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Aspects of energy efficiency management for rational energy resource utilization

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Abstract

This study delves into the multifaceted landscape of energy efficiency management with the objective of rationalizing the utilization of energy resources. The article considers a methodical approach to the study of the level of energy intensity of economic activity, covering levels of management, from the macro level to the level of an individual enterprise. In general, it is advisable to supplement the proposed approach with existing methods that extend the content to the results of energy efficiency research. Using the Life Cycle Assessment (LCA) method and other methodologies, we explore various dimensions of energy resource utilization and the scale of energy efficiency management across different stages of the lifecycle. Additionally, the study introduces levels of energy efficiency management developed by the authors, providing a structured framework for optimizing energy use. Through rigorous analysis, we evaluate the environmental impacts, energy consumption patterns, and efficiency levels associated with diverse energy management strategies. Our findings illuminate key areas for improvement and optimization in energy utilization practices, offering insight beneficial for policymakers, industry stakeholders, and environmental advocates alike. By leveraging the comprehensive framework of LCA alongside the developed levels of energy efficiency management, this research contributes to a nuanced understanding of energy efficiency management, thereby facilitating informed decision-making towards sustainable energy utilization pathways. Examining the example of building the life cycle of gas production and highlighting the main stages of its transformation from a raw resource to a finished product for consumption allows for the consideration of the entire chain of creation of the added value of this energy resource and enables control of the level of its influence on the results of the activities of economic units involved in this chain, as well as the consequences of their impact on the environment. This allows us to conclude that the approach discussed in the article can be used both for researching the energy efficiency of individual enterprises, as well as their associations, industries, and the economy in general.

Keywords:
energy efficiency management; natural gas and fossil resources; environmental impacts; political & economic stability; levels of energy efficiency; LCA analysis; energy intensity

1. Introduction

In recent decades, the issue of limited energy resources and climate change has been a significant factor influencing trends in the energy sector's development, as well as the energy policy of each country. Therefore, countries are actively implementing measures in the energy sector to address these issues, particularly concerning the rationalization of energy resource utilization. Managing energy efficiency to rationalize energy resource utilization in Ukraine involves various technical and technological aspects. Firstly, it entails the implementation of energy audit and monitoring systems (**Chaphekar et al., 2015**), utilizing advanced energy audit techniques and continuous monitoring systems to assess energy consumption patterns across different sectors (**Saxena, 2022**). This requires the deployment of smart meters, sensors, and data analytics to identify areas of inefficiency and prioritize energy-saving meas-

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ures. Secondly, it involves the integration of renewable energy sources into the existing energy infrastructure (**Falshtynskyi et al., 2020**), encompassing the development of solar, wind, biomass, and hydropower systems to diversify the energy mix and reduce the dependence on fossil fuels (**Beshta et al., 2015; Griadushchiy et al., 2007**). Thirdly, it encompasses the adoption of energy-efficient technologies alongside smart grids and demand response mechanisms (**Sinchuk, 2023**). This includes promoting and deploying energy-efficient technologies and equipment across various sectors such as industry, transportation, and buildings (**Polyanska et al., 2022a**), encompassing energy-efficient lighting, heating, ventilation, and air conditioning (HVAC) systems, as well as optimizing industrial processes (**Seheda et al., 2024**). Additionally, implementing smart grid technologies to enhance the efficiency and reliability of the electricity grid is essential, utilizing advanced metering infrastructure, grid automation, and demand response programs to optimize energy distribution and consumption (**Pylypenko et al., 2024**). Furthermore, energy storage solutions, the establishment of energy management systems (EMS), and the promotion of energy-efficient transportation play significant roles in shaping priorities in managing energy efficiency (**Koval et al., 2023**). The deployment of energy storage technologies to mitigate intermittency issues associated with renewable energy sources and optimize energy usage includes battery storage systems, pumped hydro storage, and thermal energy storage for both grid-scale and decentralized applications (**Beshta et al., 2023**). The adoption of EMS for real-time monitoring, control, and optimization of energy consumption in buildings, industrial facilities, and infrastructure involves integrating building automation systems, process control systems, and energy management software (**Rahayu et al., 2019; Kononenko et al., 2023**). Lastly, promoting energy-efficient transportation solutions such as electric vehicles (EVs), hybrid vehicles, and public transportation systems powered by clean energy sources is essential, which includes developing charging infrastructure and offering incentives for the adoption of eco-friendly vehicles (**Beshta et al., 2023; Polyanska et al., 2023a**).

Mentioned above, these aspects provide the foundation for forming the policy and regulatory framework to manage energy efficiency (**Polyanska et al., 2023b; Thanh et al., 2021**). Establishing supportive policies and regulations to incentivize energy efficiency investments and ensure compliance with energy performance standards entails several key actions. This includes setting clear energy efficiency targets, providing financial incentives such as tax credits and grants, enacting regulations to mandate minimum energy performance standards for buildings and appliances, requiring energy audits and reporting to assess and improve energy usage, offering capacity building and technical assistance, conducting public awareness campaigns, and fostering collaboration among government agencies, industry stakeholders, and the public (**Polyanska et al., 2022b; Nikolsky et al., 2022**). This comprehensive approach aims to promote sustainability, reduce energy consumption, and mitigate the environmental impact by encouraging the widespread adoption of energy-efficient technologies and practices.

