30/70, where 30 % of the transitional payment is charged to household consumers and 70 % to non-household consumers;

– the 50/50 option, where 50 % of the transitional payment is charged to household consumers and 50 % to non-household consumers;

– the 70/30 option, where 70 % of the transition payment is collected from household consumers and 30 % from non-household consumers [8].

The transitional payment model provides for financing the repayment of loans taken out by thermal power plants for implementing environmental projects. Therefore the term of its operation should be set to the term of repayment of loans taken out by plant operators for the implementation of environmental projects according to the requirements of the NPRE [8].

However, this model can be used to implement projects to modernize coal-fired power plants. In this case, obtaining bank loans will only increase the cost of projects requiring significant investments.

At present, energy companies have a unique opportunity to attract ESG investments and thereby ensure the economically secure future of energy companies [19]. A clear example of this is the companies of the DTEK Group, which have set an ambitious goal in their strategy - to become a carbon-neutral company, a leader in decarbonization in Central and Eastern Europe.

DTEK started its decarbonization journey in 2012 by constructing the first 3 MW wind turbine at the Botievska wind farm. Today, DTEK manages 1 GW of green generation (Table 4) [30-32].

Table 4 – Dynamics of electricity production indicators by DTEK Group (Ukraine) during 2012-2021 by types of generation

Characteristics	Years									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Electricity production in total, billion kWh	47.6	53.0	47.8	38.3	39.5	37.1	34.7	29.8	26.2	25.4
Including wind and sun power plants, billion kW/year	–	–	–	–	0.7	0.6	0.6	1.4	2.4	2.6
Including TPP and CHP, billion kW/year	47.6	53.0	47.8	38.3	40.1	36.5	34.1	28.4	23.8	21.4

DTEK Group's ambition is to secure the interests of its stakeholders, who today expect companies to take responsibility for future generations by creating material goods and values. Therefore, the holding company has followed ESG principles recently and aims to attract ESG investments shortly.

However, investors making decisions about investing capital in implementing modernization and environmental protection projects need to study the background of ESG investments and follow up on previous investments in environmental measures with the effect of decoupling.

In order to determine the possibility of attracting ESG investment by DTEK Group, we will carry out sectoral mapping according to the data in Tables 5-6 [30-32], which will provide an opportunity to determine the Group's portfolio at this stage.

The data in Table 5 show that during the period studied, the DTEK Group is successfully developing and increasing its assets. The volumes of capital investments and environmental costs are also increasing (Table 6).

With the growth of capital investments, indicators of environmental pollution are also significantly reduced, which we can observe according to the data in Table 7 [30-32].

Table 5 – Dynamics of performance indicators of the DTEK Group Ukraine (2012-2021)

indicators	Years									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Income, UAH billion	82.6	92.8	93.3	95.4	131.8	145.1	157.6	137.7	116.0	112.4
EBITDA, UAH billion	16.9	14.9	18.9	7.5	30.6	37.2	42.9	32.7	31.9	32.1
EBITDA margin, %	14.3	10.9	10.3	8.0	23.0	28.0	27.0	24.0	22.0	22.0
Net profit (loss), billion UAH	6.0	3.3	–19.7	–41.9	–1.2	4.6	12.4	12.6	–13.8	7.6
Assets, UAH billion	76.9	95.1	110.8	119.8	140.6	152.5	148.0	168.3	180.4	179.5
Capital investments, billion UAH	10.2	10.3	6.5	5.0	7.1	10.4	19.9	23.2	11.2	12.4
Taxes paid in Ukraine, billion UAH	9.8	10.4	12.8	14.1	17.9	22.5	26.7	23.4	20.2	19.8

Table 6 – Dynamics of ecoinvesting indicators of the DTEK Group Ukraine (2012-2021)

