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Article

Methodological Approaches To Assessing The Efficiency Of Production Resource Utilization In Dairy Processing Enterprises

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Abstract: This article examines the theoretical and methodological aspects of assessing the efficiency of production resource utilization in dairy processing enterprises. It discusses the composition of production resources, their influence on the economic performance of enterprises, and the advantages and limitations of the principal methods used to assess efficiency. Taking into account the technological characteristics of the dairy processing industry, a system of indicators reflecting the utilization of labor, material and technical, financial, and energy resources is proposed. A methodological approach combining individual indicators, comprehensive assessment, econometric analysis, and data envelopment analysis is also developed. The research findings can be used to substantiate management decisions aimed at optimizing resource consumption, reducing production costs, and improving economic efficiency in dairy processing enterprises.

Keywords: dairy processing industry, production resources, resource efficiency, labor productivity, material resources, fixed production assets, energy efficiency, production costs, comprehensive assessment, econometric analysis.

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1. Introduction

The sustainable development of industrial enterprises is directly associated with the rational utilization of production resources, reduction of production costs, and increased utilization of existing production capacities. Improving the efficiency of production resource utilization is particularly important from economic and organizational perspectives in the dairy processing industry, which is a major branch of the food industry [1].

Production in dairy processing enterprises consists of interconnected stages, including raw material reception, quality testing, cooling, storage, pasteurization, homogenization, packaging, and distribution of finished products. Labor, material, technical, and energy resources are used at each stage. The perishability of raw materials, stringent storage requirements, technological losses, and substantial energy consumption necessitate systematic assessment of resource utilization efficiency in these enterprises [2].

Efficient utilization of production resources involves not only increasing output but also reducing raw material losses, ensuring uninterrupted equipment operation, improving labor productivity, and maintaining consistent product quality. Therefore, evaluating enterprise performance solely through revenue or profit indicators is insufficient [3]. A comprehensive examination of the relationship between resource inputs and production outcomes is required [4].

Scientific studies in this field have proposed various approaches to assessing production efficiency. In particular, Ruales Guzmán and co-authors examined the potential application of data envelopment analysis to evaluate the productivity of dairy industry enterprises [5]. Gregory, Roberts, and Hader investigated methods for assessing labor productivity in dairy processing plants. These studies demonstrate the importance of considering the specific characteristics of production processes rather than relying exclusively on isolated indicators [6]. At the same time, assessing the efficiency of different types of resources in dairy processing enterprises using a unified methodological approach, identifying relationships among indicators, and linking the findings to managerial decisions remain relevant challenges [7].

2. **Methodology**

The assessment of production resource utilization efficiency has evolved from traditional productivity measurement toward multidimensional approaches that consider the interaction among labor, capital, materials, energy, and production outcomes. This transition is particularly important in dairy processing, where economic performance depends on technological continuity, raw material quality, energy consumption, equipment utilization, and production losses. Farrell established the fundamental framework for measuring productive efficiency by distinguishing technical efficiency (the maximum output obtainable from a given combination of inputs) from allocative efficiency (the selection of an economically appropriate input combination under prevailing prices). Applied to dairy processing, this implies that an enterprise is not efficient merely because it produces a large volume of dairy products; the volume must be achieved with economically justified quantities of raw milk, labor, electricity, thermal energy, packaging materials, and capital equipment.

Charnes, Cooper, and Rhodes developed data envelopment analysis (DEA), a nonparametric approach that evaluates the relative efficiency of decision-making units using multiple inputs and outputs, and Banker, Charnes, and Cooper extended it by introducing variable returns to scale. Unlike traditional productivity ratios, DEA assesses several resource categories simultaneously, and the variable-returns model suits dairy enterprises that operate at different capacities: a small enterprise may face higher unit costs because of limited equipment utilization, whereas larger capacity does not automatically guarantee higher technical efficiency. The reliability of DEA results nevertheless depends on the comparability of the enterprises and the quality of the selected indicators.

Ruales Guzmán, Rodríguez Lozano, and Castellanos Domínguez applied DEA to 19 Colombian dairy companies, using current assets, property, plant and equipment, non-current liabilities, and equity as inputs and revenue and profit as outputs. They identified seven efficient decision-making units, demonstrating the usefulness of DEA for benchmarking dairy enterprises. However, a financial-variable model does not capture physical resource consumption such as electricity, water, raw milk losses, or equipment downtime, so an expanded DEA framework incorporating technological indicators is needed. Coelli, Rao, O'Donnell, and Battese systematized frontier analysis and productivity decomposition, which makes it possible to distinguish changes in technical efficiency from technological progress and scale effects. This distinction matters because output gains may result from new equipment, better workforce organization, reduced losses, or higher capacity utilization, and these causes should be assessed separately.