Addressing technical and technological aspects is crucial for Ukraine to enhance its energy efficiency management practices and achieve sustainable utilization of energy resources (**Dychkovskyi et al., 2021; Sinchuk et al., 2022**). This involves investing in advanced technologies and innovative solutions that improve energy efficiency across various sectors, including residential, commercial, industrial, and transportation (**Iwaszenko et al., 2019**). For instance, implementing smart energy management systems, upgrading infrastructure for energy distribution and storage, and adopting renewable energy sources, such as solar and wind power, can significantly enhance energy efficiency and reduce reliance on fossil fuels. Furthermore, leveraging digitalization and data analytics technologies can enable better monitoring, optimization, and control of energy usage, leading to more precise decision-making and resource allocation (**Zapukhliak et al., 2019; Maltsev et al., 2022**). Additionally, encouraging research and development in energy-efficient technologies and promoting collaboration with international partners can accelerate progress towards achieving energy efficiency goals. Overall, integrating technical advancements and innovative solutions into energy efficiency management practices can drive economic growth, enhance energy security, and mitigate the environmental impact in Ukraine.

Analyzing various aspects of Ukraine's gas industry, such as production levels, market dynamics, and the performance of key stakeholders like Naftogaz, allows us to track the trends in gas extraction within the country. By comparing and analyzing multiple sources, we can gain a more comprehensive understanding of the state of the Ukrainian gas sector (**Dychkovskyi et al., 2013)**. ExPro Consulting's report indicates a 0.9% increase in gas production in Ukraine in 2023 compared to the previous year, suggesting a slight improvement in the country's gas extraction capabilities despite the challenging political situation caused by the Russian aggression (**ExPro Consulting, 2023a**). The ExPro Consulting company is a consulting firm that provides services in various areas, including energy, oil and gas, and market analysis. They often produce reports and analyses related to the energy sector, including gas production and market trends. However, another report from ExPro Consulting presents a contradictory finding, showing a 2% decrease in gas production in Ukraine, down to 19.8 billion cubic meters (**ExPro Consulting, 2023b**). This discrepancy raises questions about the accuracy of the data or fluctuations in gas production, highlighting the need for a detailed examination of the data dedicated to the Ukrainian natural gas industry operation. Looking back at the previous report (**ExPro Consulting, 2020**), it reveals a

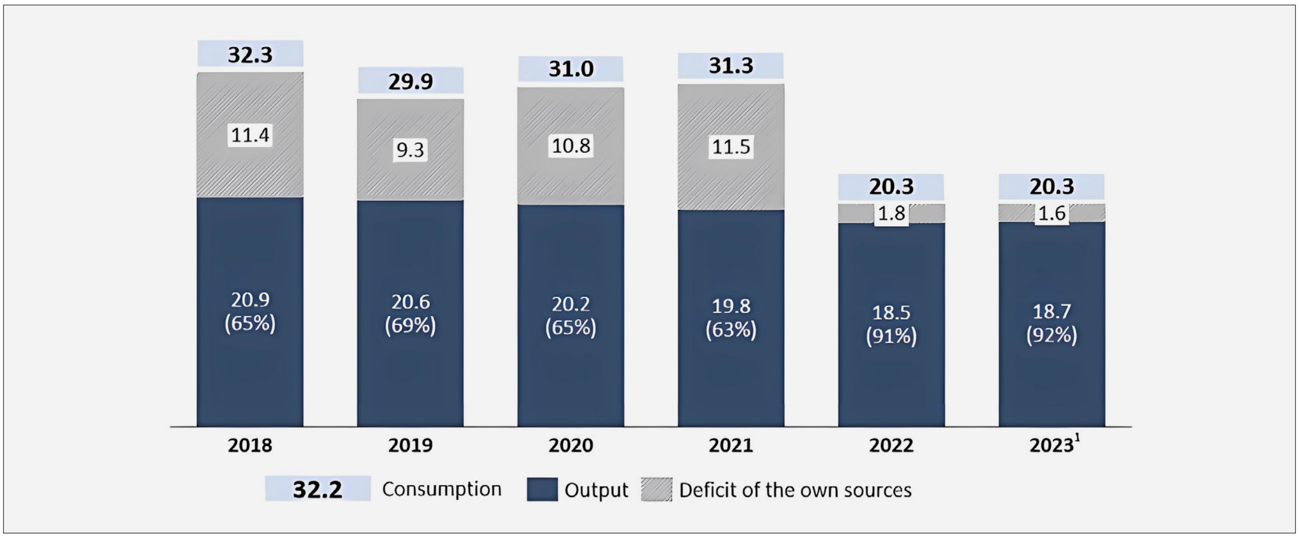

Figure 1: Dynamics of natural gas extraction and consumption in Ukraine

2% reduction in natural gas extraction in Ukraine for the year 2020. This downward trend in gas production over the years could potentially impact the country's energy security and increase reliance on imports. The National Commission for State Regulation of Energy and Public Utilities provides monitoring results for the functioning of the natural gas market in the first quarter of 2023 (**Report NGM, 2023**). This data offers valuable insight into market dynamics, pricing trends, and regulatory measures affecting the gas sector. Additionally, the annual report from NJSC "Naftogaz of Ukraine" for 2021 offers a comprehensive overview of the company's activities and financial performance. Understanding Naftogaz's role in the Ukrainian energy sector and its contribution to the national economy is crucial for assessing the overall health and sustainability of the gas industry in Ukraine (**Report NJSC NOU, 2021**).

The limitation of energy resources and climate change are also relevant issues for Ukraine. The full satisfaction of energy demand with its own resources remains a goal on the path to energy stability. For example, historically, before the pre-war period (before 2021), Ukraine met 60-70% of its natural gas needs domestically according to the previously presented analysis (see **Figure 1**), hence Ukrainian companies import natural gas to meet necessary volumes. It is important to note that after the full-scale invasion of Russia into Ukraine (February 24, 2022), energy consumption volumes, including natural gas and other fossil sources, significantly decreased, which is one of the directions for increasing energy efficiency (**Sala et al., 2024**). However, this result was not achieved through the implementation of energy-efficient technologies or other means, but rather due to population emigration and the destruction of industrial enterprises after the full-scale invasion.

