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UKRAINE'S OPPORTUNITIES FOR IMPLEMENTING A SUSTAINABLE DEVELOPMENT PROGRAM: ENVIRONMENTAL ASPECTS AND THE IMPACT OF INNOVATIVE ENERGY TECHNOLOGIES

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INTRODUCTION

Sustainable development is a concept designed to ensure a balance between economic growth, social justice and environmental sustainability[1]. In the face of global challenges such as climate change, depletion of natural resources and environmental pollution, the implementation of the principles of sustainable development becomes not just desirable, but a necessary condition for ensuring the long-term well-being of society. For Ukraine, which is facing unprecedented challenges of post-war reconstruction, the task of implementing a sustainable development program is of particular importance. The energy sector, which is one of the key drivers of the economy and at the same time a source of significant environmental burden, requires a deep transformation based on innovative technologies and approaches.

1. Economic and environmental aspects of implementing the principles of sustainable development in Ukraine

The environmental situation in Ukraine is characterized by a number of problems that reflect the unsustainable nature of previous development. Ukraine currently has significant potential for implementing the principles of sustainable development[2], despite the complex challenges it faces. Let us analyze Ukraine's main opportunities for implementing the principles of sustainable development.

Let us analyze the economic opportunities for implementing the principles of sustainable development in Ukraine. Ukraine has rich natural resources, in particular, fertile lands, which create the basis for sustainable agriculture. It should be noted that Ukraine has significant potential for the development of renewable energy sources (in particular, solar, wind and bioenergy). Recently, there has been significant development of the IT sector

[1] Support Sustainable Development and Climate Action. URL: https://www.un.org/en/our-work/support-sustainable-development-and-climate-action

[2] Transforming our world: the 2030 Agenda for Sustainable Development. URL: https://www.undp.org/ukraine/publications/transforming-our-world-2030-agenda-sustainable-development

and innovative technologies that contribute to the digitalization of the economy. The possibility of modernizing industrial infrastructure according to the principles of resource efficiency is also important.

This study is necessary to analyze Ukraine's environmental capabilities to implement the principles of sustainable development. This includes, in particular, the introduction of modern technologies for water and air purification, the expansion of protected areas and the preservation of biodiversity. Ukraine's potential for the development of a circular economy and waste management, and the possibility of integrating EU environmental standards into national legislation are significant.

Ukraine's social capabilities for implementing the principles of sustainable development are important. These include the development of inclusive education and raising the population's environmental awareness, strengthening the role of civil society in decision-making, the need to reform the healthcare and social protection systems, and decentralization, which provides more opportunities for local sustainable development initiatives.

Ukraine's institutional capabilities for implementing the principles of sustainable development should include adapting national legislation to the UN Sustainable Development Goals, expanding cooperation with international organizations and donors on sustainable development issues, European integration as an incentive for the implementation of sustainable development standards, and developing comprehensive national and regional sustainable development strategies.

Ukraine is taking gradual steps to form a regulatory framework to ensure sustainable development:

– Sustainable Development Strategy "Ukraine-2030";
– National Economic Strategy for the period until 2030;
– Energy Strategy of Ukraine for the period until 2035;
– Low-carbon Development Strategy until 2050;
– National Action Plan on Energy Efficiency;
– National Action Plan on Renewable Energy;
– Concept for the Implementation of State Policy in the Field of Climate Change for the Period Until 2030.

However, despite the presence of strategic documents, their implementation remains insufficiently effective due to limited funding, political instability, and low priority given to environmental issues.

To effectively implement the Sustainable Development Agenda, Ukraine needs to strengthen coordination between different sectors of the economy, involve the private sector in financing sustainable development projects, and ensure monitoring of progress in achieving goals.

Let's analyze the main environmental goals of sustainable development for Ukraine[3]. In this aspect, the key environmental goals of sustainable development in Ukraine are:

– climate change mitigation and adaptation. In particular, this is a 40% reduction in greenhouse gas emissions by 2030 (from 1990 levels), the implementation of a national plan for adaptation to climate change and the development of regional climate resilience strategies;

– transition to clean energy and the implementation of energy efficiency principles. In particular, this is an increase in the share of renewable energy sources to 25% in the country's energy balance, an increase in energy efficiency by 30% by 2030, modernization of energy infrastructure to reduce energy and resource losses;

– biodiversity conservation. In particular, expanding the area of the nature reserve fund to 15% of the country's territory; restoring degraded ecosystems, especially forests and wetlands; protecting rare and endangered species of flora and fauna;

– water resources protection. This includes achieving an appropriate ecological state of river basins, reducing pollution of groundwater and surface waters, and implementing integrated water resources management;

– rational use of natural resources. This includes implementing the principles of a circular economy, reducing the resource intensity of production, and encouraging environmentally responsible business;

– waste management. This includes reducing waste landfilling by 50% by 2030, increasing waste recycling to 65%, and developing infrastructure for separate collection and recycling;

– Sustainable urban development. This includes reducing air pollution in urban agglomerations, expanding green areas in cities, and introducing environmentally friendly transport.

Separately, it is necessary to analyze the existing challenges and opportunities for implementing the principles of sustainable development in Ukraine. Currently, Ukraine has significant potential to achieve environmental goals of sustainable development, but it faces certain challenges. These are, first of all, the need for significant investments in green infrastructure, the need to improve environmental legislation and the importance of raising environmental awareness and ensuring appropriate education of the population. Ukraine's opportunities for progress in implementing the principles of sustainable development include international

[3] Ostapenko Olga. Estimation of tendencies of transforming the energy sectors of World, European Union and Ukraine in the perspective to 2050 with using the renewable energy sources in the concept of Sustainable Development. In: *Social capital: Vectors of development of behavioral economics*: Collective monograph, pp. 99 – 139. ACCESS Press Publishing house. Veliko Tarnovo, Bulgaria (2021)

cooperation and access to green finance, integration of EU environmental standards, development of green technologies and innovations, and the need to involve civil society in monitoring the environmental situation.

Achieving the environmental goals of sustainable development will allow Ukraine to provide a clean and safe environment for future generations and strengthen the competitiveness of the economy at the global level.

Green Deal in Ukraine – let's analyze its essence and possibilities of integration with the European Green Deal. The Green Deal of Ukraine is a comprehensive approach to the greening of the economy and society, which is largely based on the principles of the European Green Deal[4]. Currently, for Ukraine, the Green Deal is not only an environmental initiative, but also an important component of European integration.

Ukraine's energy sector is one of the largest sources of environmental pollution. The key elements of the Green Deal are: decarbonization of the economy and energy sector, development of a circular economy, combating environmental pollution, preserving biodiversity, and promoting sustainable agriculture.

The strategic directions for the development of the Green Deal in Ukraine are as follows:

– energy transformation, which involves increasing the share of renewable energy sources, abandoning coal generation in the long term, modernizing energy infrastructure and developing smart energy networks;

– industrial greening, which involves introducing clean production technologies, modernizing industrial enterprises, developing resource-efficient production and reducing industrial emissions[5];

– development of green transport. This should include stimulating electromobility, developing infrastructure for electric transport, developing public transport and creating cycling infrastructure in cities;

– sustainable resource management. It is necessary to ensure the implementation of a waste management system, stimulating recycling and reuse, reducing plastic consumption and rational use of water resources[6].

The challenges for implementing the Green Deal in Ukraine are high initial investment costs, the need for significant modernization of outdated infrastructure, socio-economic challenges for coal regions, insufficient level of environmental awareness of citizens, and limited access to financing for green projects.