Indicators	Years									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
The volume of capital investments of DTEK:	10193	10310	6460	5015	7781	10388	19878	23180	11197	12445
DTEK Energo	7077	6698	4860	3570	6194	8416	6037	5186	1195	1896
Including mining and beneficiation of coal	3855	4212	3008	2460	3912	4552	4061	3804	3069	2165
Electricity generation	3222	2486	1852	1110	1357	2725	1511	1099	1874	2134
DTEK Networks	1495	1806	481	418	827	992	1932	3525	4853	4913
DTEK RES	1420	1562	153	7	8	370	9556	10968	36	2789
DTEK Naftogaz	201	119	940	947	932	1143	1685	2559	2524	2611
Environmental costs (excluding eco-tax), total, million UAH	548.5	976.0	777.2	822.5	858.4	1126.8	1378.3	1362.2	741.5	1080
Including capital costs, million UAH	–	370.8	203.2	101.9	111.9	349.2	299.7	371.8	250.5	344.9
Current costs, million UAH	–	526.5	507.9	659.7	672.6	732.4	1014.7	938.1	444.4	512.1
Additional costs, million UAH	–	78.7	66.1	60.9	73.8	46.1	62.9	52.3	46.6	44.8

Table 7 – Dynamics of pollution indicators of the DTEK Group Ukraine (2012-2021)

Indicators	Years									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Gross greenhouse gas emissions (GHG), thousand tons	60688.4	62545.7	56339.1	47606.6	50266.8	43598.9	35725.5	31340.5	29951.3	29007.9
Pollutant emissions, thousand tons	1126.7	1090.9	724.3	554.7	–	863.8	771.8	723.1	607.8	592.9
Water intake volumes, m^3	2193.9	2190.2	1985.9	1700.1	1816.5	1635.9	1375.2	1314.8	1136.6	1131.2
Land reclamation, ha	10.2	10.9	18.2	25.6	30.1	39.3	10.9	20.1	97.8	75.6
The total volume of waste generation, million tons	21.6	21.5	19.3	16.2	17.9	17.6	13.8	13.7	12.3	12.1
Including volume of waste processing, million tons	2.4	2.6	2.3	1.6	3.9	3.1	3.4	5.9	5.3	5.3

Using the indicator of capital investment and environmental pollution, the DTEC group will conduct a decoupling analysis, allowing us to determine the presence/absence of the decoupling effect. The decoupling effect is present in the case when, under the positive dynamics of economic growth, the indicators of negative environmental impact remain stable or show a tendency to decrease over the same period [11, 33].

According to the OECD methodology [34], the effect of decoupling is estimated by the Decoupling Index:

$$DecInd = \left(\frac{EP}{DF}\right)_{ending} \left(\frac{EP}{DF}\right)^{-1}_{beginning} = \frac{K_{EPending}}{K_{DFbeginning}}, \quad (1)$$

where *EP* – an indicator of the anthropogenic pressure on the environment (environmental pressure), natural units; *DF* – an indicator of economic growth (driving force), it is displayed most often through the gross internal product, monetary unit; K_{EP}, K_{DF} – the rate of increase in the general indicators in the ending and base (beginning) periods of the pre-season (years), respectively.

Let us consider the following values to measure *DecInd*: K_{eco} – is a chain growth rate to the previous year of the polluting factor of the DTEK enterprise (negative impact on the environment (NII)), %. K_{EV} – a chain growth rate to the previous year of the electricity production volumes, %.

DecInd is calculated by a formula similar to formula (1):

$$DecInd(t) = \frac{K_{eco\,t}}{K_{EVt}}, \quad (2)$$

where *t* – the year; K_t – the chain growth rate of the corresponding indicator:

$$K_t = (T_t - 100)\%; \quad (3)$$

T_t – the chain index of the corresponding indicator:

$$T_t = \frac{y_t}{y_{t-1}} \cdot 100\%; \quad (4)$$

y_t – the value of the corresponding indicator in the considered year; y_{t-1} – the value of the corresponding indicator in the previous year.

The data from Table 7 allows for carrying out the decoupling analysis.