The exacerbation of the energy crisis in Europe in 2022 was primarily caused by Russia's invasion of Ukraine, along with an increase in demand for energy resources (particularly gas, due to economic decarbonization efforts where gas is considered a transitional fuel) and global price hikes of energy carriers (including those stemming from the COVID-19 pandemic and the recovery of the global economy). As a result of these factors (see **Figure 2**), energy prices rose sharply, with the price of natural gas at the Dutch TTF hub reaching a historic high of over €330/MWh (**Trading Economics, 2023**).

The European Union took measures to mitigate the effects of the energy crisis. In April 2022, the EU introduced an action plan to ensure energy security, which included measures such as energy consumption reduction, diversification of supply sources, and transition to cleaner energy sources. As a result, beginning in early 2023, prices started to decline.

The energy crisis in Europe has become a challenge for Ukraine as well, being a country dependent on energy resource imports. The deficit in domestic resource extraction, as well as the prices of imported energy resources, have become additional drivers for Ukrainian companies to optimize costs related to the energy component, particularly through energy efficiency management and measures to reduce energy consumption.

According to the Law of Ukraine "On Energy Efficiency", energy efficiency is the quantitative relationship between output work, services, goods, or energy and the energy consumed as input. Energy includes all types of fuel and energy used in the national economy, including natural gas, coal, oil, petroleum products, liquefied gas, renewable energy sources, thermal energy, electric energy, and any other forms of energy (**Law of Ukraine, 2023**).

Therefore, energy efficiency management is the process of developing and implementing a set of measures to increase energy efficiency, which includes all aspects of an organization's activities, including planning, financing, management, and control. To ensure the quality of energy efficiency management, it is important to provide a comprehensive approach in three directions:

Figure 2: Dynamics of spot prices for natural gas at the Dutch TTF hub

- Development and implementation of energy-efficient technologies and equipment;
- Optimization of energy consumption in all areas of life;
- Formation of an energy efficiency culture in society.

So, energy efficiency management encompasses the development and implementation of measures aimed at enhancing energy efficiency across all facets of an organization's operations, involving planning, financing, management, and oversight. To ensure effective energy efficiency management, a comprehensive approach is crucial, focusing on the adoption of energy-efficient technologies, optimization of energy consumption in various domains, and fostering a culture of energy efficiency within society.

Taking into account the above, the purpose of the article is to research certain aspects of energy efficiency management based on the consideration of the approaches to the rational use of energy resources at different levels of achieving energy efficiency, in particular from the macro level to the level of an individual enterprise, as well as their integration with methods for assessing the impact of enterprise activities on the environment and energy consumption models for determining key areas for improvement and rational energy resource utilization.

2. Research methodology

2.1. General issues in modelling energy efficiency management

For modelling levels of energy efficiency management to rationalize the use of energy resources, various methods and methodologies can be utilized. Systems analysis is one such method, involving the comprehensive analysis of the entire energy system, from production to consumption, using a systemic approach (**Kosobokov et al., 2018**). It considers interconnected factors like technology, infrastructure, policies, and behaviours to identify opportunities for improving energy efficiency. Additionally, the Life Cycle Assessment (LCA) Methodology examines the environmental impacts of a product or service throughout its entire life cycle, helping quantify energy consumption, emissions, and other environmental burdens associated with different stages (**Sala et al., 2019**).

Another important methodology is energy auditing, which involves assessing energy systems within a facility or organization to identify inefficiencies and potential areas for improvement. This process typically includes analysing energy use patterns, identifying energy-saving opportunities, and recommending efficiency measures (**Sherry Huang, 2021**). Moreover, calculation methodology of energy efficiency indicators develops and utilizes values to quantify energy efficiency at various management levels, aiding in tracking energy consumption, identifying trends, and evaluating the effectiveness of management efforts (**Bosseboeuf et al., 1997; Vladyko et al., 2022**). On the other hand, modelling and simulation techniques use computer programs and mathematical models to predict the performance of energy management strategies, allowing for testing different scenarios, optimizing system designs, and estimating potential energy savings before implementation. Strategic planning plays a crucial role as well, involving the development of long-term goals and action plans to enhance energy efficiency, including setting targets, prioritizing initiatives, allocating resources, and monitoring progress (**Dyczko, 2023**).

2.2. Life Cycle Assessment (LCA) methodology for energy efficiency management

Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle. When applied to energy efficiency management, LCA helps assess and optimize the environmental performance of energy-related activities. The first step in conducting an LCA for energy efficiency management is defining the goal and scope of the study. This involves identifying specific energy-related activities to be analysed, such as energy production, distribution, consumption, or a combination thereof. Additionally, defining the boundaries of the system under study and the functional unit, which represents the unit of measurement for comparison (e.g. per unit of energy produced or consumed), is essential.

Data collection involves gathering information on all inputs (e.g. materials, energy, water) and outputs (e.g. emissions, waste) associated with the energy-related activities being assessed. This includes acquiring data on energy inputs and outputs at each stage of the life cycle, from extraction and production to transportation, use, and disposal (**Kononenko et al., 2023**). Subsequently, the inventory of inputs and outputs is compiled to assess the potential environmental impacts associated with energy efficiency management. This entails evaluating various impact categories, such as greenhouse gas emissions, air and water pollution, resource depletion, and ecosystem impacts. Impact assessment methods may vary depending on the specific goals and scope of the study, but typically involve utilizing impact assessment models and characterization factors to quantify and compare environmental impacts across different stages of the life cycle.

