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Energy Consumption and Energy Costs Based on Time-of- Day Tariffs in Seafood Processing Units in Kerala, India

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Abstract

Energy conservation in seafood processing is crucial due to the highly energy-intensive nature of its main stages such as pre-processing, processing, and storage, which must operate under cold chain conditions. The variability of energy tariffs based on Time of Day (TOD) significantly impacts the economic sustainability of these operations. This study evaluates the electrical energy consumption patterns of seafood processing units in South India, categorized by production capacity. Primary data were collected from 10 seafood processing units, assessing energy consumption during Normal Load Time (NLT), Peak Load Time (PLT), and Off-Peak Load Time (OLT) over a one-year period. Results revealed that smaller capacity units (<30 T/D) accounted for 56% of total production during PLT, despite energy tariffs being highest during this time. These low-capacity units also exhibited higher mean energy consumption and costs compared to larger units, suggesting inefficiencies. The findings highlight the need for optimized energy management strategies, such as rescheduling production to lower-tariff periods and adopting more energy-efficient technologies. Implementing such measures could reduce energy costs and improve the overall profitability of seafood processing operations, particularly for smaller units.

Keywords: Energy consumption, energy efficiency, seafood processing units, time of day tariff, electrical energy.

Introduction

The global consumption of aquatic animal foods has seen a remarkable increase, reaching an estimated 162 million tonnes in 2021, up from just 28 million tonnes in 1961 (Food and Agricultural Organization [FAO], 2023). This surge in consumption has significantly influenced the seafood industry, where 45% of the total production is consumed fresh, while the remaining 55% undergoes processing through freezing (29%), canning (14%), and curing (12%) methods (Pedro & Nunes, 2007). As a result, the seafood industry has become a crucial player in global trade, with seafood exports growing by 20% since the 1970s, driven by rising demand and higher market prices (FAO, 2022).

In 2022, India's seafood sector achieved record exports valued at US$ 8.09 billion, amounting to 17,35,286 metric tonnes (MPEDA, 2023). Kerala, with its 118 seafood processing units, plays a pivotal role in this sector. Energy is indispensable in the seafood processing industry, particularly for preserving fish beyond fresh consumption. Key energy-intensive operations include refrigeration, ice production, air conditioning, drying, and smoking (Parker & Tyedmers, 2015). The primary goal of energy management within this context is to reduce energy consumption and production costs while maintaining product quality (Miller, 1986).

Energy efficiency is increasingly recognized as a cornerstone of global energy transition strategies (Zuberi et al., 2020) and understanding the specific energy consumption of each product is essential for effective budgeting, forecasting, and planning (Jekayinfa, 2007). However, many seafood processing units lack detailed information on their energy consumption patterns. This gap underscores the importance of internal monitoring and energy auditing, which can enhance energy efficiency and reduce costs, especially in an environment of fluctuating energy prices.

A thorough analysis of energy consumption is essential for creating an effective energy management plan. Implementing energy-saving measures is

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critical for improving efficiency in various sectors, including seafood processing, while also aligning with national energy policies by adopting modern, energy-efficient technologies (Ibrik & Mahmoud, 2005). Seafood processing plants consume significant amounts of electricity, particularly for operating compressors in freezers, cold storage, ice-making machines, and for lighting and air conditioning (United Nations Environment Programme [UNEP], 1999). Due to the perishable nature of seafood, a reliable and continuous power supply is crucial to ensure its safety and quality (Gokoglu & Yerlikaya, 2015).

Energy consumption in seafood plants is influenced by several factors, including the age, size, level of automation, processing intensity, management practices, layout, equipment efficiency, and the variety of products processed in the processing plant (UNEP, 1999). Rising energy costs significantly affect the profitability of these operations, making cost-reduction measures through improved energy efficiency essential (Department of Fisheries and Aquaculture, 2007). Compressor units, which account for 73% of the total power demand, are particularly energy-intensive, with consumption further impacted by the shape and size of frozen products (Bureau of Energy Efficiency [BEE], 2015).

Enhancing energy efficiency not only reduces operating costs but also lowers emissions, contributing to a smaller footprint (University of Warwick, 2005; Boopendranath & Hameed, 2013). Revising tariffs could further reduce energy subsidies and improve service quality (Klug et al., 2022). Energy audits play a key role in identifying consumption patterns and devising conservation strategies (Department of Fisheries and Aquaculture, 2007). These audits pinpoint areas where energy use can be optimized, encouraging operational and behavioural changes critical for meeting climate goals (Koasidis et al., 2022). Addressing financial barriers to energy efficiency may also require supplementary programs that provide financial incentives (Schubert, Breitschopf, & Plötz, 2021).