Table 8 – Categories of Decoupling Index by Tapio

Weak 0 < Decoupling Index < 0.8	Strong Decoupling Index < 0	Recessive	Expansive
Positive Decoupling-effect		1.2 > Decoupling Index >0.8 Coupling effect	
Observed if the condition of simultaneous growth of economic growth rates and NII, but when the growth rates of the former exceed the latter	Observed if conditions of growth of economic growth rates and a simultaneous decrease in rates of NII	Observed if the rate of economic growth and NII tend to decrease	Observed if the rate of economic growth and NII tend to increase
Negative Overcoupling effect		Decoupling Index > 1.2	
Observed if the rate of economic growth and the rate of change of NII tend to decline, but when the rate of decline of economic growth exceeds the rate of decline of NII	Observed if the rate of economic growth tends to decline and the rate of change in NII to increase	Decoupling-effect observed if with a simultaneous decline in economic growth and NII, but when the rate of decline in NII exceeds the rate of decline in economic growth)	Overcoupling-effect observed if the rate of economic growth and the rate of change of NII tend to increase, but when the growth rate of the latter exceeds the former

To describe the decoupling effect of transportation by rail, we will use the classification of decoupling types according to P. Tapio [33]. Depending on the density of the relationship between economic growth and the rate of nature of the Decoupling Index, researchers distinguish four subcategories and eight logical degrees (Table 8).

Let us denote: T_{GHG} is an index of gross greenhouse gas emissions, %; T_Z is an index of pollutant emissions, %; T_W is an index of water intake volumes, %; T_G is an index of volumes of unprocessed waste.

4 Results and Discussion

Applying the chain growth indices of the corresponding indicators calculated according to formula (4), we offer the following formula for finding the integral indicator of the growth rates of NII, using the geometric mean, that is, a number that can be used to replace each of these numbers so that their product does not change:

$$T_{Integ} = \sqrt[4]{T_{GHG} \cdot T_Z \cdot T_W \cdot T_G} \quad (5)$$

Guided by formula (3), let us find an integral indicator of the growth rate of negative factors,%:

$$K_{Integ} = (T_{Integ} - 100)\% \quad (6)$$

We propose to calculate the integral $DecInd$ by a formula similar to formula (2):

$$DecInd_{Integt} = \frac{K_{Integt}}{K_{EVt}}. \quad (7)$$

Similarly to (7), we make a notation of K_{Inv} is the chain growth rates compared to the previous year according to the volume of capital investments in DTEK, %.

$$DecInd_{Integt} = \frac{K_{Integt}}{K_{Invt}}.$$

The calculation results are summarized in Table 9 and Figure 1.

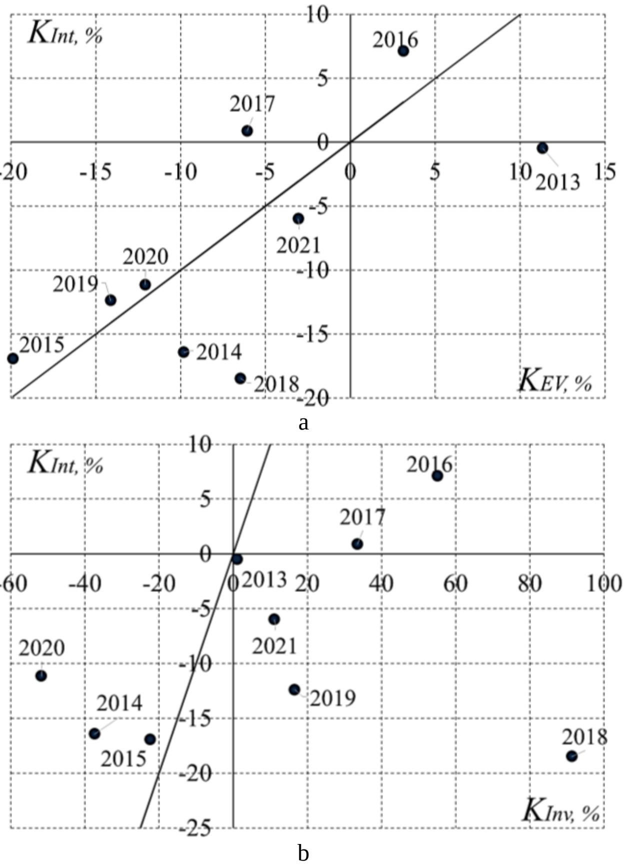

Figure 1 – The dynamics of growth indices of the integral indicator of polluting factors of the DTEK from the volume of electricity production (a) and capital investment (b)