[4] A European Green Deal. Striving to be the first climate-neutral continent. URL: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/ european-green-deal_en.

[5] Net Zero by 2050. IEA, Paris. URL: https://www.iea.org/reports/net-zero-by-2050.

[6] Zero waste. URL: https://zerowaste.org.ua.

The following prospects and opportunities for implementing the Green Deal in Ukraine can be formulated, namely:

– access to international green finance and EU funds;

– creation of new jobs in green sectors;

– significant potential for the development of green innovations and technologies;

– increasing the state's energy security through diversification of sources;

– improving the quality of life of citizens through environmental improvement.

It should be noted that Ukraine's Green Deal has the potential to become a catalyst for economic and social transformation, but its successful implementation requires coordinated efforts by the state, business, civil society, and international partners.

Decarbonization in Ukraine: Current Status and Challenges. Ukraine is currently facing the difficult task of decarbonizing its economy, which has historically been characterized by high carbon intensity. Despite a significant reduction in greenhouse gas emissions since 1990 (by more than 60%), this has occurred mainly due to the economic downturn, rather than targeted policies.

The main challenges for decarbonizing Ukraine's industry are as follows: high energy intensity of the economy (2-3 times higher than the EU average); outdated energy and industrial infrastructure; significant dependence on fossil fuels; low energy efficiency of buildings and industry; and limited financing for the green transition.

The following strategic directions of decarbonization in Ukraine should be highlighted:

– transformation of the energy sector, which will involve the development of renewable energy sources (solar, wind, bioenergy), a gradual transition from coal generation, modernization of power grids and the development of energy storage systems;

– increasing energy efficiency. This direction can be ensured through thermal modernization of the housing stock, the introduction of energy-efficient technologies in industry, optimization of urban heat supply systems and stimulation of energy saving at the level of individual households;

– development of low-carbon transport. This direction is ensured by electrification of public transport, stimulation of the development of electromobility, optimization of freight transportation and development of railway transport;

– implementation of the principles of circular economy and waste management. In particular, here it is necessary to consider the implementation of waste management systems, the development of the

processing industry, stimulation of resource reuse and provision for landfill gas utilization.

Decarbonization policy and regulation in Ukraine will be ensured by Ukraine's Nationally Determined Contribution (NDC) to the Paris Agreement, which provides for a reduction in greenhouse gas emissions of up to 65% from 1990 levels by 2030; integration of the requirements of the European Green Deal into national legislation; development and implementation of a carbon pricing mechanism; creation of a system for monitoring, reporting and verification of greenhouse gas emissions.

The following should be assessed as promising opportunities for ensuring the decarbonization of the economy and energy production in Ukraine:

– harnessing the potential of "green" hydrogen;

– developing smart energy networks;

– using natural solutions for carbon absorption (reforestation);

– attracting green investments and financing;

– developing sustainable agriculture.

Successful decarbonization of Ukraine requires a systematic approach, significant investments and a coordinated policy. This is not only an environmental imperative, but also an economic necessity to ensure the country's competitiveness in the context of the global green transition.

The green transition in Ukraine involves a gradual transformation of the economy towards environmentally sustainable, resource-efficient and low-carbon development. This process covers all sectors of the economy and society and is an integral part of Ukraine's European integration.

The key areas of the Green Transition in Ukraine are:

– energy transformation, which includes increasing renewable energy capacity (solar, wind, bioenergy), increasing energy efficiency in all sectors, modernizing energy infrastructure, developing energy storage systems and smart grids, and gradually phasing out coal and transitioning to carbon-neutral energy sources;

– industrial greening, i.e. introducing clean production technologies, reducing the resource intensity of industry, developing eco-innovations and green technologies, and applying the principles of industrial symbiosis and the circular economy;

– sustainable transport. This direction involves the development of electromobility and related infrastructure, the modernization of public transport, the stimulation of the use of bicycles, the optimization of logistics chains;

– sustainable urban development. This includes, in particular, energy-efficient modernization of buildings, the expansion of green areas in cities, the implementation of the concept of smart cities and the development of sustainable urban planning;

– sustainable agro-industrial complex, which involves the development of organic farming, the implementation of agro-ecological practices, increasing the efficiency of water use and reducing emissions in the agricultural sector.

The tools for implementing the Green Transition in Ukraine are:

– legislative regulation: harmonization with EU standards, introduction of carbon pricing mechanisms;

– economic incentives: green tariffs, tax breaks, environmental subsidies;

– financing: green bonds, international funds, private investments;

– education and information: raising environmental awareness, training specialists for the green economy.

Let's analyze the challenges and prospects of the Green Transition in Ukraine. The challenges include high initial investment costs; socio-economic problems of regions dependent on traditional industries; insufficient level of technological development; institutional barriers and imperfect legislation.

The following prospects for the Green Transition of Ukraine can be identified: creation of new jobs in green sectors of the economy, increasing the state's energy security and reducing dependence on imported energy resources, improving the quality of the environment and public health, and strengthening the competitiveness of the Ukrainian economy in international markets.

A successful green transition in Ukraine requires a systemic approach, political will, significant investments and active participation of all stakeholders – government, business, civil society and international partners.

Let’s analyze the environmental threats in Ukraine. The key environmental problems in Ukraine are:

– air pollution. Here we should consider the high level of industrial emissions, especially in industrial regions; significant pollution from coal-fired thermal power plants; increasing emissions from road transport in urban agglomerations; transboundary air pollution;

– water resources. Pollution of rivers and groundwater by industrial effluents; eutrophication of water bodies due to excessive use of fertilizers; unsatisfactory condition of water supply and drainage systems; drying up of small rivers and degradation of wetlands;

– land use problems. Soil degradation and the spread of erosion processes, land pollution with heavy metals and pesticides, irrational use of agricultural land, reduction of forest cover and illegal logging;

– waste. Accumulation of industrial and domestic waste, insufficient level of waste processing and disposal, the problem of unauthorized landfills, accumulation of hazardous waste, including radioactive waste;

– loss of biodiversity. Reduction of the ranges of rare species of flora and fauna, fragmentation of natural ecosystems, spread of invasive species, insufficient level of nature conservation areas.

In the conditions of war, Ukraine has faced new environmental challenges. These include, in particular, climate change (an increase in the average annual temperature, an increase in the frequency and intensity of extreme weather events, changes in the amount and distribution of precipitation, drought and desertification in the southern regions), military-ecological threats (pollution of territories as a result of hostilities, destruction of critical infrastructure with environmental consequences, risks of man-made disasters at industrial facilities and mine contamination of land); man-made risks (worn-out industrial infrastructure, risks of accidents at chemical plants, insufficient control over hazardous facilities, potential threats from waste accumulation facilities); institutional problems (imperfections of environmental legislation and mechanisms for its implementation, insufficient funding for environmental protection measures, weak monitoring of the state of the environment and a low level of environmental awareness and education of the population).

These environmental threats require a systematic approach to their solution, including strengthening environmental policy, introducing modern technologies, ecological modernization of the economy and active involvement of the public in environmental protection activities.

Let's analyze the environmental threats in the energy sector of Ukraine. Environmental threats from the thermal energy sector of Ukraine are significant. In particular, coal-fired generation creates significant emissions of greenhouse gases, especially CO_2, pollutes the air with sulfur and nitrogen oxides, generates significant volumes of ash and slag waste, pollutes soils and water resources with heavy metals, and thermal pollution of water bodies used for cooling occurs.