Optimizing energy use in the seafood industry requires minimizing consumption at every stage, from raw material procurement to product delivery (En, Shao, Fan, Ye, & Jun, 2014). In Kerala, seafood processing plants primarily rely on electricity and diesel as their main energy sources (BEE, 2015). However, high electricity prices can negatively impact on the economic sustainability of the industry (Nguyen, 2008). The Kerala State Electricity Board (KSEB) utilizes Time of Day (TOD) metering with variable tariffs depending on the time of day: normal rates between 6 a.m. and 6 p.m., peak rates between 6 p.m. and 10 p.m., and off-peak rates from 10 p.m. to 6 a.m., with the highest charges during peak hours. By taking advantage of dynamic tariffs, seafood plants can reduce costs by shifting energy-intensive activities to off-peak times when prices are lower (Förster, Harding, & Buhl, 2024).

This study aims to quantify production output during each TOD tariff period (normal, peak, and off-peak), assess hourly production efficiency across different tariff periods, evaluate energy utilization efficiency in kilowatt-hours per tonne, and analyze energy cost efficiency in terms of mean energy costs per tonne of final product during normal, peak, and off-peak times.

Materials and Methods

The study focused on energy usage and energy cost analysis in seafood processing units located in central Kerala, specifically those with European Union (EU) approval. The analysis categorized these units based on their installed production capacities. A year-long study was conducted using a pre-tested form survey at 10 selected seafood processing units in Cochin, Kerala. These units, involved in processing various seafood like shrimps, fish, squid, cuttlefish, and octopus, were assessed for their electricity consumption patterns according to the time-of-day (TOD) tariff system and their production capacity measured in tonnes per day (T/D).

Of the ninety-one EU-approved seafood industries in Kerala (MPEDA, 2021), 51% have a processing capacity ranging between 25-55 metric tonnes per day. For this study, the selected companies were categorized into four groups: <30 T/D (3 units), 30-40 T/D (2 units), 40-50 T/D (2 units), and >50 T/D (3 units). Classifying companies into capacity-based groups ensures a representative sample of the diverse scales of operation in the seafood processing industry. This allows for the inclusion of small, medium, and large processors, reflecting a broad cross-section of the industry. By grouping companies into well-defined categories, it becomes easier to compare and contrast their performance, output, and challenges. This can help in making meaningful generalizations across different segments of the industry. Using standard ranges or logical groupings based on existing industry norms helps align

Table 1. Comparison of Seafood Processing Units Based on Machinery Age, Mechanization, Production, Energy Use and Energy Cost.

Classification of seafood unit (T/D)	Average age of the machinery (years)	Level of mechanization	Average production (T/Hr)	Average Energy use (kWh/T)	Average cost of energy (INR/kWh/T)
<30	14	Semi-automated	28.58	774.45	12030
30-40	12	Semi-automated	49.89	1090.75	9632
40-50	7	Semi-automated and upgraded machines	85.5	729	6257
>50	5	Semi-automated and upgraded machines	94.79	948.33	8219

the study with broader research frameworks. Data on infrastructure characteristics, processing activities, refrigeration systems, and energy consumption (based on approximate monthly electricity bills) were collected using questionnaire to quantify key factors such as total production, mean production per hour, energy utilization, and energy costs in these units

The study compared the performance of these categories of seafood processing units based on TOD energy consumption—during normal load time (NLT, 6 am to 6 pm), peak load time (PLT, 6 pm to 10 pm), and off-peak load time (OLT, 10 pm to 6 am). The cost per unit of energy (kWh) according to the TOD tariff was INR 5.5 during NLT, INR 8.5 during PLT, and INR. 4.3 during OLT. Statistical analysis was carried out using Microsoft Excel and PAST v.3.22 (Hammer, Harper, & Ryan, 2001) to assess total production, mean production per hour, energy utilization, and energy cost across the selected unit's significance was fixed at $p<0.05$

The total daily production was determined by assessing the production capacity utilization of each unit, from the raw material receiving stage to the final storage stage, representing only the quantity of product produced in a day. Energy consumption for each unit from raw material receiving to the final storage stage was then calculated based on energy usage as indicated in the invoices.