According to the classification of types of decoupling according to P. Tapio [33], the trend of growth rates of electricity generation volumes and the integral indicator of environmental pollution is accompanied by a recessive coupling-effect since both the indicators of electricity production volumes and the indicators of environmental pollution during the analyzed period show a decline. Besides, almost at the same speed.

Table 9 – Decoupling Index Dynamics of DTEK (2013-2021)

Year	Decoupling Index relative to the volumes of electricity production					Integral Decoupling Index relative to investments
	GHG	emissions of pollutants	volumes of water intake	volumes of unprocessed waste	Integral	
2013	0.2698	–0.2801	–0.0149	–0.1377	–0.0430	–0.4254
2014	1.0114	3.4251	0.9507	1.0246	1.67457	0.4400
2015	0.7799	1.1782	0.7241	0.7103	0.8527	0.7576
2016	1.7835	6.9144	2.1852	–1.311643836	2.2691	0.1289
2017	2.1832	–4.6075	1.6363	–0.5878	–0.1441	0.0261
2018	2.7916	1.6464	2.4634	4.37101	2.8580	–0.2024
2019	0.8692	0.4468	0.3110	1.7704	0.8768	–0.7454
2020	0.3669	1.3199	1.1219	0.8490	0.9230	0.2157
2021	1.0316	0.8028	3.1436	2.8071	1.9638	–0.5380

The trend of growth rates of capital investments and the integral indicator of environmental pollution is also accompanied by a recessive coupling effect, but at a faster rate, which shows that with each unit of capital investment in the modernization of TPPs and CHPs of the DTEK Group, the amount of environmental pollution is rapidly reduced.

Regression analysis methods are used to identify implicit and veiled relationships between observation data.

In this case, linear regression does not adequately approximate the experimental data. Thus, the challenge is to find a nonlinear multiple regression equation that fits the empirical points well, preferably in the best possible way. The model specification is proposed to be carried out by the method of directed enumeration using the method of least squares (LSM) [35]. The approximation quality is estimated using the coefficient of determination (the closer to one, the better) and the average approximation error (the closer to zero, the better). The contribution of each independent variable to the variation of the studied (predicted) dependent variable is determined based on the constructed regression equation.

As is well known [36], LSM works well when the number of experiments sufficiently exceeds (by about an order of magnitude) the estimated components of the regression equation. The deterioration of the ratio between the number of estimated coefficients and the number of experiments has negative consequences for the following reasons. First, the variances of the estimates of the values of the elements of the vector of coefficients located on the main diagonal of the covariance matrix of the estimation errors increase. Second, it reduces the degrees of freedom, which is equal to the difference between the number of experiments and estimated parameters, leading to an expansion of the confidence intervals covering the actual values of the regression equation coefficients. The consequence is an increase in the probability of accepting the hypothesis of the insignificant factors for which the calculated confidence intervals cover zero. Thus, the cumulative effect of these causes under conditions of lack of initial data reduces the adequacy of the model.

Promising possibilities arise when using artificial orthogonalization of the results of a passive experiment [11, 35]. The set of results of statistical data on DTEK reports forms a passive experiment. At the same time, the corresponding matrix of initial data is not orthogonal, which excludes the possibility of independent evaluation of the influence of each of the factors and their interactions, which ensures the elimination of insignificant components of the regression equation.