The final step in the LCA process is interpretation, where the results of the inventory analysis and impact assessment are scrutinized in the context of the study objectives and stakeholder needs. This may involve identifying hotspots where environmental impacts are most significant, evaluating trade-offs between different energy efficiency strategies, and identifying opportunities for improvement. Through the application of the LCA methodology to energy efficiency management, organizations can gain insight into the environmental performance of their energy-related activities, identify improvement opportunities, and make informed decisions to minimize environmental impacts throughout the life cycle of energy products, processes, and services.

2.3. Mathematical apparatus for modelling

In the realm of sustainable development, the assessment of environmental impacts is paramount. Life Cycle Assessment (LCA) stands as a formidable methodology, offering a holistic view of the environmental repercussions of a product, process, or service across its entire life cycle. Its application in energy efficiency management not only facilitates understanding, but also enables the optimization of the environmental performance associated with energy-related activities. At the heart of LCA lies a robust mathematical framework, empowering analysts to quantify and evaluate environmental impacts with precision.

Despite its undeniable utility, LCA encounters several challenges, including data availability, uncertainty propagation, and system boundary definition. Addressing these challenges necessitates the ongoing refinement of mathematical models, enhancement of data quality and accessibility, and broader stakeholder engagement. In the dynamic landscape of energy management, the ability to forecast, analyze, and optimize performance is indispensable. Mathematical apparatus, in conjunction with sophisticated simulation techniques, emerges as a powerful ally, offering the means to predict outcomes, test scenarios, and optimize designs with precision.

In energy management, mathematical models serve as the backbone of simulation techniques, encapsulating the underlying principles governing the behaviour of energy systems. These models translate real-world phenomena into mathematical equations, capturing relationships between variables, such as energy consumption, system parameters, and environmental factors.

The energy efficiency of the EU economy can be assessed using the indicator of energy intensity of GDP, calculated as the ratio of energy consumption to GDP. This indicator characterizes the amount of energy resources expended in producing one unit of GDP.

$$E_{GDP} = \frac{E_0}{GDP} \tag{1}$$

where:

E_{GDP} – the energy intensity of GDP,

E_0 – energy consumption; GDP – Gross Domestic Product.

Computer simulations leverage mathematical models to replicate the behaviour of complex energy systems in a virtual environment. By inputting data and specifying boundary conditions, simulations enable the exploration of system dynamics, the evaluation of performance metrics, and the prediction of outcomes under different scenarios. Specific methods and types of mathematical models commonly used in energy management are:

- Energy Balance Models: these models track the flow of energy through a system by accounting for inputs, outputs, and internal transformations. They are often used to analyze energy consumption patterns, identify inefficiencies, and optimize energy utilization (**Ghil, 1981**).
- Dynamic Simulation Models: dynamic simulation models represent the temporal behaviour of energy systems by accounting for time-dependent variables and feedback loops. They are useful for assessing transient responses, predicting system dynam-

ics, and optimizing control strategies (**Moran et al., 2023; Wojtacha-Rychter et al., 2021**).

- Optimization Models: optimization models aim to find the best solution to a given problem by systematically exploring different combinations of variables while satisfying specified constraints. They are employed to optimize energy system designs, resource allocation, scheduling, and operational strategies (**Babets et al., 2023**).
- Statistical Models: statistical models utilize historical data to identify patterns, trends, and relationships between variables. They are valuable for forecasting energy demand, analyzing consumption patterns, and identifying factors influencing energy performance (**Sdvyzhkova et al., 2022**).
- Building Energy Models: building energy models represent the thermal behaviour of buildings by integrating physical characteristics, occupancy patterns, HVAC systems, and environmental conditions. They are used to evaluate building energy performance, assess the impact of energy-saving measures, and optimize HVAC control strategies (**Yu et al., 2022**).
- Renewable Energy Models: renewable energy models simulate the generation, integration, and utilization of renewable energy sources such as solar, wind, and biomass. They are employed to assess the technical and economic feasibility of renewable energy projects, optimize system configurations, and forecast renewable energy generation (**Valencia-Calvo, et al., 2020**).
- Life Cycle Assessment (LCA) Models: LCA models quantify the environmental impacts associated with the entire life cycle of energy systems, including raw material extraction, production, transportation, utilization, and disposal. They are used to assess the environmental sustainability of energy technologies, compare alternative options, and identify opportunities for improvement (**Bieda et al., 2023**).
- Economic Models: economic models analyze the financial aspects of energy systems, including investment costs, operating expenses, revenues, and savings. They are employed to evaluate the economic viability of energy projects, conduct cost-benefit analyses, and optimize investment decisions (**Nakata, 2004**).

Modelling and simulation techniques empower stakeholders to explore a myriad of scenarios, ranging from system modifications to changes in operational strategies. By simulating diverse conditions, energy managers can assess the feasibility and effectiveness of potential interventions, identifying optimal pathways for achieving energy efficiency and cost savings. From building energy-efficient structures to designing renewable energy systems, mathematical models and simulations facilitate the optimization of system designs. By iteratively refining parameters and configurations, designers can fine-tune energy systems to maximize performance while minimizing resource consumption and environmental impacts.

3. Results and discussion

For effective energy efficiency management of an organization, it is important to implement measures to enhance energy efficiency that correspond to its size, goals, and objectives. In other words, the larger the organization, the more global the task of managing energy efficiency, and its prioritization is advisable. It is important to consider at which level the organization's energy efficiency management is situated, as this will enable its quality integration into the global energy efficiency management system, and more effectively control and monitor the results.