Results and Discussion

Quantity produced and energy consumed are important efficiency indicators for production units (Sanchez et al., 2023), which enable them to attain sustainability goals, primarily through reducing, wastage of energy and energy costs (Aderemi, A. O., Ilori, Aderemi, H. O., & Akinbami, 2009).

The total average energy consumption of the representative samples were 1,46,277 kWh and the total average electricity charges based on monthly invoices were Rs. 8,09,433. In general, electricity supplied by Kerala State Electricity Board (KSEB, Government of Kerala) was the prime source of energy, though, diesel-based backup power generators were set to meet the demand in case of grid power supply failure or scheduled power cut from the grid.

The total seafood production in the 10 seafood processing units during the study period was estimated at 9516 MT. The percentage contributions by different units classified based on production capacities to total seafood production are depicted in Fig.1. The highest production level was recorded by high production capacity units (>50T/D, 33% and 40-50 T/D 30%) (Fig.1).

Units with a capacity of less than 30T/D contributed 56% of their total production during Peak Load Time (PLT) and recorded the lowest production at 17% during Off-Peak Load Time (OLT). Similarly, units in the 30-40T/D category produced 41% of their total output during PLT and 23% during OLT. This pattern was also observed in the 40-50T/D and >50T/D categories (Fig. 2). Notably, the low-capacity units (<30T/D) demonstrated exceptionally high production during PLT, contributing 56%, which surpassed the output of the other categories.

In the Normal Load Time (NLT) period (A), production increased from 16.67 T/Hr in units with a capacity of less than 30 T/D to 67.5 T/Hr in units

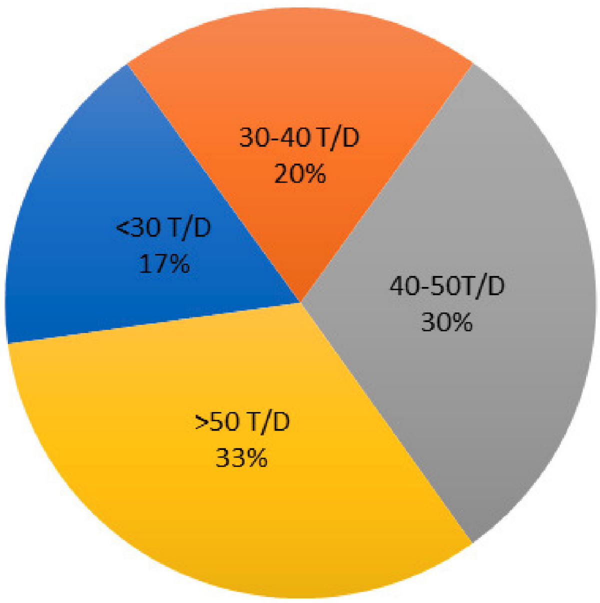

Fig. 1. Percentage contributions of different categories of plants to the total production

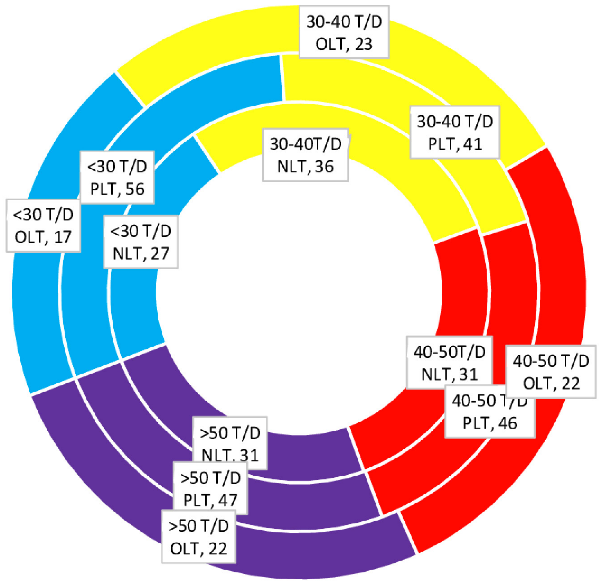

Fig. 2. Percentage contributions of different types of units to total production across the three Time of Day (TOD) tariff periods: (NLT – Normal Load Time, PLT- Peak load time and OLT- Off-peak load time)

with a capacity of more than 50 T/D. The mean production varied significantly across the different capacity groups (F = 91.9, p < 0.001), as shown in Fig. 3 (i) (A). The lowest average production was observed in units with less than 30 T/D capacity (28.58 ± 6.09 T/Hr), which was significantly lower than the other groups. Production steadily increased