Energy is a major resource component in dairy processing: electricity is used for refrigeration, pumping, mixing, compressed-air systems, and packaging, while thermal energy is used for pasteurization, cleaning, evaporation, and drying. Xu and Flapper examined energy use and efficiency strategies in global fluid-milk processing and in butter, concentrated milk, milk powder, and whey-related production. They demonstrated the value of benchmarking energy consumption at the level of production processes and showed that specific energy consumption differs considerably across product categories and facilities, so benchmarks should reflect product structure and technology. Rad and Lewis emphasized reliable resource consumption data and benchmarking, and linked energy efficiency, water conservation, waste reduction, and production costs, which supports an integrated system of indicators. Briam, Walker, and Masanet showed that the choice of energy allocation method significantly influences the interpretation of efficiency in enterprises producing several products on shared infrastructure, so allocation must be transparent and technically justified. Simulation modeling, such as the computer simulation framework for energy use, greenhouse gas emissions, and process economics in fluid milk production makes it possible to evaluate changes in refrigeration systems, pasteurization conditions, production schedules, and equipment before capital investments are made.

Production efficiency is also related to quality management, because defective products and process deviations increase resource consumption. Ruales Guzmán, Castellanos Domínguez, and Brun developed and validated instruments identifying 32 quality

management practices and seven productivity indicators for the dairy industry, demonstrating the need to integrate quality considerations into performance evaluation. Gregory, Roberts, and Hader contributed an early method for evaluating labor productivity in milk plants. Because personnel requirements vary across production stages, equipment configurations, and automation levels, labor productivity should be interpreted together with other indicators: a reduction in staff may raise output per worker while increasing maintenance costs or reducing operational flexibility.

The reviewed literature shows that dairy processing efficiency is a multidimensional phenomenon. Integrating technological, financial, environmental, and organizational indicators is therefore a more comprehensive approach than relying on individual productivity measures.

The methodological foundation of the study comprises a systems approach, economic analysis, comparison, classification, the coefficient method, comprehensive assessment, and economic-mathematical modeling. Resources are classified into labor, material and technical, financial, and energy categories and examined in relation to production outcomes. Labor efficiency is assessed through employee productivity, use of working time, qualification levels, and organization of production; material resources through raw milk consumption, auxiliary and packaging materials, and production losses; fixed production assets through equipment capacity, technical condition, operating time, and production volume; energy resources through electricity and thermal energy per unit of output, refrigeration system efficiency, and use of energy-saving technologies; and financial resources through production expenses, unit costs, working capital turnover, profit, and profitability, examined alongside resource consumption.

The study proposes three interrelated directions of assessment. The first determines the efficiency of individual resource categories through specific indicators, helping to identify changes in resource consumption and problems at particular production stages. The second is a comprehensive assessment that combines labor productivity, material intensity, fixed asset productivity, energy intensity, and profitability into a unified system; because these indicators have different units, they must be normalized to a comparable scale and the weighting coefficients justified. The third comprises econometric analysis, which identifies statistical relationships between resource factors and production outcomes, and data envelopment analysis, which evaluates the relative efficiency of enterprises using multiple input and output indicators. A key feature of the methodology is that production resources are treated as an interconnected system, which accounts for how changes in the use of one resource affect the consumption of other resources and final economic outcomes.

3. Results

The study systematized the principal methodological approaches to assessing production resource utilization efficiency in dairy processing enterprises and proposed a system of indicators reflecting industry-specific characteristics.

First, the limitations of evaluating production resource efficiency using a single indicator were established [8]. Labor productivity reflects employee performance; material intensity indicates material consumption; fixed asset productivity describes the utilization of fixed production assets; energy intensity reflects energy requirements; and profitability represents financial outcomes. Analyzing these indicators together enables a broader assessment of enterprise performance.

Second, the need to account for the technological characteristics of dairy processing was identified [9]. The perishability of raw milk, refrigeration and storage requirements, technological processing stages, and diversity of finished products directly affect resource utilization efficiency. Therefore, raw material losses, capacity utilization, and energy consumption should be analyzed together with general economic indicators [10].

Third, a methodological approach integrating specific indicators into a comprehensive assessment system was proposed. This approach facilitates comparisons between enterprises, identification of strengths and weaknesses in resource utilization, and justification of management decisions. Indicator selection should avoid duplication and the repeated measurement of the same economic phenomenon [11].

Fourth, the methodological importance of econometric modeling in identifying relationships between production resources and enterprise outcomes was substantiated. This approach allows assessment of the relationships between labor, fixed capital, material resources, energy consumption, and production volume or value added. However, the reliability of results depends on data quality, sample size, and appropriate model specification.