Energy efficiency management can be considered at various levels, including global, macro-level, meso-level, micro-level, and individual.

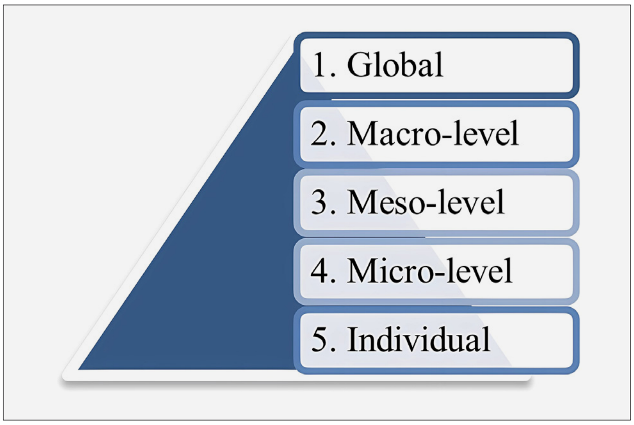

Figure 3: Levels of energy efficiency management

Global level energy efficiency management involves the development and implementation of international agreements and conventions, as well as the formulation of common goals and directions for all countries worldwide.

Macro-level energy efficiency management involves the development and implementation of national energy strategies, as well as the creation of regulatory frameworks to stimulate energy efficiency.

Meso-level energy efficiency management involves the development and implementation of regional energy programs, as well as support for local initiatives in the field of energy efficiency.

Micro-level energy efficiency management involves the development and implementation of energy programs for enterprises, organizations, and individual households.

Individual energy efficiency management involves making personal decisions that contribute to energy conservation.

Table 1: Levels of energy efficiency management

Level of energy efficiency management	Examples of goals	Examples of measures/actions
Global level	Reducing global greenhouse gas emissions, energy consumption, and achieving global energy efficiency.	Implementation of international energy efficiency standards, development of a unified strategy to achieve energy efficiency goals. Adoption of energy standards for buildings, industrial enterprises, vehicles, etc.
Macro-level	Decreasing the overall energy consumption of a country, reducing the country's energy dependence, improving air quality, and reducing negative environmental impact.	Advancement of energy auditing and energy management. Promotion of energy efficiency concepts among the population and businesses.
Meso-level,	Decreasing energy consumption within a region and creating new jobs in the field of energy efficiency.	Development of energy-efficient technologies and innovations for the region. Provision of financial support for energy-efficient projects. Promoting energy efficiency ideas among the region's population.
Micro-level	Lowering energy costs for a company, organization, or household. Improving financial performance in energy-related aspects. Decreasing negative environmental impact.	Introduction of energy-efficient technologies and equipment, conducting energy audits, and implementing energy-saving measures. Promoting energy efficiency among employees, organization members, or households.
Individual	Decreasing personal energy consumption and reducing negative environmental impact.	Efficient use of electricity, gas, or other energy resources, transitioning to energy-efficient technologies. Behavioural changes contributing to energy conservation.

Table 2: Energy consumption by country

Country	Energy consumption, MWh		Difference	%
	2021	2022		
Belgium	651.28	593.13	-58.15	-9%
Czech Republic	500.09	500.09	0	0%
Germany	3349.44	3140.1	-209.34	-6%
Spain	1337.45	1337.45	0	0%
France	2721.42	2465.56	-255.86	-9%
Italy	1744.5	1686.35	-58.15	-3%
Netherlands	837.36	732.69	-104.67	-13%
Poland	1256.04	1209.52	-46.52	-4%
Portugal	232.6	255.86	23.26	10%
Romania	395.42	372.16	-23.26	-6%
Sweden	546.61	534.98	-11.63	-2%
Ukraine	1058.33	755.95	-302.38	-29%

Each level of energy efficiency management has specific goals and measures corresponding to the scale of the respective level.

It should be noted that despite the common goal of achieving energy efficiency, each level is characterized by specific goals and the potential means and actions to achieve them, which is all discussed in **Table 1**.

Table 3: GDP by country

Country	GDP, mln US dollars		Difference	%
	2021	2022		
Belgium	601	583	-17.31	-3%
Czech Republic	282	291	8.74	3%
Germany	4 279	4 082	-196.03	-5%
Spain	1 446	1 418	-27.85	-2%
France	2 959	2 779	-180.26	-6%
Italy	2 155	2 050	-105.62	-5%
Netherlands	1 030	1 009	-20.28	-2%
Poland	681	688	6.78	1%
Portugal	256	255	-0.34	-0.1%
Romania	286	301	14.88	5%
Sweden	640	591	-48.53	-8%
Ukraine	200	161	-39.26	-20%

It is important to note that measures at different levels are interconnected and complement each other. Only a comprehensive approach to energy efficiency management can ensure significant results in the fields of energy conservation and sustainable development. The implementation of measures to enhance energy efficiency is important not only from the perspective of reducing the anthropogenic impact on the environment from emissions generated by burning traditional forms of energy, but also from the standpoint of the economic efficiency

Table 4: Energy intensity by countries

Country	GDP, mln US dollars		Energy consumption, MWh		Energy intensity of GDP			
	2021	2022	2021	2022	2021	2022	Difference	%
Belgium	601	583	651	593	1.1	1.0	-0.07	-6%
Czech Republic	282	291	500	500	1.8	1.7	-0.05	-3%
Germany	4 279	4 082	3 349	3 140	0.8	0.8	-0.01	-2%
Spain	1 446	1 418	1 337	1 337	0.9	0.9	0.02	2%
France	2 959	2 779	2 721	2 466	0.9	0.9	-0.03	-4%
Italy	2 155	2 050	1 745	1 686	0.8	0.8	0.01	2%
Netherlands	1 030	1 009	837	733	0.8	0.7	-0.09	-11%
Poland	681	688	1 256	1 210	1.8	1.8	-0.09	-5%
Portugal	256	255	233	256	0.9	1.0	0.09	10%
Romania	286	301	395	372	1.4	1.2	-0.15	-11%
Sweden	640	591	547	535	0.9	0.9	0.05	6%
Ukraine	200	161	1 058	756	5.3	4.7	-0.6	-11%

of energy consumption. In 2022, the EU reached a turning point in the process of moving away from relatively cheap Russian energy resources, making the issue of energy efficiency even more pressing.