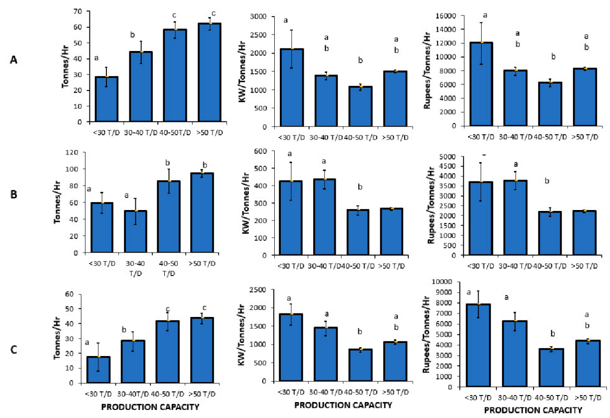

Fig. 3. Mean ± SD values of (i) production per hour, (ii) energy use and (iii) cost of energy in NLT (A), PLT (B) and OLT (C) in various capacity classes of seafood processing units operated in Cochin.

with higher capacity categories, reaching 62.15±3.90 T/Hr in units with more than 50 T/D capacity. However, Tukey's pairwise analysis showed no significant difference between the 40-50 T/D and >50 T/D groups.

During the Peak Load Time (PLT) period (B), production ranged from 28.75 T/Hr in the 30-40 T/D units to 105 T/Hr in the 40-50 T/D units. Significant differences in mean production among the capacity groups was observed (F = 28.4, p < 0.01), as depicted in Fig. 3 (i) (B). The lowest mean production during PLT was recorded in the 30-40 T/D units (49.89 ± 15.45 T/Hr), which was not significantly different from units with less than 30 T/D capacity (59.79 T/Hr). The higher-capacity units (40-50 T/D and >50 T/D) had higher mean production rates (85.5 ± 14.51 T/Hr and 94.79 ± 4.36 T/Hr, respectively), with no significant difference between them.

In the Off-Peak Load Time (OLT) period (C), the lowest mean production was observed in the units with less than 30 T/D capacity (17.65 ± 9.47 T/Hr), which was significantly lower than all other groups (F = 42.7, p < 0.01), as shown in Fig. 3 (i) (C). Production steadily increased, reaching 43.75 ± 3.51 T/Hr in the >50 T/D units, with no significant difference between the 40-50 T/D and >50 T/D groups, according to Tukey's pairwise analysis.

In the Normal Load Time (NLT) period (A), energy consumption varied greatly within the <30 T/D units, ranging from 66.37 to 4918.54 kWh/T. The mean energy consumption for these units was significantly higher, at 2116 ± 515 kWh/T, as shown in Fig. 3 (ii) (A).

During the Peak Load Time (PLT) (B) and Off-Peak Load Time (OLT) (C), energy consumption in the <30 T/D units was lower, averaging 428 ± 381 kWh/T in PLT and 1829 ± 1006 kWh/T in OLT. In the 30-40 T/D units, energy consumption remained lower across all time periods: 1384 ± 98 kWh/T in NLT, 437.27 ± 18 kWh/T in PLT, and 1451.67 kWh/T in OLT, although these values were not significantly different from those in the <30 T/D units.

The 40-50 T/D units recorded the lowest energy consumption across all load periods: 1072 ± 98 kWh/T in NLT, 261 ± 151 kWh/T in PLT, and 854 ± 29 kWh/T in OLT, as shown in Fig. 3 (ii) (A), (B), and (C). This lower energy consumption could be attributed to a shortage of workers during overtime. However, these values were not significantly different from the >50 T/D units, which had energy consumption of 1509 ± 37 kWh/T in NLT, 269 ± 19 kWh/T in PLT, and 1067 ± 148 kWh/T in OLT.

Fig. 3 (iii) illustrates the mean energy cost (INR/kWh/T) during Normal Load Time (NLT), Peak Load Time (PLT), and Off-Peak Load Time (OLT) across different capacity categories. The highest energy costs were recorded during NLT, with mean values ranging from 6257 ± 538 INR/kWh/T in 40-50 T/D units to 12030 ± 3003 INR/kWh/T in units with less than 30 T/D capacity.

During PLT, energy costs ranged from 2201 ± 1290 INR/kWh/T in 40-50 T/D units to 3715 ± 3307 INR/kWh/T in <30 T/D units, a pattern that continued into the OLT period, as shown in Fig. 3 (iii) (C). Overall, lower-capacity units consistently had higher energy costs across all load periods, while 40-50 T/D units registered the lowest mean energy costs, likely due to more efficient machinery.