Combined heat and power plants (CHPs) are also powerful sources of pollutant emissions in populated areas due to the low energy efficiency of outdated equipment and significant atmospheric pollution when they operate on fuel oil or coal.

The risks of nuclear energy in Ukraine cannot be ignored, in particular, potential accidents at nuclear power plants, problems with the storage and disposal of radioactive waste, thermal pollution of cooling water reservoirs, outdated equipment at some power units, and the vulnerability of nuclear power plants to external threats and cyberattacks.

The problems of Ukraine's hydropower industry include changes in the hydrological regime of rivers, flooding of valuable lands by reservoirs, disruption of fish migration routes, eutrophication of reservoirs, and risks of flooding of coastal areas.

The environmental impact of the gas sector is methane emissions due to leaks in transportation systems, contamination of soils and groundwater during gas production, potential risks in hydraulic fracturing technology, and accidents at gas pipelines and gas distribution stations.

Infrastructure challenges in Ukraine's energy sector include a high level of wear and tear of energy infrastructure, significant losses in electrical and thermal networks, risks of accidents at substations and power lines, and soil contamination due to oil leaks from transformers.

Systemic problems of the Ukrainian energy sector include insufficient flexibility of the energy system for the integration of renewable sources, high level of energy intensity of the economy, dependence on energy imports, insufficient investments in environmental modernization of energy facilities, low level of implementation of carbon capture and storage technologies.

In connection with the above, the following ways to reduce environmental threats should be considered, namely: environmental modernization of thermal power plants, installation of modern emission treatment systems, diversification of the energy balance in favor of renewable sources, implementation of energy-efficient technologies and equipment, improvement of the environmental monitoring system of energy facilities, development of smart energy networks and stimulation of decarbonization of the energy sector.

Solving these environmental problems of the energy sector requires a comprehensive approach that combines technological modernization, improving the legislative framework and implementing the best available technologies, taking into account the economic capabilities of Ukraine.

New environmental threats have emerged in Ukraine in wartime conditions, directly related to the environmental consequences of hostilities. In particular, soil and water pollution has increased, heavy metal pollution from shells and ammunition has occurred, chemical pollution has occurred as a result of the destruction of infrastructure and the ingress of fuel and lubricants into the soil and water, and soil structure has been disrupted by explosions and equipment.

Atmospheric pollution has significantly increased. In particular, these include emissions of toxic substances during fires at industrial facilities, air pollution due to the burning of petroleum products, dust smog from the destruction of civilian and industrial buildings, and greenhouse gas emissions from large-scale fires.

Damage to ecosystems has significantly increased – the destruction of forests and nature reserves, the destruction of habitats for rare species of flora and fauna; mine contamination of territories, which makes their use impossible and disrupts the migration routes of birds and animals.

During the war, threats to critical infrastructure facilities in Ukraine have significantly increased. Risks in the energy sector have increased due to damage to nuclear power plants with the risk of radiation contamination, destruction of hydroelectric dams with the threat of flooding of territories, damage to thermal power plants with emissions of pollutants and disruption of network infrastructure systems. Threats to the chemical industry are tangible due to damage to chemical enterprises with the risk of toxic emissions, destruction of hazardous substance storage facilities, uncontrolled emissions of ammonia, chlorine and other hazardous compounds and pollution of water resources with chemicals.

Water supply and drainage problems have significantly increased due to the destruction of water supply systems and treatment facilities, contamination of drinking water sources, disruption of sewage systems and the risk of epidemics due to water contamination. As a result of the war, it is necessary to take into account the long-term environmental consequences associated with waste management, the accumulation of construction debris from destroyed facilities, problems with the disposal of military equipment and ammunition, disruption of household waste collection and processing systems, and the formation of unauthorized landfills. Problems with arable land have arisen that have a long-term perspective. These are the contamination of agricultural land, the impossibility of its cultivation due to mining, disruption of land reclamation systems, and a decrease in soil fertility. There are institutional problems associated with the weakening of the environmental monitoring system, a reduction in funding for environmental protection measures, the suspension of the implementation of environmental programs, and a decrease in the effectiveness of environmental control.

The following ways of overcoming environmental threats should be considered: creating a system of operational monitoring of the environmental consequences of the war, developing programs for the ecological restoration of the affected territories, attracting international assistance to solve environmental problems, introducing the latest technologies for cleaning up contaminated territories, and integrating ecological restoration into general plans for post-war reconstruction.

The war creates unprecedented environmental threats for Ukraine, which will require significant resources and efforts to overcome both during the war and in the post-war period.

2. The impact of innovative energy technologies in the context of implementing the principles of sustainable development in Ukraine

Innovative energy technologies play a key role in implementing the principles of sustainable development in Ukraine. Let's analyze the main aspects of this impact[7].

Ukraine's energy sector is characterized by significant dependence on fossil fuels, outdated infrastructure, and high energy intensity of the economy. These factors create significant challenges for the country's sustainable development, including: significant greenhouse gas emissions, energy dependence, significant losses in energy generation and transportation, and economic costs of energy imports. The introduction of innovative energy technologies can significantly transform Ukraine's energy sector and contribute to achieving sustainable development goals[8]. This will be facilitated by renewable energy sources (solar energy, wind energy, bioenergy, and small-scale hydropower), energy-efficient technologies (smart grids, energy storage systems, energy-efficient buildings and industrial processes, cogeneration and trigeneration), and decarbonization of transport (electric vehicles and charging infrastructure, hydrogen technologies, and electrification of public transport)[9].

The introduction of innovative energy technologies creates significant economic and social benefits: creating new jobs, reducing energy dependence, increasing the competitiveness of the economy, improving the quality of life of the population and developing local communities.

Despite the significant potential for the introduction of innovative energy technologies, there are significant challenges on the way to their implementation. These include, in particular, the need for significant investments, regulatory barriers, technological limitations, lack of qualified personnel, and social resistance to change.

To maximize the positive impact of innovative energy technologies on the sustainable development of Ukraine, it would be advisable to develop a

[7] Ostapenko O, Alina G, Serikova M, Popp L, Kurbatova T and Bashu Z. (2023) Towards Overcoming Energy Crisis and Energy Transition Acceleration: Evaluation of Economic and Environmental Perspectives of Renewable Energy Development. In: Koval V, Olczak P (eds) *Circular Economy for Renewable Energy. Green Energy and Technology*. Cham: Springer,. https://doi.org/10.1007/978-3-031-30800-0_7

[8] Ostapenko, O., Savina, N., Mamatova, L., Zienina-Bilichenko, A. & Selezneva, O. Perspectives of application of innovative resource-saving technologies in the concepts of green logistics and sustainable development. Turismo: Estudos &Práticas (UERN), Mossoró/RN, Caderno Suplementar, 02. (2020) URL: http://geplat.com/rtep/index.php/tourism/article/view/488.

[9] Ostapenko, O., Olczak, P., Koval, V., Hren, L., Matuszewska, D., Postupna, O. Application of Geoinformation Systems for Assessment of Effective Integration of Renewable Energy Technologies in the Energy Sector of Ukraine. Appl. Sci., 12, 592 (2022). https://doi.org/10.3390/app12020592

comprehensive energy transition strategy, improve the legislative framework and create attractive investment conditions, invest in research and development, develop educational programs for training specialists, introduce mechanisms to stimulate energy efficiency, support local energy initiatives and strengthen international cooperation.

Innovative energy technologies are a key tool for ensuring the sustainable development of Ukraine, allowing to simultaneously achieve economic, social and environmental goals.

