# Improving Production Resource Efficiency in Dairy Processing Enterprises: An Integrated Conceptual Framework for Emerging Economies

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***Abstract:*** *Efficient use of production resources is an important condition for improving the economic performance and competitiveness of dairy processing enterprises. The industry faces specific operational challenges associated with the perishable nature of raw milk, fluctuations in raw material supply, high material and energy requirements, and the generation of secondary resources during processing. This article develops an integrated conceptual framework for improving production resource efficiency in dairy processing enterprises. The study applies a comparative and analytical review of scientific literature on technical efficiency, energy consumption, circular economy, and process-level resource management. The findings are synthesised into five interconnected management dimensions: resource allocation, production process optimisation, energy efficiency, circular resource use, and digital monitoring. The framework emphasises that resource efficiency should be assessed not only through cost reduction but also through resource productivity, production capacity utilisation, material losses, energy intensity, and the economic value of recovered by-products. The proposed approach provides a theoretical basis for subsequent empirical research and for developing practical resource-efficiency assessment tools for dairy processing enterprises in emerging economies.*

***Keywords:*** *dairy processing industry; production resources; technical efficiency; resource productivity; energy efficiency; circular economy; production management; emerging economies*

## Introduction

The efficient use of production resources is a central issue in industrial economics because the competitiveness of manufacturing enterprises depends not only on production volumes but also on the productivity of raw materials, labour, equipment, energy, and financial capital. In the food-processing sector, these relationships are particularly important because production processes depend on the continuous availability of raw materials, compliance with quality requirements, and the coordination of multiple technological operations. Dairy processing represents a specific segment of the food industry. Raw milk is perishable, its supply may fluctuate seasonally, and its transformation into finished products requires coordinated processing, cooling, storage, packaging, and distribution operations. Inefficiencies at one stage may consequently affect the performance of the entire production system.

Previous research has demonstrated that technical efficiency in dairy processing is associated with organisational characteristics, management capacity, and the utilisation of production facilities. Beber, Lakner and Skevas [1], examining 243 dairy processing firms in southern Brazil, reported an average technical efficiency score of 77%. Their findings also highlighted the importance of management capacity and unused processing capacity. These

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results illustrate that improving performance does not necessarily require proportional increases in resource inputs; it may also require better organisation and utilisation of existing productive assets.

Energy use constitutes another important dimension of dairy-processing efficiency. Xu and Flapper [2] examined energy consumption across global dairy processing facilities and identified substantial differences in energy intensity between products, countries, and individual plants. Such differences indicate that resource-efficiency improvements should account for the characteristics of specific production processes rather than rely exclusively on general cost-reduction measures.In parallel, circular economy research has examined opportunities to retain material and energy value within industrial production systems. Stanchev et al. [3] investigated anaerobic treatment of dairy-processing effluents and its contribution to resource recovery and energy savings. This perspective broadens the concept of efficiency by considering whether secondary outputs can be transformed into economically useful resources. Despite these developments, the practical management of production resources requires an integrated approach that connects operational efficiency, energy consumption, material recovery, and management information. The purpose of this article is therefore to develop a conceptual framework for improving production resource efficiency in dairy processing enterprises, with particular relevance to emerging economies.

Materials and Methods

The study uses a conceptual and analytical research design based on a comparative review of scientific literature concerning dairy processing efficiency, energy use, circular economy, and production management. The selected literature was examined according to three criteria: relevance to dairy processing or closely related food-manufacturing processes; contribution to the understanding of resource use or production efficiency; and applicability to enterprise-level management decisions.

The analysis consisted of three stages. First, the main resource-related challenges of dairy processing were identified. Second, the reviewed studies were compared to determine the principal mechanisms through which enterprises may improve resource productivity. Third, the identified mechanisms were integrated into a conceptual framework linking resource inputs, production processes, management practices, and operational outcomes. The study is conceptual rather than econometric. It does not use a primary enterprise-level dataset, estimate a production function, or calculate original efficiency scores for Uzbek dairy processors. Accordingly, the proposed framework represents an analytical synthesis intended to guide subsequent empirical testing.

Results

*The specific characteristics of resource management in dairy processing.* The efficiency of dairy processing enterprises is determined by the interaction of several resource categories. Raw milk is the principal material input, while equipment, labour, energy, water, packaging materials, and financial capital support its transformation into finished products.