The description of the content of **Equation 1** allows to reasonably approach its use on the considered levels of energy efficiency research presented in **Figure 3**. In particular, the content of the energy intensity of GDP leads to its decrease, namely, the smaller this indicator is, the smaller the amount of energy resources is needed to achieve the expected results of the economic activity of the country's economy. Achieving the optimal value is possible due to either a decrease in the consumption of energy resources, which, based on the forecasts given by analysts, should not be expected, or an increase in the results of the enterprises' activities. In fact, there is a wide range of research directions, the consideration of which depends on the volume, intensity, and type of use of energy resources.

Returning to **Equation 1**, it should be noted that the energy intensity of GDP is an important indicator of a country's energy efficiency. The lower the energy intensity of GDP, the more efficiently a country utilizes energy resources. The energy intensity of GDP can be calculated for different countries, regions, or economic sectors. For the analysis of economic energy efficiency, 12 countries (including Ukraine) with varying levels of energy consumption and GDP size have been selected (**Enerdata, 2023**). **Table 2** illustrates the tendency of energy consumption for some European countries.

It is important to note that the energy consumption of most of the countries analyzed in 2022 compared to 2021 decreased or remained at the same level, except for Portugal, where consumption increased by 10% (**World Bank, 2023**).

Continuing the study of the energy intensity of GDP in the **Table 3** presents the value of this indicator for 2021-2022.

Regarding the size of the GDP, there was a decrease in most of the analyzed countries, except for Romania, the Czech Republic and Poland, where there was an increase of 5%, 3% and 1%, respectively.

Based on the data shown in **Tables 2** and **3** regarding energy consumption and the volume of GDP with the use of **Equation 1**, **Table 4** presents the results of energy intensity calculation for the countries considered in this article.

The energy intensity of GDP is influenced by factors such as the economic structure (with a higher proportion of industry typically leading to a higher energy intensity of GDP), climate (countries with colder climates generally have higher energy intensity of GDP), and the level of technological development (countries with higher technological advancement tend to have lower energy intensity of GDP as they adopt energy-efficient technologies).

According to **Table 4** data, in 2022, the energy intensity of GDP decreased in most EU countries compared to 2021. This trend is positive as it indicates that EU countries are succeeding in improving the energy efficiency of their economies. Among the analyzed countries, Sweden, the Netherlands, and Belgium had the lowest energy intensity of GDP in 2022. These countries have high technological levels and significant investments in renewable energy sources.

To achieve these results, the European Commission has created an ambitious plan called REPowerEU aimed at reducing Europe's energy dependence on Russia. The plan includes a wide range of measures, including diversifying energy sources, developing renewable energy sources, and increasing energy efficiency. In the context of energy efficiency, the REPowerEU plan aims to increase the mandatory energy savings target from 9% to 13% by 2030 (**European Commission, 2023**). It is worth noting that this plan is an example of decision-

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Table 5: Energy intensity of production of the Italian gas company «Eni» **(Eni, 2022)**

Results of activity (profit before income taxes), ***mln. U.S. dollars***		**Energy consumption,** ***MWh***		**Energy intensity of production**			
2021	2022	2021	2022	2021	2022	Diff.	%
601	583	651	593	1.1	1.0	-0.07	-6%

making at the highest level of energy efficiency management - the global level.

Among the analyzed countries, Ukraine, Romania, and Poland had the highest energy intensity of GDP in 2022. These countries have a significant share of industry in their economic structure, which requires substantial energy resources accordingly.

As for Ukraine, its energy intensity of GDP is at a very high level and significantly exceeds the indicators of the analyzed EU countries. Despite the decrease in Ukraine's energy intensity of GDP in 2022, this result was achieved not due to the implementation of energy-efficient technologies or other actions, but due to the full-scale invasion by Russia, which resulted in the destruction and damage of a significant portion of Ukraine's infrastructure, including power plants, heating networks, residential buildings, and large industrial facilities.

To overcome the problem of low energy consumption efficiency, in 2023 the Government of Ukraine adopted the National Energy Strategy of Ukraine for the period up to 2050, which envisages increasing energy efficiency (**ME of Ukraine, 2023**). The implementation of this strategy will allow Ukraine to achieve significant success in reducing the energy intensity of GDP. However, substantial investments in energy-efficient technologies and the implementation of relevant programs are required for this.

The EU has also developed and implemented several regulatory acts aimed at increasing energy efficiency, by reducing the consumption of energy resources. During the period from 2020 to 2023, various regulations and strategies aimed at reducing energy consumption and increasing energy efficiency were adopted and implemented in the European Union. Here are some of them:

- "Green Deal" strategy - this strategy includes a wide range of initiatives and measures aimed at reducing greenhouse gas emissions, transitioning to clean energy sources, and increasing energy efficiency in all sectors of the economy.
- Energy Efficiency Directive - this law sets mandatory energy efficiency goals for EU countries and is aimed at reducing energy consumption in construction, transport, industry, and other sectors.
- Effort Sharing Regulation - this mechanism regulates the obligations of EU countries to reduce greenhouse gas emissions in non-economic sectors, such as agriculture, communications, and waste.
- Clean Technologies Program - this program provides financial support for the development and implementation of energy-efficient and environmentally friendly technologies.