Fifth, the potential of data envelopment analysis to determine relative efficiency among enterprises was discussed. This method helps identify enterprises achieving higher production outcomes with available resources and establish benchmarks for comparing the performance of other enterprises.

Sixth, the need to link economic and technological indicators when developing managerial decisions to improve production resource efficiency was substantiated. Reducing raw material losses, minimizing equipment downtime, introducing energy-efficient technologies, improving employee qualifications, and digitalizing production processes are important directions for increasing resource efficiency [12].

It should be emphasized that these findings consist of theoretical and methodological analysis and proposals. Since calculations based on actual enterprise-level statistical data were not performed, the article does not report numerical efficiency results or enterprise rankings.

4. Discussion

When selecting methods for assessing production resource utilization efficiency in dairy processing enterprises, it is necessary to consider the characteristics of enterprise operations, product mix, and availability of information.

The specific-indicator method is straightforward and practically convenient, allowing problems related to individual resource categories to be identified quickly. However, it does not cover all aspects of enterprise performance. For example, an increase in labor productivity may indicate higher production output while energy consumption or raw material losses increase simultaneously. Therefore, conclusions based on individual indicators should be checked against other resource indicators [13].

The comprehensive assessment method makes it possible to integrate several indicators into a single system. However, its results depend on indicator selection, normalization, and weighting. Arbitrary weights may artificially exaggerate or diminish the importance of certain resources. Consequently, the criteria for selecting weights should be explicitly stated, and the sensitivity of the results should be tested.

Econometric modeling identifies statistical relationships between resources and production outcomes. It is important for quantitatively substantiating economic decisions intended to improve resource efficiency. Nevertheless, the existence of a statistical relationship does not necessarily imply causality. Factors such as technological level, product mix, equipment depreciation, raw material quality, and capacity utilization should also be considered [14].

Data envelopment analysis is distinguished by its ability to account for multiple resource and outcome indicators simultaneously. It can identify relatively efficient enterprises and use their performance as a benchmark for others. However, the results depend on the selected group of enterprises, the variables included, and data quality.

As an original methodological approach, the study proposes integrating these methods in successive stages. Initially, specific indicators are used to assess individual resource categories. Next, comprehensive assessment produces an aggregated picture of enterprise performance. When sufficient statistical data are available, econometric analysis and data envelopment analysis are used to investigate resource efficiency determinants and differences between enterprises in greater depth.

The practical significance of this approach lies in assessing resource utilization efficiency not only through financial outcomes but also in conjunction with technological losses, energy consumption, and capacity utilization in production processes.

The findings are consistent with, and extend, the reviewed literature. The DEA application of Ruales Guzmán et al. relied on financial variables; the proposed framework complements such models with physical and technological indicators,

namely raw milk losses, energy intensity, capacity utilization, and equipment downtime, so that efficiency reflects how resources are actually consumed and not only their financial value. Likewise, the evidence of Xu and Flapper and Briam et al. that energy performance depends on product mix and allocation method implies that energy-intensity indicators should be calculated by product category, with transparent allocation rules, before enterprises are compared.

The staged structure of the approach also has practical implications. Where enterprises lack long statistical series, specific indicators and comprehensive assessment can be applied immediately and still reveal losses and inefficient production stages, whereas econometric analysis and DEA become appropriate as larger and more reliable plant-level datasets accumulate. Interpreting labor productivity together with equipment, energy, and quality indicators helps managers avoid decisions that improve one indicator at the expense of another, for example, workforce reductions that raise output per worker but increase maintenance costs [15].

Several limitations should be acknowledged. The study is theoretical and methodological, and no calculations were performed with actual enterprise-level data; the proposed system of indicators, weighting procedures, and DEA specification have therefore not been empirically validated. Comprehensive assessment is sensitive to normalization and weighting, DEA results depend on the sample of enterprises and the variables included, and econometric estimates indicate association rather than causality. Future research should apply the framework to plant-level data from dairy processing enterprises, test the sensitivity of alternative weighting schemes, compare DEA models with constant and variable returns to scale, and examine whether the proposed indicators explain differences in costs and profitability.

5. Conclusion

This study shows that assessing production resource utilization efficiency in dairy processing enterprises requires an interconnected system of indicators covering labor, material and technical, financial, and energy resources, and that the technological characteristics of the industry, including raw material perishability, storage and refrigeration requirements, technological losses, and high energy consumption, must be built explicitly into the assessment. Combining specific indicators with comprehensive assessment and, where data allow, econometric modeling and data envelopment analysis provides a staged methodological basis for identifying shortcomings, comparing enterprises, and directing managerial action toward reducing raw material losses, ensuring continuous equipment operation, introducing energy-saving technologies, increasing labor productivity, and digitalizing production, thereby improving economic performance, optimizing costs, and strengthening competitiveness; empirical validation with enterprise-level data remains the next step.

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