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## THE CONCEPT OF ENERGY EFFICIENCY AND ITS ANALYTICAL INDICATORS

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### Abstract

This article systematically analyzes the essence of energy efficiency, its key performance indicators, and assessment methodologies within modern industrial manufacturing. The research clarifies the distinctions between energy efficiency and energy conservation, emphasizing the economic significance of fundamental metrics such as energy intensity and efficiency coefficients. Furthermore, the paper provides a classification of technical, organizational, and human factors influencing industrial energy consumption. A significant part of the study focuses on the role of Artificial Intelligence (AI) and Internet of Things (IoT) technologies in energy management within the context of Industry 4.0, specifically exploring the potential of LSTM neural networks for demand forecasting and predictive maintenance.

**Keywords:** Energy efficiency, energy intensity, industrial energy, Artificial Intelligence (AI), LSTM neural networks, energy monitoring, optimization, predictive analysis.

### Introduction

Energy efficiency is considered one of the most critical concepts in modern economy and industrial manufacturing. This concept implies maximizing the benefits derived from energy resources while achieving superior results with minimal energy consumption. In other words, energy efficiency represents the



optimality of the amount of energy consumed relative to the volume of products manufactured or work performed.

From a scientific perspective, energy efficiency encompasses two primary aspects: the rational utilization of energy resources and the minimization of energy losses. The concept of energy efficiency is often confused with energy conservation. However, they differ significantly: while energy conservation refers to the reduction of energy consumption, energy efficiency signifies achieving greater results by consuming less energy.

#### Key Indicators of Energy Efficiency

Various indicators are employed to evaluate energy efficiency, which may vary depending on the nature of the production process.

1. Energy Efficiency Coefficient The energy efficiency coefficient is determined using the following formula:

$$\eta = \frac{E_{foydalanilgan}}{E_{sarflangan}} \quad (1)$$

he lower the energy intensity, the higher the efficiency.

#### Specific Energy Consumption (SEC)

Specific energy consumption represents the amount of energy used per unit of product mass:

$$SEC = \frac{E}{m} \quad (2)$$

#### Efficiency Coefficient (Coefficient of Performance)

$$\eta = \frac{A_{foydali}}{A_{umumiy}} \cdot 100\% \quad (3)$$

#### Classification of Energy Efficiency

Energy efficiency is categorized into several key areas:

- Technological Efficiency — focus on equipment performance;
- Economic Efficiency — focus on cost reduction;
- Environmental Efficiency — focus on waste and emission reduction;
- Organizational Efficiency — focus on management system effectiveness.

Improving energy efficiency is a priority in modern economics, playing a vital role in resource conservation, production cost reduction, and environmental



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sustainability. Research indicates that energy efficiency levels depend on a set of interrelated fundamental factors:

1. **Technical and Technological Factors** Technical factors directly determine the physical level of energy consumption:

- **Obsolescence and Physical Wear of Equipment:** Outdated machinery consumes 30-50% more energy than modern equivalents. Physical wear leads to increased friction and mechanical losses.
- **Energy Transmission Losses:** Resistance in electrical grids, transformation losses, and poor insulation in thermal pipelines are primary drivers of inefficiency.
- **Technological Innovation:** Implementing Automated Process Control Systems (APCS) and Variable Frequency Drives (VFD) allows for real-time energy optimization.

2. **Organizational and Management Factors** A systemic approach and proper management can significantly reduce energy waste:

- **Optimization of Production Modes:** Reducing "idle mode" time and aligning peak production hours with energy system capacities.
- **Work Schedule and Logistics:** Organizing shifts based on differentiated energy tariff rates enhances economic performance.

3. **Human Factors and Intellectual Potential** The efficiency of any high-tech system depends on the competence of the personnel:

- **Staff Qualifications:** Employees trained in energy management (ISO 50001) principles approach resource utilization more consciously.
- **Violation of Operating Rules:** Failure to follow technological regulations causes energy waste and premature equipment failure.

4. **External and Macroeconomic Factors** External environments also impact enterprise performance:

- **Climate and Natural Conditions:** Ambient temperature and humidity directly affect the workload of cooling and heating systems.
- **Energy Prices and Tariff Policy:** Price fluctuations in a market economy stimulate enterprises to invest in energy-saving technologies.

**Methods for Improving Energy Efficiency**

**Technical and Engineering Solutions** Technical modernization provides the fastest and most tangible results:



- High-Efficiency Electric Motors: Transitioning to IE3 and IE4 class motors can reduce electromechanical losses by 10-15%.
- Variable Frequency Drives (VFD): Controlling motor speed based on real-time load in pump and ventilation systems can save up to 30% of electricity.
- LED Lighting and Intelligent Sensors: Integrating LED technology with motion sensors minimizes lighting energy consumption.

#### Organizational-Management Methods

- Energy Monitoring and Targeting: Continuous control of consumption across units to identify anomalous waste.
- Load Shifting: Moving production cycles from peak hours to off-peak periods to achieve economic efficiency.