3. Analysis of the status of heat pump implementation in Ukraine in the context of sustainable development

The introduction of heat pumps in Ukraine is showing gradual positive dynamics, although compared to European countries, the penetration level of this technology remains quite low. As of 2024, the following key aspects of the introduction of heat pumps in Ukraine can be distinguished:

– heat pump installations prevail in the private sector – especially in new buildings in the middle and premium segments;

– interest in heat pumps in the commercial sector (hotels, shopping centers, office premises) is gradually growing;

– application in the multi-apartment residential sector is limited;

– the growth of the heat pump market accelerated in 2022-2023 due to the energy crisis and damage to the energy infrastructure.

By pump type, the largest market share in Ukraine is occupied by: air heat pumps (air-to-water and air-to-air) – about 75% of the market; ground-source heat pumps – about 20% of the market; water heat pumps – about 5% of the market.

Factors that will contribute to the development of the heat pump market in Ukraine in the short term:

1. Energy security – the need to reduce dependence on imported energy sources;

2. Decarbonization course – Ukraine's commitment to reducing greenhouse gas emissions;

3. State support programs – "Energodim" programs, "warm credits" and regional initiatives;

4. High prices for traditional energy carriers – rising gas and electricity tariffs;

5. International support – grants and technical assistance from international organizations.

Barriers that arise in the way of mass implementation of heat pumps in Ukraine:

1. High initial cost – investment costs are 2-4 times higher compared to traditional heating systems;

2. Limited awareness – consumers are not sufficiently informed about the benefits of heat pumps;

3. Insufficient number of qualified specialists – lack of design and installation specialists;

4. Regulatory barriers – complex procedures for obtaining permits for the implementation of geothermal heat pumps;

5. Problems with electricity networks – the need to modernize networks to accommodate additional load;

6. War and economic instability – limited financial opportunities for long-term investments.

Heat pumps contribute to achieving sustainable development goals in Ukraine in the following areas: environmental aspects (reduction of CO_2 emissions (by 50-80% compared to gas boilers), absence of local emissions of pollutants, reduction of the use of exhaustible resources), economic aspects (reduction of operating costs (savings of 30-60% compared to gas heating), development of local production and services, reduction of energy imports), social aspects (increased comfort (possibility of cooling premises in summer), creation of new jobs, reduction of energy poverty (in the future)).

Based on current trends, the following areas of development of heat pump implementation in Ukraine can be predicted:

1. Growing demand for hybrid systems – a combination of heat pumps with other energy sources;

2. Development of industrial applications – introduction of high-temperature heat pumps in production processes;

3. Integration with smart energy systems – heat pumps as an element of the Smart Grid;

4. Increasing the share of heat pumps in district heating systems;

5. Development of local production of components – localization of production to reduce costs.

To accelerate the introduction of heat pumps in Ukraine, the following recommendations can be offered:

1. Improving financial support mechanisms – expanding co-financing and preferential lending programs;

2. Development of competencies – creating educational programs for training specialists;

3. Information campaigns – raising public awareness of the benefits of heat pumps;

4. Regulatory changes – simplifying the procedures for obtaining permits and connecting to networks;

5. Stimulating innovation – supporting research and development in the field of heat pumps;

6. Integration into the post-war reconstruction strategy – including heat pumps as a priority technology for the restoration of energy infrastructure.

The introduction of heat pumps has significant potential for transforming Ukraine's energy sector and promoting sustainable development, but realizing this potential requires systemic measures at all levels.

4. Environmental aspects of implementing innovative technologies in the heat and power industry

The environmental challenges of traditional heat power in Ukraine are significant. Traditional heat power in Ukraine, which is based mainly on the combustion of fossil fuels, creates a significant burden on the environment through greenhouse gas emissions (boiler plants and CHPs running on fossil fuels are a significant source of CO_2), air pollution (emissions of nitrogen oxides, sulfur, particulate matter and other pollutants), thermal pollution of water bodies (due to the use of water for cooling), the formation of ash and slag waste (especially when using coal), the impact on landscapes and biodiversity (during fuel extraction and construction of facilities).

Ukraine has significant potential for implementing a sustainable development program through the introduction of innovative energy technologies. The environmental aspects of the energy transition are critical for ensuring long-term sustainability and quality of life. The introduction of innovative energy technologies in Ukraine will have a number of environmental benefits. In particular, when implementing heat pumps, the environmental benefits are the absence of direct emissions of pollutants at the place of operation, a reduction in greenhouse gas emissions by 50-80% compared to gas boilers, the absence of risks of fuel spills and fires and minimal impact on local ecosystems. When implementing biomass technologies, the following environmental benefits should be assessed: potential carbon neutrality with sustainable use of biomass, utilization of agricultural and forestry waste, reduction of methane emissions from biomass decomposition. However, the implementation of biomass technologies will also create a number of problems associated with the potential reduction of biodiversity with monoculture cultivation and emissions of particulate matter.

The introduction of solar thermal energy will also have a number of environmental advantages – the absence of harmful emissions during operation, minimal water consumption, insignificant impact on biodiversity with the correct placement of installations, long service life and the possibility of recycling components.

When introducing geothermal energy sources, the following environmental advantages should be assessed: minimal greenhouse gas emissions, stability of operation regardless of weather conditions. However,

the introduction of geothermal energy sources will also create a number of potential risks associated with the release of mineralized water and local seismic effects.

Cogeneration and trigeneration technologies also have a number of advantages that contribute to their implementation: increased fuel efficiency, reduced specific emissions per unit of energy produced and reduced thermal pollution.

Promising innovative technologies in the energy sector are new generation district heating systems, which provide for the integration of low-temperature heat sources and renewable energy, reduce transportation losses and enable the utilization of excess heat from industrial processes.

To assess the environmental impact of innovative energy technologies, the implementation of heat pumps should also assess the life cycle and ecological footprint. When assessing the environmental impact of innovative technologies, it is important to consider the full life cycle, which includes: equipment production (mining of rare metals for heat pumps and electronics, energy intensity of component production, emissions during transportation), operation (direct and indirect emissions of pollutants, water consumption, impact on local ecosystems), end of life cycle (possibility of recycling components, potential pollution during disposal, restoration of territories).

To assess the effect of the implementation of innovative energy technologies, integrated environmental effects are also considered. Thus, the implementation of innovative technologies in the thermal power industry has a complex impact on ecosystems: improving air quality (reducing the incidence of respiratory and cardiovascular diseases), reducing acid rain (due to reducing emissions of sulfur and nitrogen oxides), preserving water resources (reducing water consumption and thermal pollution of water bodies), reducing landfill areas (reducing the volume of ash and slag waste), mitigating climate change (reducing greenhouse gas emissions).

During the implementation of innovative energy technologies, environmental challenges of the transition period will arise, namely: disposal of obsolete equipment (the need for safe disposal of boilers, heating mains and other equipment), land reclamation (land restoration after the closure of boiler houses and CHPs), refrigerant management (the need for safe systems to prevent refrigerant leaks from heat pumps), sustainable development of biomass (avoiding soil depletion and preserving biodiversity), balanced use of geothermal resources (preventing reservoir depletion).

Various methods have been developed to assess the environmental impact of innovative technologies. The following are used for a comprehensive assessment of the environmental impact of innovative technologies in the heat and power industry:

– Life Cycle Assessment (LCA) – analysis of impacts at all stages from production to disposal;

– Carbon Footprint – assessment of direct and indirect greenhouse gas emissions;

– Water Footprint – analysis of water resource consumption and pollution;

– Ecological Footprint – comprehensive assessment of impacts on ecosystems.