The characteristics of these resources create interdependent management challenges. Inadequate coordination between raw milk supply and processing capacity may lead to underutilisation of equipment or increased losses. Poorly coordinated production schedules may increase downtime, while inefficient thermal processes may raise energy consumption. In addition, the treatment or disposal of processing by-products may create costs while

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leaving potentially recoverable material value unused. Consequently, production resource efficiency should be understood as the relationship between economically valuable output and the resources consumed to produce it. This definition requires attention to both the quantity and quality of output, as well as to losses and the utilisation of available capacity.

The following dimensions are particularly relevant:

- Raw material efficiency: the relationship between the quantity of raw milk processed and the volume of saleable products obtained.
- Technical and capacity efficiency: the utilisation of processing equipment and installed production capacity.
- Labour productivity: the volume or value of output generated per employee or unit of labour time.
- Energy and water efficiency: the consumption of energy and water per unit of output.
- Financial resource efficiency: the relationship between working capital, operating expenditure, inventory turnover, and production results.
- Secondary resource utilisation: the extent to which by-products and recoverable material flows are converted into useful outputs.

These dimensions should be evaluated jointly because improvement in one indicator does not necessarily guarantee improvement in overall enterprise performance.

*Integrating technical efficiency and production management*

Technical efficiency provides a useful basis for evaluating whether an enterprise can increase output using its existing resources. The study by Beber, Lakner and Skevas [1] demonstrates the relevance of plant-level analysis and the importance of management capacity and production-capacity utilisation.

For dairy processors, this perspective suggests that the assessment of resource efficiency should distinguish between insufficient resource availability and inefficient use of existing resources. These are different management problems and require different interventions. Where raw material availability is the principal constraint, improving procurement coordination and supply reliability may be necessary. Where equipment is underutilised, production scheduling, product-mix planning, and coordination between processing stages may be more appropriate. Where material losses are high, process control and quality management may offer greater benefits than expanding production capacity. The proposed framework therefore connects resource inputs with the processes through which they are transformed into marketable products. It also recognises that capacity utilisation and management practices must be assessed together: high utilisation alone does not establish efficiency if it is accompanied by excessive energy consumption, material losses, or declining product quality.

Energy efficiency as a component of economic performance. Energy consumption is an important operational cost in dairy processing because different products and technological operations have different energy requirements. Xu and Flapper [2] show that energy intensity varies considerably across dairy products and processing facilities.

This variation suggests that enterprise-level energy management should begin with the identification of energy-intensive operations. Depending on the production configuration, these may include heating, pasteurisation, refrigeration, evaporation, drying, cleaning, and compressed-air systems.

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A practical assessment should distinguish between total energy expenditure and energy intensity. Total expenditure reflects the overall scale of operations, whereas energy intensity indicates the amount of energy consumed per unit of production. A reduction in total energy use may result from lower output rather than from improved efficiency. For this reason, energy indicators should be interpreted alongside production volumes and product composition.

The economic assessment of energy-saving measures should also consider investment costs, operating costs, equipment performance, and expected service life. Without enterprise-level data, it is not possible to determine which intervention would provide the highest return for a particular dairy processor. Nevertheless, energy-intensity monitoring offers a basis for identifying operational weaknesses and comparing performance over time.

Circular economy and the utilisation of secondary resources

Circular resource management extends conventional efficiency analysis by examining the potential value of material flows that would otherwise require treatment or disposal. In dairy processing, whey and wastewater are important examples of secondary streams. Depending on their composition, available technology, product quality requirements, and market conditions, these streams may provide opportunities for resource recovery. However, such opportunities should not automatically be treated as profitable. Their economic feasibility depends on the cost of collection, separation, treatment, equipment, energy, quality control, and marketing.

Stanchev et al. [3] demonstrate the relevance of evaluating dairy-processing effluents in terms of both environmental performance and resource recovery. Their research provides a basis for considering anaerobic treatment not merely as a waste-management operation but also as a potential source of recoverable energy. For enterprise management, the principal implication is that material efficiency should be evaluated across the production system. A secondary stream may create value when recovered, but the additional processing required may also generate costs. Investment decisions should therefore compare the expected value of recovered resources with the full costs of recovery and the alternative costs of treatment or disposal.

The proposed framework incorporates circular economy principles as a distinct but interconnected component of resource management. This allows enterprises to assess material losses and recovery opportunities without assuming that every recovery technology is economically justified.