First, we convert the scaling (normalization) of the actual values of the factors to the interval (0; 1] according to the formula:

$$X_i^* = X_i / X_{\max},$$

where X – the considered factor; $i = \overline{1,10}$ – an observation number.

The technology of processing the results of a passive experiment [36] is used, which makes it possible to establish a relationship between the values of greenhouse gas emissions (the determining parameter of the studied complex system) and a large number of supposedly influencing factors in a situation where the total number of experiments is not enough to build an adequate model. This enabled it to independently filter out insignificant factors and interactions, simplifying the estimated regression equation's structure and increasing its accuracy. Thus, we limited ourselves to only four factors that most impact greenhouse gas emissions.

As a result, a multifactor nonlinear dependence was constructed:

$$GHG^* = 0.1814 - 0.2158 \cdot \sqrt{S^*} - 0.0594 \cdot I^{*3/2} + 1.0273 \cdot E^* \quad (8)$$

where GHG^* – gross emissions of GHG; S^* – environmental costs (excluding eco-tax); I^* – investments in the modernization of the DTEK group (capital investments); E^* – electricity production; symbol “*” means that we are considering normalized dimensionless quantities.

The coefficients of the multivariate nonlinear regression (8) after the initial linearization were found in matrix form by the generalized least squares method.

According to model (8), we can see that the growth of electricity production causes an increase in greenhouse gas emissions. They are in a direct linear relationship. The minus sign before investments in modernization and environmental costs shows that gross greenhouse gas emissions decrease when these parameters increase.

The obtained coefficient of determination for this model is $R^2 = 0.986$. It is close to 1, indicating sufficient density between the variables.

The calculated value of the Fisher coefficient according to the sample data is $F = 143.46$, and the critical value of the Fisher coefficient is $F_{kr} = 4.76$ according to the degrees of freedom 6, 3, and the significance level.

According to Fisher's test, F > Fkr showed that with a reliability of 95 %, it is assumed that the proposed mathematical model is adequate to the statistical data, and based on the accepted model, economic analysis can be carried out.

The average approximation error $\overline{A} = 2.88$ %. Thus, the regression values differ from the corresponding empirical values by an average of 2.88 %, which can be considered a good enough result.

To implement the emission reduction program, by 2030, it is necessary to reduce by 25 % relative to the value for 2019 [31, 32], i.e., 23505.38 thousand tons, while the production of electricity for 2030 is planned in the amount of 27 000 million kWh [31, 32]. To achieve this goal, forecast values of environmental costs are proposed, which amount to 2292 million UAH. and investments in the modernization of the DTEK group (capital investments), 20 851 million UAH on average per year.

The dependence graph (8) is shown in Figure 2 at a constant volume of electricity production.

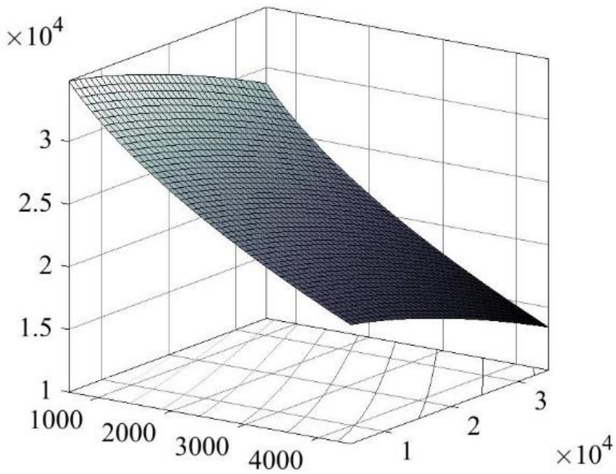

Figure 2 – The surface of the dependence of GHG emission volumes on investments in modernization and environmental costs at a constant volume of electricity production of the DTEK group

For fixed values of the forecast value of environmental costs, 2292 million UAH and the planned 27 000 million kWh electricity production is built according to model (8) graph of the dependence of gross greenhouse gas emissions on the amount of capital investments (Figure 2).