Given the relevance of the study of energy consumption and the energy intensity indicator dependent on it, we suggest applying a similar approach at the level of a separate enterprise to assess its energy efficiency and energy consumption. In addition, this methodological approach can also be used to evaluate future projects aimed at increasing both the economic efficiency of the enterprise and its ecological and environmental component. In this case, **Equation 1** will look like this:

$$E_{prod} = \frac{E_{ent}}{R} \qquad (2)$$

where:

E_{prod} – the energy intensity of production,
E_{ent} – energy consumption,
R – results of activity, namely Gross Profit at enterprise, etc.

To demonstrate how the proposed approach to determine energy consumption affects the level of energy resource efficiency, we suggest considering an example of an enterprise's activity Eni S.p.A. Eni is an Italian multinational oil and gas company, it is presented in 62 countries, and currently is Italy's largest industrial company (see **Table 5**).

It should be noted that the calculation of the energy intensity of production or any other process of transformation of energy resources from raw materials to a finished product can be used to assess the life cycle of energy resources, particularly LCA analysis. In this case, the method of energy efficiency assessment combined with LCA analysis will allow for the solving of the following tasks:

- consider all processes of transformation of energy resources at the stages of the life cycle;
- determine the impact on the environment due to the LCA analysis methodology;
- determine the level of energy load on the enterprise's activity;
- determine the impact of energy load on the economic results of activity.

European companies, striving to achieve the goals of sustainable development, actively use the LCA methodology. In particular, the Italian multinational energy company Enel SpA, which is a world leader in the field of electricity and infrastructure, uses LCA analysis to assess the environmental impact of its activities at various

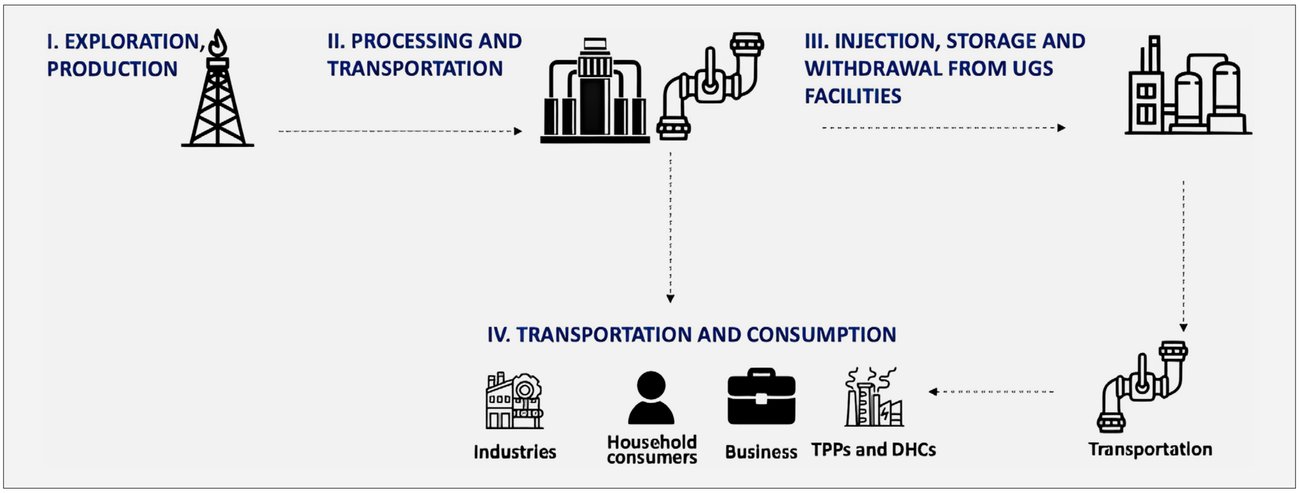

Figure 4: Description of the life cycle of energy resources using the example of natural gas and its impact on the environment

Table 6: Potential ecological risks at the stages of natural gas life cycle

Exploration, production	Processing and transportation	Injection, storage, and withdrawal from UGS facilities	Transportation and consumption
Environmental risk is soil and water pollution due to the use of chemicals used in drilling; generation of waste during drilling, the accumulation of which poses a serious threat to the environment; pollution of groundwater during the mining process	There is a risk of accidents at gas preparation plants that could lead to emissions of pollutants, water pollution and fires. In addition, production and technological costs and other types of energy are necessary to maintain the proper condition of the gas network.	The environmental risk is the leakage of gas from the tanks, which can lead to air and soil pollution, as well as the danger of explosions and fires.	Environmental risks are the burning of gas, which leads to emissions of greenhouse gases, the formation of harmful substances that pollute the atmosphere. Due to possible accidents, there are risks of gas leakage from pipelines, which can in turn lead to soil and water pollution, as well as explosions.

stages of electricity production and supply, to develop greener products and services, and to support informed investment decision-making and operations (**Enel, 2022**). Also, France's largest electricity company and one of the largest electricity producers in the world, EDF, or Électricité de France, uses LCA to assess the environmental impact throughout their life cycle.

As an example for consideration, **Figure 4** presents a scheme of the life cycle of such an energy resource as gas and its potential impact on the environment at each of its stages.

Based on the description of the life cycle of natural gas in **Table 6**, the potential negative impact on the environment is described.