Effective environmental policy and regulation are key to minimizing negative impacts. This should include:

1. Setting strict environmental standards – for all heat generation technologies;

2. Implementing the polluter pays principle – economic mechanisms for internalizing environmental costs;

3. Environmental certification of equipment – to ensure compliance with environmental requirements;

4. Monitoring and reporting – systems for monitoring environmental performance;

5. Stimulating environmental innovations – supporting the development of more environmentally friendly technologies.

The following prospects for further reducing the environmental impact of heat pumps should be assessed:

1. Integration with "green" electricity – powering heat pumps from renewable energy sources;

2. Development of carbon capture and storage (CCS) technologies – for biomass and other installations;

3. Introduction of chlorine-free refrigerants – to reduce the global warming potential;

4. Development of more efficient thermal insulation materials – to reduce heat losses;

5. Creation of closed resource use cycles – to minimize waste.

The introduction of innovative technologies in the heat and power industry has significant potential to reduce the environmental load and promote sustainable development, but requires an integrated approach taking into account all stages of the life cycle and possible environmental consequences.

5. The UBP method (Umweltbelastungspunkte or Environmental Impact Points)

UBP (Umweltbelastungspunkte) [10] – is a Swiss method of environmental impact assessment, also known as the Environmental Impact Points method. This method is a comprehensive tool for assessing various environmental impacts and is one of the most developed environmental assessment methods in the world. The UBP method is based on the distance-to-target principle, which assesses environmental impact depending on how much it exceeds established environmental goals or standards. The main characteristics of the UBP method:

– single scale – all environmental impacts are converted into a single dimensionless value (ecopoints);

– aggregation – the ability to sum up different types of impacts;

– normalization – correlation with defined environmental goals;

– weighting – taking into account the relative importance of different environmental aspects.

UBP calculation methodology[11]. The UBP calculation includes the following steps:

1. Inventory – accounting for all material and energy flows in the system;

2. Classification – distribution of flows by impact categories;

3. Characterization – assessment of potential environmental impact for each category;

4. Normalization – comparison with environmental objectives or permissible levels of impact;

5. Weighting – assignment of weight coefficients to different impact categories;

6. Aggregation – summing up weighted values into a single indicator.

The formula for calculating UBP for a specific pollutant:

$$UBP = Em \cdot (F / Fk)^2 \cdot C \cdot Wf, \quad (1)$$

where: Em – quantity of pollutant emissions, F – actual pollutant flow, Fk – critical flow (target value), C – constant ensuring compliance with the scale, Wf – weighting factor.

UBP environmental impact categories. The UBP method covers a wide range of environmental impact categories, in particular, it takes into account:

– Climate change – greenhouse gas emissions;

[10] Umweltbelastungspunkte (UBP). URL: https://www.wecobis.de/service/lexikon/ubplex.html#:~:text=Die%20Ermittlung%20der%20Umweltbelastung%20erfolgt,Einwirkungen%20entsprechend%20ihrer%20Sch%C3%A4dlichkeit%20bestimmt

[11] Ökofaktoren Schweiz 2021 gemäss der Methode der ökologischen Knappheit. URL: https://www.bafu.admin.ch/bafu/de/home/themen/wirtschaft-konsum/publikationen-studien/publikationen/oekofaktoren-schweiz.html

– Ozone depletion – emissions of ozone-depleting substances;
– Acidification – emissions of acid-forming substances;
– Eutrophication – excessive enrichment of water bodies with nutrients;
– Photochemical smog – formation of ground-level ozone;
– Human toxicity – health effects of toxic substances;
– Ecotoxicity – effects on ecosystems;
– Resource depletion – use of non-renewable resources;
– Land use – effects on land use and biodiversity;
– Water use – consumption of water resources;
– Waste generation – generation of various types of waste;
– Noise pollution – effects of noise on people and ecosystems;
– Radiation effects – ionizing radiation.

Recently, the UBP method has been widely used in the thermal power industry. In the context of innovative technologies in heat power engineering, the UBP method allows:

1. Compare different technologies – a comprehensive assessment of the environmental impact of different heat generation systems;
2. Optimize systems – identifying "bottlenecks" from an environmental point of view;
3. Make informed decisions – a scientific basis for choosing the most environmentally friendly solutions;
4. Communicate results – presenting complex environmental impacts in a clear form;
5. Set goals – scientifically based definition of environmental goals.

An example of the application of the UBP method for different heat supply technologies is shown in Table 1.

The main advantages of the UBP method should be noted:
– comprehensiveness – includes a wide range of environmental impacts;
– relevance – based on current environmental goals and regulations;
– scientific validity – developed on the basis of scientific principles;
– transparency – clear calculation methodology;
– flexibility – the ability to adapt to different contexts;
– communicability – results are presented in a clear form.

It is also worth noting certain limitations of the UBP method:
– subjectivity of weighting – the determination of weighting factors involves subjective assessments;
– regional specificity – the method was developed mainly for the Swiss context;
– complexity of calculations – requires a significant amount of data;
– sensitivity to input data – results depend on the quality of the input data;
– uncertainty – does not always take into account uncertainty in the data and models.

Table 1

Example of application of the UBP method for different heat supply technologies

Technology	UBP (per kWh of thermal energy)	Main influencing factors
Gas boiler	240-300	CO_2, NOx emissions, resource depletion
Oil boiler	380-450	SO_2 emissions, heavy metals, CO_2
Coal boiler	550-650	Particulate emissions, SO_2, CO_2, waste
Electric boiler	50-650	Depends on electricity source
Heat pump*	30-200	Refrigerants, electricity consumption
Solar collector	20-40	Materials production, recycling
Biomass boiler	100-150	Particulate emissions, land resources

* *Values strongly depend on the structure of power generation*

A comparison of the UBP method and other well-known environmental assessment methods is shown in Table 2.

Prospects for development and adaptation in Ukraine. The UBP method has the potential for adaptation and application in the Ukrainian context, namely:

1. Adaptation to national environmental goals – revision of critical flows in accordance with Ukrainian standards;
2. Localization of weighting factors – consideration of environmental priorities specific to Ukraine;
3. Integration into environmental management systems – use as a decision-making tool;
4. Harmonization with European approaches – approximation to EU standards;
5. Use for eco-labeling – certification of products and technologies.

The UBP method is a powerful tool for comprehensively assessing the environmental impact of innovative technologies in the heat and power industry and contributes to the implementation of sustainable development principles through a well-founded choice of environmentally optimal solutions.

6. UBP (Environmental Load Points) method for evaluating heat pumps

Let us consider the features of the application of the UBP method for heat pumps. The UBP method provides a comprehensive approach to assessing the environmental impact of heat pumps, covering the entire life cycle from production to disposal. The use of this method allows you to obtain a single

aggregated indicator of environmental load, which simplifies comparison with alternative heat supply technologies.

Table 2

Comparison of the UBP method and other known environmental assessment methods

Method	Features	Comparison with UBP
Ecological Footprint	Area-based assessment	Less detailed, focus on resources
Carbon Footprint	Focus only on greenhouse gases	Narrower approach, does not consider other impacts
Life Cycle Assessment (LCA)	Detailed analysis of all stages	UBP can be used as an impact assessment method in LCA
ReCiPe	Similar aggregated method	Different weighting approaches
IMPACT 2002+	Focus on health and ecosystem damage	Different aggregation methodology

The main key stages of the life cycle when assessing the environmental impact of heat pumps:

– component production (evaluates raw material extraction (copper, aluminum, steel, rare metals), energy consumption during production, pollutant emissions, water and land use);

– transportation and installation (evaluates emissions during transportation, energy consumption during installation, materials for installation work);

– operation (evaluates electricity consumption, potential refrigerant leaks, maintenance and repair);

– disposal (evaluates recycling of components, disposal of refrigerants, waste disposal).