An integrated framework for resource-efficiency management

The synthesis of the reviewed literature results in a five-dimensional framework.

Table 1.

Integrated dimensions of production resource efficiency in dairy processing enterprises

| Dimension | Main management focus | Suggested indicators |
|---|---|---|
| Resource allocation | Availability and coordination of raw materials, labour, capital, and equipment | Raw material availability; inventory turnover; capacity utilization |
| Production process optimisation | Coordination of technological operations and reduction of losses | Material yield; downtime; production losses per unit of output |

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| | | |
|---|---|---|
| Energy and water management | Reduction of resource intensity without compromising product quality | Energy use per unit of output; water use per unit of output |
| Circular resource utilisation | Recovery and economically viable use of secondary material flows | Share of recoverable by-products utilised; recovery cost; net economic value recovered |
| Digital monitoring and management | Timely measurement of resource consumption and operational performance | Data completeness; frequency of monitoring; deviations from resource-use targets |

The framework connects each resource category with management decisions and measurable indicators. Its central principle is that resource efficiency should not be reduced to a single financial ratio. Instead, it should be assessed through a set of complementary indicators reflecting input consumption, process performance, and the economic value of output. The dimensions are interdependent. Better raw material planning may reduce losses and improve equipment utilisation. More reliable process monitoring may help identify excessive energy consumption. Circular resource recovery may reduce disposal requirements but may also require additional capital and operating expenditure. Digital monitoring can support the coordination of these dimensions by providing timely information on resource use and production performance. However, digitalisation should be treated as an enabling management mechanism rather than as an efficiency outcome in itself. Its contribution depends on data quality, the relevance of selected indicators, and the ability of managers to act on the information obtained.

Discussion

The proposed framework contributes to the analysis of production resource efficiency by integrating several dimensions that are often considered separately. Technical efficiency focuses on the relationship between inputs and output, energy analysis identifies differences in resource intensity, and circular economy research examines the recovery of material and energy value. Combining these perspectives enables a more comprehensive assessment of production performance.

The framework also has implications for emerging economies, where the availability of detailed enterprise-level data may constrain sophisticated quantitative analysis. A structured set of operational indicators can provide an initial basis for monitoring resource use and identifying areas requiring further investigation. Once consistent data have been collected, the framework can be extended through benchmarking, productivity analysis, or production-frontier methods. For dairy processing enterprises in Uzbekistan, the framework may be relevant to the assessment of raw material losses, capacity utilisation, energy consumption, labour productivity, and secondary resource recovery. However, its practical effectiveness cannot be established without applying it to actual enterprise data. Differences in plant size, product mix, processing technology, supply arrangements, and market conditions may lead to different efficiency profiles.

Several limitations should be recognised. First, the article develops a conceptual framework rather than testing a causal model. Second, the selected literature does not provide a representative dataset for Uzbek dairy processing enterprises. Third, the proposed indicators require consistent definitions and comparable measurement periods

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before they can be used for inter-enterprise benchmarking. Future empirical research should apply the framework to a sample of dairy processing enterprises, collect comparable operational and financial data, and test the relationship between management practices and resource-efficiency outcomes. Such research could examine whether capacity utilisation, energy intensity, material yield, and the adoption of digital monitoring are associated with differences in enterprise productivity and operating costs.

5. Conclusion

This article develops an integrated conceptual framework for improving production resource efficiency in dairy processing enterprises. The analysis demonstrates that resource efficiency involves more than reducing operating expenditure: it requires coordinated management of raw materials, production capacity, labour, energy, water, financial resources, and secondary material flows.

Five dimensions were identified: resource allocation, production process optimisation, energy and water management, circular resource utilisation, and digital monitoring. Their integration provides a basis for selecting indicators that reflect both operational performance and economic outcomes.

The framework offers a theoretical starting point for assessing resource efficiency in dairy processing enterprises in emerging economies, including Uzbekistan. Its contribution is the structured integration of production management, technical efficiency, energy use, and circular resource recovery within a single analytical approach.

The proposed framework has not yet been empirically validated for Uzbek dairy processing enterprises. Its practical value should therefore be evaluated through enterprise-level data collection and subsequent quantitative analysis. This would make it possible to identify the most significant sources of resource inefficiency and assess the economic feasibility of specific improvement measures.

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