#### Digital and Innovative Methods (Industry 4.0)

- Internet of Things (IoT): Utilizing a network of "smart" meters and sensors for real-time data collection.
- Artificial Intelligence (AI) and Big Data: Analyzing vast datasets to forecast energy demand and automate equipment optimization.

#### Methodological Basis for Assessing Energy Efficiency

To determine the efficiency of energy consumption, the following methods presented in Table 1 are utilized.

**Table 1**

Method Name	Description and Scope of Application
Energy Audit	A comprehensive assessment of an object's energy status, establishing the energy balance, and identifying energy loss points.
Statistical Analysis	Investigating the correlation between energy consumption and production volume based on historical data.
Mathematical Modeling	Representing energy consumption through functional dependencies in the form of $E=f(P,T,X)$ and calculating optimal values.
AI-Based Analysis	Modeling non-linear processes and identifying consumption trends using neural networks.

#### Organizational Methods

In describing organizational methods, demonstrating their integration with technical solutions strengthens the scientific foundation. These methods represent



low-cost or no-investment measures that yield high efficiency. It is recommended to expand these points as follows:

1. Energy Monitoring This method involves not only tracking consumption but also real-time data collection and analysis.

Objective: To identify energy waste and establish "baseload" consumption levels.

Practical Significance: Utilizing Smart Meters to build a database for each workshop or individual large-scale equipment. This data subsequently serves as the primary training data for the AI model.

2. Load Optimization A method of reducing electrical grid stress by correctly distributing production capacities over time.

Strategy: Shifting energy-intensive processes from "peak" hours (hours of maximum electricity consumption) to "valleys" (periods of low consumption).

Economic Impact: Allows for a significant reduction in costs within multi-tariff billing systems (if implemented at the enterprise).

Linking Organizational Methods with AI: To link organizational methods with AI, the following logical chain can be utilized:

### **Data is collected through Monitoring.**

The AI algorithm forecasts the load profile for the next day based on this data.

Based on the Organizational Decision (load optimization), equipment operating schedules are adjusted according to the AI forecast.

Recommended small Table 2 follows.

**Table 2**

Method	Current State	Optimized State (Proposal)
Monitoring	Monthly billing and manual reporting	Real-time digital monitoring and data acquisition
Load Management	Irregular and unscheduled equipment startup	Planned operating schedule based on AI forecasting

### **Methods for Assessing Energy Efficiency**

The following methods are utilized to determine energy efficiency:

- Energy Audit
- Statistical Analysis



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- Mathematical Modeling
  - Artificial Intelligence-Based Analysis

### The Correlation Between Energy Efficiency and Economic Efficiency

The relationship between energy efficiency and economic efficiency serves as a fundamental pillar for the economic component of the dissertation. These two concepts are complementary categories, yet they are measured using different sets of indicators.

Their correlation can be analyzed across three primary dimensions:

1. The Share of Energy Costs in Production Costs In industrial enterprises, a significant portion of the product cost—ranging from 10% to 40% depending on the sector—is attributed to energy resources.

- Correlation: An increase in energy efficiency (reduction in kWh consumption) leads directly to a decrease in production costs and enhances the enterprise's market competitiveness.

- Mathematical Expression:

$$I_s = \frac{E_{jami} \cdot T_{tarif}}{V_{mahsulot}}$$

### Artificial Intelligence and Energy Efficiency

The link between Artificial Intelligence (AI) and energy efficiency is not merely a technological novelty; it is the cornerstone of the "Digital Energy" revolution in industry. While traditional methods (statistics and auditing) rely heavily on human intervention, AI analyzes thousands of variables per second to make autonomous, data-driven decisions.

The impact of AI on increasing efficiency can be analyzed across four priority areas:

1. Demand Forecasting By leveraging historical data, weather forecasts, and production schedules, AI (specifically Machine Learning) can predict an enterprise's future energy requirements with 95-98% accuracy.

- Result: Enterprises avoid over-purchasing energy and can proactively anticipate "peak" loads.

- Method: LSTM (Long Short-Term Memory) neural networks yield the best results when working with time-series data.



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2. Predictive Maintenance A sudden spike in an equipment's energy consumption often signals an underlying fault.

- Role of AI: By analyzing vibration, temperature, and current flow in motors and transformers, AI provides early warnings before equipment failure.
- Economic Impact: Faulty machinery invariably wastes more energy. AI intervention can reduce this waste by 10-15%.

3. Dynamic Load Balancing AI synchronizes production lines in a specific sequence to ensure that total power consumption does not exceed established limits.

- Algorithm: Genetic algorithms or Reinforcement Learning are utilized to construct the most optimal operating schedules.

1. Real-time Process Optimization AI systems continuously adjust operational parameters to maintain the highest possible efficiency levels during active production cycles.

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