Let us analyze the impact categories in the UBP method and their significance for heat pumps. When applying the UBP method for heat pumps, special attention is paid to the main impact categories, the characteristics of which are given in Table 3.

Let us demonstrate the calculation of UBP for heat pumps of different types. Let us take air heat pumps (air-to-air, air-to-water) as an example. Then the total UBP indicator is determined as the sum of all UBP indicators for different stages of the heat pump life cycle:

$$\text{UBP (total)} = \text{UBP (production)} + \text{UBP (transportation)} + \quad (2)$$
$$+ \text{UBP (operation)} + \text{UBP (disposal)}.$$

Here are typical UBP values for different stages of the heat pump life cycle for air source heat pumps (per kWh of heat produced):

– production: 15-25 UBP;
– transportation and installation: 2-5 UBP;
– operation: depends on the electricity source (20-150 UBP);
– disposal: 3-8 UBP.

Ground source heat pumps, in environmental assessment compared to air-source ones, have an additional burden due to drilling wells or excavation work for collectors, production of additional components (pipes, coolant), and a longer service life (positive impact on LCA).

Here are typical UBP values for different stages of the heat pump life cycle for ground source heat pumps (per kWh of heat produced):

– production of the entire system: 25-40 UBP;
– operation: UBP is 15-30% lower than for air source heat pumps due to the higher COP (coefficient of performance).

Table 3

Characteristics of impact categories in the UBP method and their significance for heat pumps

Impact category	Significance for heat pumps	Key factors
Climate change	High	Emissions from electricity generation, global warming potential of refrigerants
Ozone depletion	Medium-high	Refrigerant leaks (depending on type)
Resource depletion	Medium	Use of copper, aluminum, rare metals
Acidification	Low-medium	SOx, NOx emissions from electricity generation
Eutrophication	Low	Emissions from component production
Toxicity	Medium	Materials and chemicals in the production process
Water use	Low-medium	Cooling in production, drilling wells for geothermal systems
Land use	Low (air), Medium (soil)	Installation area, excavation for ground collectors

Water source heat pumps have intermediate values between air source and ground source heat pumps in terms of UBP, but with additional load due to water intake and drainage and potential thermal impact on water bodies.

Let us present the results of the comparative overall environmental impact of different heating systems using the UBP method, the results are given in Table 4.

Table 4 shows that, according to UBP, the most environmentally friendly innovative energy technologies are the use of thermal power plants with electricity consumption from renewable energy sources and the use of solar collectors.

The key factors that most determine the UBP level of heat pumps are the following:

1. Electricity source, as the electricity generation structure has the greatest impact on the overall UBP of heat pumps. The impact factor values on UBP from the electricity generation source are shown in Table 5.

Table 4

Comparison of the overall environmental impact of different heating systems (UBP per kWh of heat)

Technology	UBP Range	Notes
Gas condensing boiler	240-300	High contribution from CO_2 emissions
Heat pump (electricity from renewable energy sources)	30-80	Lowest impact when powered by renewables
Heat pump (average energy mix of Ukraine)	90-180	Significant contribution from coal-fired generation
Electric boiler (average energy mix of Ukraine)	250-350	High electricity consumption without multiplier effect
Biomass boiler	100-150	Significant contribution from particulate emissions
Solar collectors	20-40	Lowest overall impact

Table 5

Impact factor value on UBP from the source of electricity generation

Electricity source	Impact multiplier on UBP
Coal generation	×4-5
Gas generation	×2-3
Average energy mix of Ukraine	×3-4
Nuclear energy	×1-1.5
Renewable sources	×0.5-1

2. Refrigerant type. The effect of different refrigerants on the overall UBP is shown in Table 6 for example.

Table 6

Effect of different refrigerants on overall UBP

Refrigerant	Global Warming Potential (GWP)	Impact on UBP
R410A	2088	High
R32	675	Average
R290 (пропан)	3	Low
R744 (CO_2)	1	Lowest
R1234ze	<1	Lowest

3. Coefficient of performance (COP). The influence of the COP values on the relative UBP of the operation for the example is shown in Table 7.

Table 7

Influence of heat pump efficiency index values COP on relative UBP of operation

COP	Relative UBP of operation
2.0	100%
3.0	67%
4.0	50%
5.0	40%

4. Heat pump service life. The impact of service life on the annual UBP of production for the example is shown in Table 8.

Table 8

Effect of service life on annual UBP production

Service life	Impact on annual UBP production
10 years	100%
15 years	67%
20 years	50%
25 years	40%

7. Practical application of the UBP method for heat pumps in Ukraine

The following scenarios for using the UBP method for heat pumps in Ukraine can be considered:

– selection of the optimal heat supply technology (comparison of different types of heat pumps and alternative systems, taking into account local conditions (climate, energy mix, resource availability));

– optimization of design solutions (selection of the type and capacity of the heat pump, selection of a refrigerant with a lower environmental impact, optimization of the heat distribution system);

– environmental certification (assessment of compliance with environmental standards, labeling of energy efficiency and environmental friendliness);

– development of policies and support programs (scientifically based criteria for state support programs, establishment of environmental requirements for procurement).

For effective application of the UBP method in Ukraine, it must be adapted to Ukrainian conditions. In particular, for correct application of the UBP method in Ukraine it is necessary to:

– localize input data (use the structure of Ukrainian energy generation, take into account local climatic conditions, adapt to Ukrainian emission standards);

– revise critical flows (align with national environmental goals, synchronize with European standards within the framework of European integration);

– adjust weighting factors (take into account local environmental priorities, reflect the specifics of regional problems).

The main recommendations for manufacturers to reduce the UBP of heat pumps are as follows:

– optimization of production processes (reduction of energy intensity of production, use of materials with lower environmental impact, introduction of waste-free technologies);

– design improvement (increasing efficiency (COP), reducing the mass of materials used, extending service life);

– use of environmentally friendly refrigerants (switching to refrigerants with low global warming potential GWP, preventing refrigerant leaks).

The main recommendations for designers and users to reduce the UBP of heat pumps are as follows:

– selection of the optimal system (correct capacity calculation, selection of a heat pump with a high COP, combination with other renewable sources);

– efficient operation (optimal operating modes, regular maintenance, prevention of refrigerant leaks);

– use of "green" electricity (installation of own renewable energy sources (solar panels), selection of "green" tariffs).

For Ukraine, in the long term, the following promising areas of improvement of the UBP method for heat pumps should be taken into account, namely:

– integration with digital technologies (automated data collection for real-time UBP calculation, optimization of operating modes taking into account environmental impact);

– dynamic assessment (taking into account changes in the structure of energy generation during the day/season, adaptive management with UBP minimization);

– expansion of coverage (inclusion of social aspects (noise, visual impact), consideration of impact on local infrastructure);

– integration with environmental and economic assessment tools (combination with life cycle cost analysis (LCC), monetization of environmental impacts).

The UBP method provides a powerful tool for a comprehensive environmental assessment of heat pumps and contributes to making informed decisions about their implementation in the context of sustainable development of Ukraine.