The reliable zone for this regression is constructed for the level of significance $\alpha = 0.05$ (Figure 3), and the critical value of the Student's coefficient according to the table of values is equal to $t_{kr} = 2.365$.

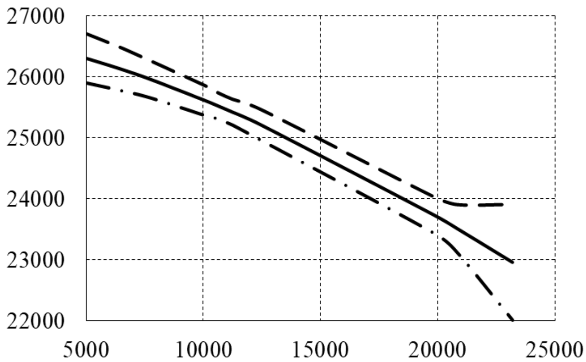

Figure 3 – Regression confidence zone of the dependence of GHG emission volumes on investments in modernization at a constant environmental cost and constant volume of electricity production

That is, for the forecast value, the confidence interval for the forecast, calculated with reliability $p = 95$ %, is 22 009.27 $\le I_{\text{pr}} \le$ 23 909.81.

5 Conclusions

Thus, according to the achieved results, it was established that the high pace of global transformations, the priority of reducing dependence on fuel and energy imports, the development of RES, and the commitment to reduce carbon emissions require immediate measures for the modernization of energy enterprises and, therefore, the implementation of large-scale and capital-intensive projects for the reconstruction of TPP/CHP equipment and construction of facilities for cleaning flue gases from emissions of sulfur dioxide, and nitrogen oxides. The mechanisms and sources of financing are not defined in the NPRE. Unfortunately, however, the mechanisms and sources of their financing are not defined in the NPSV.

The exact financing mechanisms for projects of reconstruction/modernization of power generation facilities that were in operation before the introduction of the new electricity market have lost their relevance, and new ones have not been developed or introduced into the national legislation.

Therefore, it is evident that TPPs/CHPs do not have the necessary resources to finance the modernization of their equipment because the limited prices for electricity established by the National Regulator do not ensure the creation of funds necessary for the implementation of projects for the gasification of their TPPs/CHPs, on the contrary, they make the situation more difficult for the performance by the electric power industry of Ukraine of the tasks defined by the NPRE.

Using the method of sectoral mapping, an assessment of the country's energy reality and the reconstruction of the power industry in the post-war years were carried out. It is well established that the regulatory changes introduced by the Government to stabilize the industry and solve critical problems are insufficiently effective and unable to ensure the viability of energy enterprises and their further development in the context of "green transformations".

Alternative options for financing the development of energy companies in the context of "green transformation" were considered. It is well established that a unique opportunity for implementing TPP/CHP modernization projects is the inclusion of ESG investments. It is emphasized that the decision to provide ESG investments in global practice is made based on the results of studying the background of the development of companies, accompanying their previous investments with the decal effect and their compliance with ESG principles. Based on DTEK Group's data, the readiness of energy companies to attract ESG investments has been proven.