Therefore, the study of the energy production processes is based on the consideration of their life cycle. That allows for the identification of the directions and ways of their rational use. In particular, the analysis of the volumes of production, transportation, storage, distribution allows for the supplementation of the the analysis with possible losses and the investigation of the impact of these processes on the environment. The obtained results of such studies can serve as an informative base for determining energy intensity and energy consumption.

4. Conclusions

Thus, the aspects of energy efficiency research proposed in the article offer management technologies for the implementation of the task of increasing it. The efficient management of energy is crucial across multiple levels: globally (such as within the EU), at the macro-level (within countries), meso-level (across regions), micro-level (within organizations and enterprises), and individual level (for every person). Since each level operates at different scales, it's vital for goals and strategies to align with the specific level of implementation, ensuring they are feasible and coherent with higher-level objectives. The European initiative, REPowerEU, exemplifies effective management decision-making in energy efficiency on a global scale. Embracing a holistic approach to enhancing energy efficiency across these diverse levels offers numerous benefits, including reducing reliance on imported energy, mitigating greenhouse gas emissions, and curbing energy resource expenses – particularly pertinent for Ukraine.

The proposed methodical approach to determining the load on the processes associated with various operations of converting energy resources from raw materials to finished goods expands and complements the analytical instrumentation of management activities and helps to make decisions regarding the optimization of energy consumption. The well-known and widely used technology of LCA analysis is proposed to be considered together with the energy load indicator, which allows for the combining of both the economic and environmental components of management activities.

Research results can be valuable for enterprises in various sectors of the energy sector, since this approach considers these features based on the consideration of the life cycle stages of energy resources. In general, the application of the proposed aspects of energy efficiency management enables the enterprise to make decisions aimed at achieving the goals of sustainable development, considering both economic and environmental consequences of activities.

Environmental risks associated with gas drilling include soil and water pollution resulting from chemical usage, waste generation, and the potential accumulation of hazardous materials, which pose significant threats to the environment. Additionally, gas preparation plants present the risk of accidents leading to pollutant emissions, water contamination, and fires, necessitating substantial energy and financial resources for maintenance. Leakage of gas from tanks constitutes another environmental risk, potentially causing air and soil pollution, as well as the heightened risk of explosions and fires. Moreover, gas burning during production emits greenhouse gases and harmful substances, contributing to atmospheric pollution, while pipeline accidents pose further risks of gas leakage, soil and water contamination, and explosive hazards. Therefore, in our further research, we will propose measures for hazard prevention and study the behaviour of energy resource consumers to promote efficient and economical consumption.

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SAŽETAK

Aspekti upravljanja energetskom učinkovitošću za racionalno korištenje energetskih resursa

Ovo istraživanje proučava višestruke načine upravljanja energetskom učinkovitošću s ciljem racionalizacije korištenja energetskih resursa. U članku se razmatra metodički pristup proučavanju razine energetskoga intenziteta gospodarske aktivnosti koji pokriva razine upravljanja od makrorazine do razine pojedinoga poduzeća. Općenito, predloženi pristup potrebno je dopuniti već postojećim metodama koje obuhvaćaju i rezultate istraživanja energetske učinkovitosti. Koristeći se metodom procjene životnoga ciklusa (engl. *Life Cycle Assessment*, LCA) i drugom metodologijom, u ovome su radu istražene različite dimenzije korištenja energetskih resursa i opseg upravljanja energetskom učinkovitošću u različitim fazama životnoga ciklusa. Osim toga, u ovome su radu predstavljene i razine upravljanja energetskom učinkovitošću koje su razvili autori pružajući strukturirani okvir za optimizaciju korištenja energije. U radu su detaljno analizirani i procijenjeni utjecaji na okoliš, obrasci potrošnje energije i razine učinkovitosti povezane s različitim strategijama upravljanja energijom. Rezultati provedenoga istraživanja omugućuju poboljšanje i optimizaciju praksi iskorištavanja energije nudeći korisne uvide kreatorima politika, dionicima u industriji i zagovornicima zaštite okoliša. Korištenjem sveobuhvatnoga okvira LCA zajedno s razvijenim razinama upravljanja energetskom učinkovitošću ovo istraživanje doprinosi razumijevanju upravljanja energetskom učinkovitošću, čime se olakšava donošenje odluka u smjeru održivoga korištenja energije. Istraživanje primjera životnoga ciklusa proizvodnje plina i isticanje glavnih faza njegove transformacije od sirovine do gotova proizvoda za potrošnju omogućuje razmatranje cijeloga lanca stvaranja dodane vrijednosti ovoga energenta i kontrolu razine njegova utjecaja na rezultate djelatnosti gospodarskih jedinica uključenih u ovaj lanac, kao i posljedice njihova utjecaja na okoliš. Temeljem provedenoga istraživanja zaključuje se da se pristup koji se razmatra u radu može koristiti za istraživanje energetske učinkovitosti pojedinačnih poduzeća te njihovih udruženja, industrije i gospodarstva općenito.

Ključne riječi:
upravljanje energetskom učinkovitošću, izvori prirodnoga plina i fosilnih goriva, utjecaj na okoliš, politička i gospodarska stabilnost, razine energetske učinkovitosti, LCA analiza, energetska intenzivnost

Author's contribution

Alla Polyanska (Dr. Sci., Professor) – description of the problem; development of the research methodology, performance of the preliminary calculation; and analysis of the results. **Yuliya Pazynich** (PhD, Associated Professor)– participation in the formation of the management energy system, and justification of the ecological aspects. **Chrystyna Mykhailyshyn** (PhD student) – carrying out the analytical data. **Dmytro Babets** (Dr. Sci., Professor) – developing the algorithm for calculation and determination of modelling parameters. **Piotr Toś** (Mgr.) – forming the mathematical model, and conducting the preliminary calculation.