Our study assessed the environmental impact of heat pump implementation options using the "UBP (Umweltbelastungspunkte) 2021" method (updated version), adapted to the conditions of Ukraine. The environmental impact of implementation options for different heat pump variants was assessed in the Treeze Ltd program for assessing life cycle indicators for heat pumps[12]. Additionally, an ecological heat pump calculator program[13] was used, which allows taking into account the influence of the characteristics of the low-temperature heat source for the heat pump (from renewable energy sources or household and industrial secondary energy resources), the influence of the energy efficiency index (EER) of the heat pump (general and local values are taken into account), the type of building (old or new), as well as the structure of the source of electricity consumed by the heat pump (local sources, electricity from the network or electricity from renewable sources). The obtained research results allow assessing the ecological impact (adapted to the conditions of Ukraine) on the environment of various options, circuit solutions and operating modes of the heat pump, the type of source of electricity consumed by the heat pump (local, network, from renewable sources).

In Fig. 1–4, for example, the values of the environmental impact indicators of heat pumps using the UBP method using natural renewable sources of low-temperature heat (air and geothermal energy) for an overall efficiency factor of 3, electricity from the Ukrainian power grid and from renewable sources are shown for our study. The values obtained in the

[12] Treeze Ltd's life cycle assessment software product. URL: https://treeze.ch.

[13] Heat pump calculator. URL: https://rechner.pawis.ch/HTMLWaermepumpen24_de_v1/Oekobilanzrechner_Waermepumpen_2024_deutsch_v1_UVEK2022.html

research results are in good agreement with the data given in Tables 1 and 4 for the environmental impact indicator using the UBP method for heat pumps using electricity from the Ukrainian power grid and from renewable sources.

Based on the analysis of the values of the environmental impact indicators according to the UBP Method for heat pumps (according to the results of the analysis of the indicators in Fig. 1-4), the improvement of the environmental impact indicators of heat pumps when using electricity from renewable sources compared to electricity from the Ukrainian power grid was confirmed.

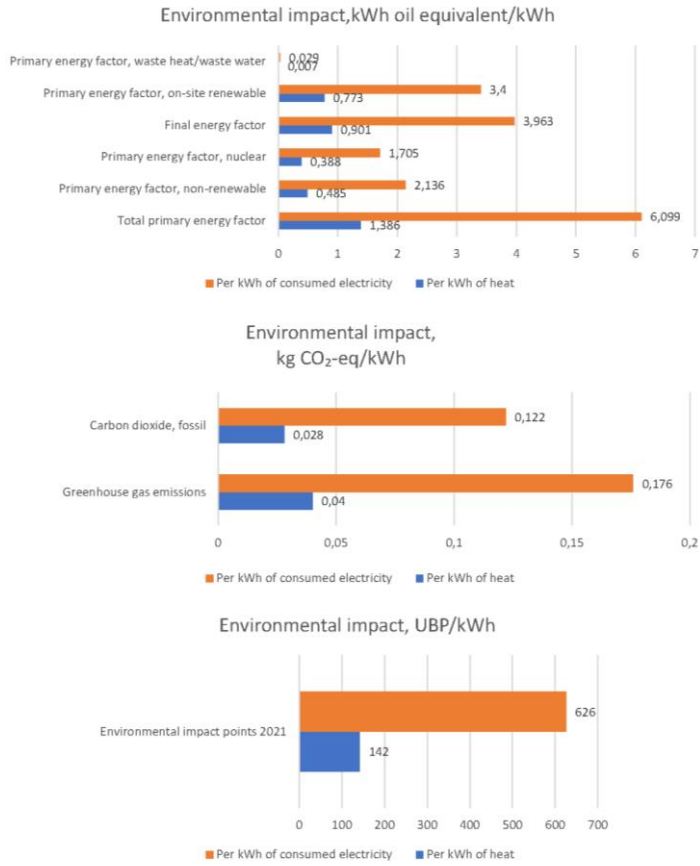

Fig. 1. Environmental impact indicators for an air-to-water heat pump, new building, overall efficiency factor 3, electricity from the grid

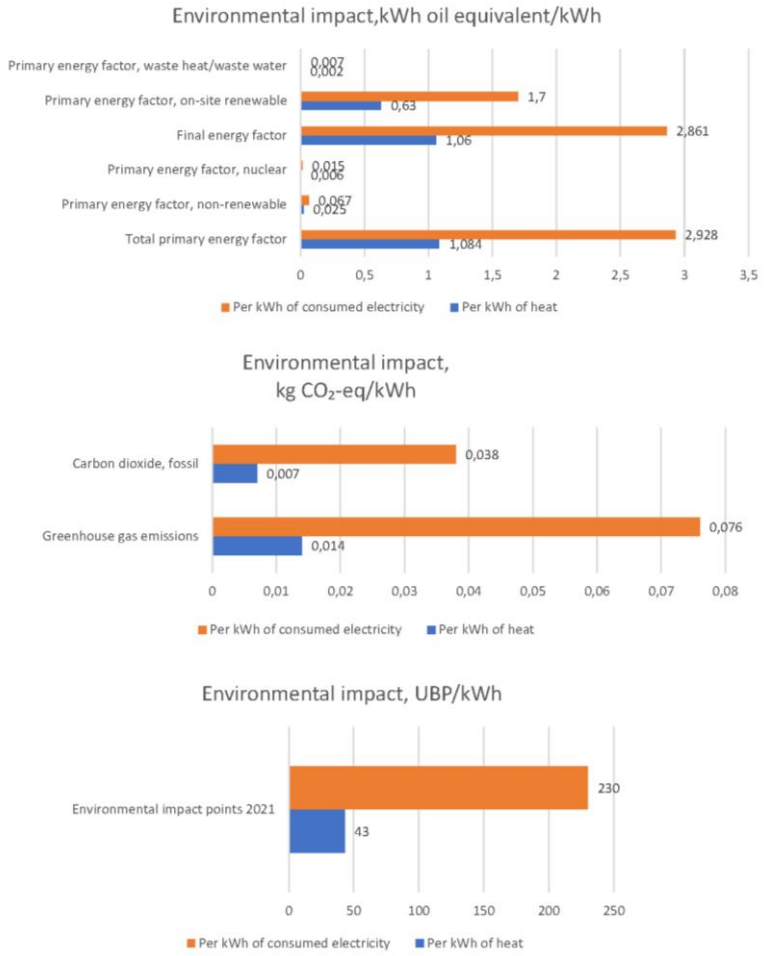

Fig. 2. Environmental impact indicators for an air-to-water heat pump, new building, overall efficiency factor 3, renewable electricity