References

1. Levchenko, S. (2023). Ensuring economic security of thermal power plants with accelerated decarbonization of the energy industry. *Economic Herald of State Higher Educational Institution "Ukrainian State University of Chemical Technology"*, Vol. 17 (1). pp. 27-35, http://dx.doi.org/10.32434/2415-3974
2. National plan to reduce emissions from large combustion plants. Order of the CMU from 08.11.2011 No. 796-p. Available online: https://zakon.rada.gov.ua/laws/show/796-2017-%D1%80#Text
3. On the approval of the Updated Nationally Determined Contribution of Ukraine to the Paris Agreement. Order of the CMU from 30.07.2021 No. 868-p. Available online: https://zakon.rada.gov.ua/laws/show/868-2021-%D1%80#Text
4. About the National Energy and Climate Change Plan for the period up to 2030. Order of the CMU from 29.12.2021 No. 1803-p. Available online: https://zakon.rada.gov.ua/laws/show/1803-2021-%D1%80#Text
5. Strategy for environmental security and adaptation to climate change for the period up to 2030. Order of the CMU from 20.10.2021 No. 1363-p. Available online: https://zakon.rada.gov.ua/laws/show/1363-2021-%D1%80#Text
6. Operational plan for the implementation in 2022-2024 of the Strategy for Environmental Security and Adaptation to Climate Change for the period up to 2030. Order of the CMU from 20.10.2021. No. 1363-p. Available online: https://zakon.rada.gov.ua/laws/show/1363-2021-%D1%80#Text
7. Omelchenko, V., Chekunova, S., Bilyavskyi, M., Khytryk, T., Konechenkov, A., Mishchenko, M., and Doborovolskyi, D. (2022). *Decarbonization of Ukrainian Energy (Economics): The Impact of Russian Aggression, Ambitious Goals, and Potential Opportunities for Ukraine in the Postwar Years.* Razumkov Center, Kyiv, Ukraine.
8. Report "Economically justified approach to the introduction of the National plan for reducing emissions in Ukraine based on the experience of reducing emissions of harmful pollutants into the air by large incineration plants in Europe" (2020). *IEPr of NASU*. Available online: https://vse.energy/docs/Report_NP%20.pdf
9. Vlasenko, Yu. (2023). 5 GW of generation in the Ukrainian energy system remain damaged as a result of russian missile attacks – information from the First Deputy Minister of Energy. Available online: https://interfax.com.ua/news/economic/899696.html
10. Still time to reverse damage to 'ravaged' ecosystems, declares UN chief, marking World Environment Day (2021). Available online: https://news.un.org/en/story/2021/06/1093382
11. Dvigun, A., Datsii, O., Levchenko, N., Shyshkanova, G., Platonov, O., and Zalizniuk, V. (2022). Increasing ambition to reduce the carbon trace of multimodal transportation in the conditions of Ukraine's economy transformation towards climate neutrality. *Science and Innovation*, Vol. 18 (1), pp. 96-111, https://doi.org/10.15407/scine18.01.096
12. Arroyo, F. R. M., Miguel, L. J. (2020). Low-carbon energy governance: Scenarios to accelerate the change in the energy Matrix in Ecuador. *Energies*, Vol. 13(18), 4731, https://doi.org/10.3390/en13184731
13. Madaleno, M., Nogueira, M.C. (2023) How renewable energy and CO_2 emissions contribute to economic growth, and sustainability – An extensive analysis. *Sustainability*, Vol. 15, pp. 33-47, https://doi.org/10.3390/su15054089
14. Zhang, H., Chen, H. H., Lao, K., Ren, Z. (2022). The Impacts of resource endowment, and environmental regulations on sustainability – Empirical evidence based on data from renewable energy enterprises. *Energies*, Vol. 15, 4678, https://doi.org/10.3390/en15134678
15. Li, Z., Shen, T., Yin, Y., and Chen, H. H. (2022). Innovation input, climate change, and energy-environment-growth nexus: evidence from OECD and Non-OECD countries. *Energies*, Vol. 15(23), 8927, https://doi.org/10.3390/en15238927
16. Ahmed Z., Cary, M., Shahbaz, M., Vo, X. V. (2021). Asymmetric nexus between economic policy uncertainty, renewable energy technology budgets, and environmental sustainability: Evidence from the United States. *Journal of Cleaner Production*, Vol. 313, 127723, https://doi.org/10.1016/j.jclepro.2021.127723
17. Papadis, E., Tsatsaronis, G. (2020). Challenges in the decarbonization of the energy sector. *Energy*, Vol. 205, 118025, https://doi.org/10.1016/j.energy.2020.118025