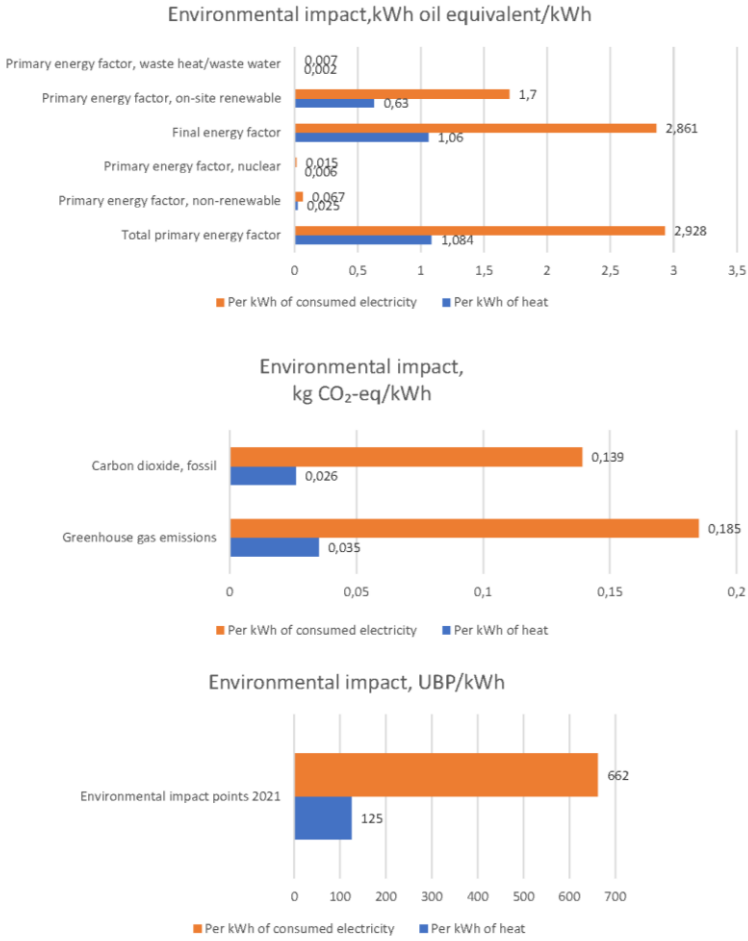

Fig. 3. Environmental impact indicators for brine (geothermal energy)-to-water heat pump, new building, overall efficiency factor 3, electricity from the grid

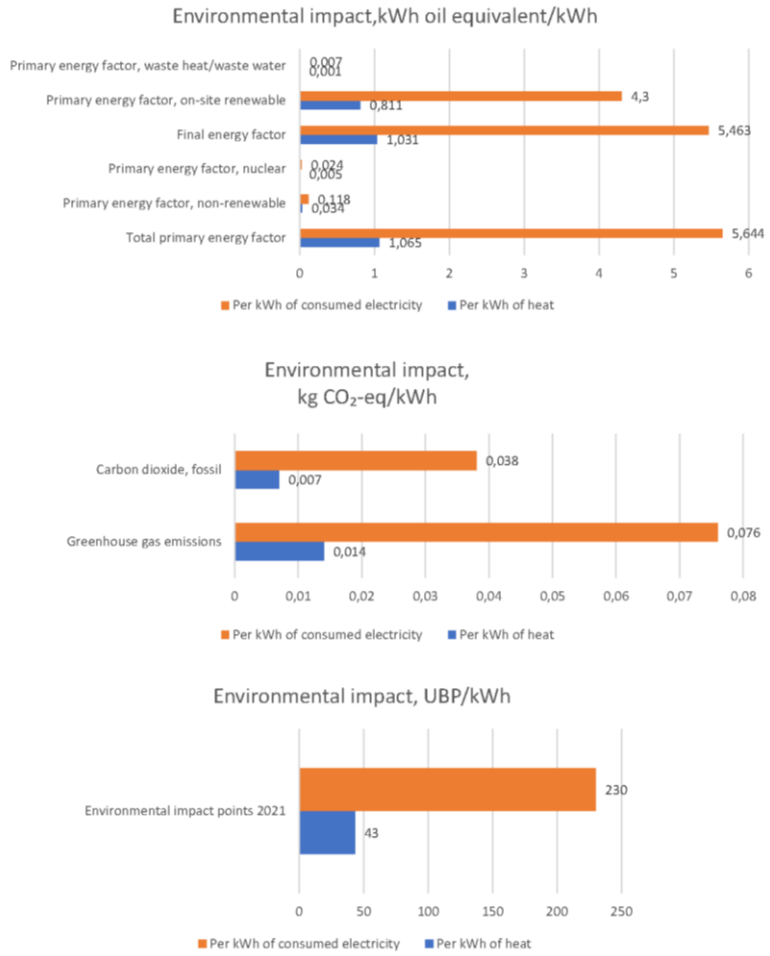

Fig. 4. Environmental impact indicators for brine (geothermal energy)-to-water heat pump, new building, overall efficiency factor 3, renewable electricity

Our study assessed Ukraine's capabilities for implementing the sustainable development program, taking into account environmental aspects and the impact of innovative energy technologies. The economic and environmental aspects of implementing the principles of sustainable development in Ukraine were analyzed, the impact of innovative energy technologies in the context of implementing the principles of sustainable development was assessed. The state of implementation of heat pumps in

Ukraine in the context of sustainable development was analyzed. The environmental aspects of implementing innovative technologies in the heat power industry of Ukraine were assessed. The UBP Method (Umweltbelastungspunkte or Environmental Impact Points) was analyzed and its capabilities and features of application for assessing heat pumps were assessed. The principles of practical application of the UBP method for heat pumps in Ukraine were shown. The study assessed the environmental performance of heat pumps using the UBP method, confirming the improvement in the environmental impact of heat pumps when using electricity from renewable sources compared to electricity from the Ukrainian grid. Our study applied scientific and methodological foundations and results from previous studies.

CONCLUSIONS

Sustainable development is a concept designed to ensure a balance between economic growth, social justice and environmental sustainability. In the face of global challenges such as climate change, depletion of natural resources and environmental pollution, the implementation of the principles of sustainable development becomes a necessary condition for ensuring the long-term well-being of society. For Ukraine, which is facing unprecedented challenges of post-war reconstruction, the task of implementing the sustainable development program is of particular importance. The energy sector, which is one of the key drivers of the economy and at the same time a source of significant environmental burden, requires a deep transformation based on innovative technologies and approaches.

Our study assessed Ukraine's capabilities to implement the sustainable development program, took into account environmental aspects and the impact of innovative energy technologies. The economic and environmental aspects of implementing the principles of sustainable development in Ukraine were analyzed, the impact of innovative energy technologies in the context of implementing the principles of sustainable development was assessed. The state of implementation of heat pumps in Ukraine in the context of sustainable development was analyzed. The environmental aspects of the implementation of innovative technologies in the heat power industry of Ukraine are assessed. The UBP Method (Umweltbelastungspunkte or Environmental Impact Points) is analyzed and its capabilities and features of application for the assessment of heat pumps are assessed. The principles of practical application of the UBP method for heat pumps in Ukraine are shown.

The study assessed the environmental performance of heat pumps using the UBP method, and confirmed the improvement of the impact of heat pumps on the environment when using electricity from renewable sources

compared to electricity from the Ukrainian power grid. Our study applied scientific and methodological foundations and results from previous studies.

SUMMARY

For Ukraine, which is facing unprecedented challenges of post-war reconstruction, the task of implementing a sustainable development program is of particular importance. The energy sector, which is one of the key drivers of the economy and at the same time a source of significant environmental burden, requires a deep transformation based on innovative technologies and approaches. Our study assessed Ukraine's capabilities for implementing a sustainable development program, took into account environmental aspects and the impact of innovative energy technologies. The economic and environmental aspects of implementing the principles of sustainable development in Ukraine were analyzed, the impact of innovative energy technologies in the context of implementing the principles of sustainable development was assessed. The state of implementation of heat pumps in Ukraine in the context of sustainable development was analyzed. The environmental aspects of implementing innovative technologies in the heat power industry of Ukraine were assessed. The UBP Method (Umweltbelastungspunkte or Environmental Impact Points) was analyzed and its capabilities and features of application for assessing heat pumps were assessed. The principles of practical application of the UBP method for heat pumps in Ukraine were shown. The study assessed the environmental performance of heat pumps using the UBP method, confirming the improvement in the environmental impact of heat pumps when using electricity from renewable sources compared to electricity from the Ukrainian grid. Our study applied scientific and methodological foundations and results from previous studies.

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