18. Fan, X., Ji, W., Guo, L., Gao, Z., Chen, L., Wang, J. (2023). Thermo-economic analysis of the integrated system of thermal power plant and liquid air energy storage. *Journal of Energy Storage*, Vol. 57, 106233, https://doi.org/10.1016/j.est.2022.106233
19. Hayuduky, I. P. (2017). Low-carbon development: global motivation tools. *Investments: Practice and Experience*, Vol. 2, pp. 22-26.
20. Nitlarp, T., Kiattisin, S. (2022). The impact factors of Industry 4.0 on ESG in the energy sector. *Sustainability*, Vol. 14(15), 9198, https://doi.org/10.3390/su14159198
21. Polyakova, K. (2023). Green energy: Action plan for 2023. *Economic Truth*. Available online: https://www.epravda.com.ua/columns/2023/01/24/696297
22. Hurduzeu, G., Noja, G. G., Cristea, M., Drăcea, R. M., Filip, R. I. (2022). Revisiting the impact of ESG practices on firm financial performance in the energy sector: new empirical evidence. *Economic Computation & Economic Cybernetics Studies & Research*, Vol. 56(4), pp. 37-53, http://dx.doi.org/10.24818/18423264/56.4.22.03
23. Kharisova, A. Z., Shvayko, I. V., Shalina, O. I., Ostryakova, A. F., Singizov, I. Y. (2022). *Ensuring economic security by modifying renewable energy systems*. *In: Popkova, E.G., Sergi, B.S. (eds) Geo-Economy of the Future*. *Springer, Cham, Switzerland*, pp. 851-858, https://doi.org/10.1007/978-3-030-92303-7_88
24. Borysiak, O. V. (2022). Innovative potential of energy enterprises and critical climate technologies within war conditions. *Innovative Economy*, Vol. 2-3, pp. 25-28, https://doi.org/10.37332/2309-1533.2022.2-3.4
25. Belousova, K. (2022). Ukraine to replace green tariff with a new Net billing model. Available online: https://ecopolitic.com.ua/ua/news/v-ukraini-hochut-zaminiti-zelenij-tarif-na-novu-model-net-billing-shho-zminitsya/
26. A European Green Deal, striving to be the first climate-neutral continent. *European Commission*. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
27. On Approval of the Regulation on Imposition of Special Duties on the Transmission System Operator to Ensure the Public Interests in the Process of Functioning of the Electric Energy Market. The CMU Resolution 838-2022-p of 22.07.2022. Available online: https://zakon.rada.gov.ua/laws/show/838-2022-%D0%BF#Text
28. Levchenko, S. (2022). Toolkit for providing economic and safe future of energy enterprises. *Economic Herald of State Higher Educational Institution "Ukrainian State University of Chemical Technology"*, Vol. 16(2), pp. 30-38, https://dx.doi.org/10.32434/2415-3974-2022-16-2-30-38
29. Vlasenko, Yu. (2022). How to provide 25% of energy from RES without support from the budget. *Economic Truth*. Available online: https://www.epravda.com.ua/columns/2022/07/25/689577
30. Reporting of DTEK financial and non-financial results 2012-2020. Available online: https://dtek.com/investors_and_partners/reports
31. Financial statement DTEK 2021. Available online: https://energo.dtek.com/en/ir/financial-statements-2021
32. Sustainable Development DTEK. Available online: https://dtek.com/sustainable_development/reportsesg
33. Tapio, P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*. Vol. 12, pp. 137-151, https://doi.org/10.1016/j.tranpol.2005.01.001
34. Mensah, C. N., Long, X., Boamah, K. B., Bediako, I. A., Dauda, L., Salman, M. (2018). The effect of innovation on CO_2 emissions of OECD countries from 1990 to 2014. *Environmental Science Pollution Research*, Vol. 25, pp. 29678-29698, https://doi.org/10.1007/s11356-018-2968-0
35. Greene, W. H. (2018). *Econometric Analysis*. Pearson, New York, USA
36. Pal, M., Bharati, P. (2019). *Applications of Regression Techniques*. Springer Nature, Singapore, https://doi.org/10.1007/978-981-13-9314-3