Efforts to identify and implement changes within the operational chain can result in substantial reductions in energy consumption, as evidenced by a 13.1% decrease in energy usage per ton of seafood produced in Ecuador (Sánchez, Reséndiz, Alvarado, & Martínez, 2023). Numerous energy-saving measures have been identified in seafood processing (Aderemi et al., 2009; BEE, 2015; Alzahrani, Petri, & Rezgui, 2020; Indzere et al., 2020), emphasizing the critical role of optimized energy management in the industry.

In the present study, energy consumption in seafood processing units of varying production capacities was analyzed across different times of day (TOD) based on a differential tariff regime. It was observed that these units tended to schedule higher production during Peak Load Time (PLT), despite the energy tariff being twice that of Off-Peak Load Time (OLT) and 1.3 times that of Normal Load Time (NLT). This underscores the need to align production schedules with energy tariff periods in order to reduce cost and improve profitability.

Interestingly, units with lower installed capacities experienced higher energy costs, per unit weight while those with higher capacities, despite their larger production volumes, recorded lower energy consumption and costs. This is likely due to the performance efficiency of machinery, as many high-capacity units (40-50 T/D and >50 T/D) were equipped with advanced technology and modern equipment, with an average machinery age of 5 years, and were regularly maintained. In contrast, low-capacity units (<30 T/D and 30-40 T/D) used machinery that was more than 10 years old, which likely contributed to their higher energy costs. Production efficiency and energy consumption in food processing units are influenced by several factors, including the age and efficiency of equipment (UNEP, 1999; Aderemi et al., 2009). Therefore, it is important that machinery in seafood processing, which handles energy-intensive processes such as freezing, heating, cooling, and drying, require regular maintenance to avoid energy wastage (Murali et al., 2021).

The comparison of seafood processing units based on factors such as machinery age, mechanization level, production output, energy use, and energy cost are also presented in **Table 1**. The findings emphasize that good management practices, effective policy and planning, and optimal supply chain management are critical for improving the efficiency and sustainability of seafood processing units (Amulya, Murali, Alfiya, Delfiya, & Samuel, 2018).

The results of this study suggest that seafood processing units can improve profitability by aligning their production processes in line with the differential energy tariff (Time of Day, or TOD) and also by conducting periodic energy audits. Typically, seafood processing units in the state operate both day and night shifts, however the study noticed that 60–70% of the daily production is processed during the night shift (6 p.m. to 6 a.m.). During the day, products are prepared and loaded into freezers, allowing it to freeze overnight, which reduces the need for manpower during night shifts. These frozen products are then packed during the next day shift.

A significant portion of production, particularly in lower-capacity units, occurs during Peak Load Time (PLT) from 6 p.m. to 10 p.m., when energy costs are highest. Given this, there is a clear opportunity for these units to reschedule their production processes to take advantage of lower TOD tariff rates, which would help reduce energy costs.

Liu, R., Liu, Z., Chen, Li, and Zhang (2024) emphasize that the main goal of TOU (Time-of-Use) tariffs is to enhance energy utilization and cost efficiency. By strategically managing consumption during various tariff periods, incorporating energy storage solutions, emphasizing renewable energy sources, and minimizing grid dependence during peak hours, this approach caters to both grid stability and economic efficiency. TOU tariffs encourage consumers to modify their energy usage behaviors, thereby reducing peak demand and fostering a more balanced energy grid. Moreover, efficient energy usage not only cuts operating costs but also lessens the carbon footprint of products; excessive energy consumption can result in inefficient processing and increased emissions (University of Warwick, 2005). Thus, adopting TOU tariffs can play a significant role in promoting sustainability while optimizing operational efficiency.

Conclusion

This study analysed energy consumption and costs across ten seafood processing units in Kerala, categorized by their production capacities, to evaluate the impact of Time-of-Day (TOD) tariffs on energy use. The findings revealed that smaller capacity units (<30 T/D) had higher energy costs and inefficiencies, particularly during Peak Load Time (PLT), when tariffs were highest. These units exhibited higher energy consumption per tonne of product, mostly due to older machinery and less efficient operational practices compared to higher-capacity units. On the other hand, larger units (>50 T/D) demonstrated better energy efficiency, benefiting from advanced technology and modernized equipment.

The results emphasize the need for small and medium processing units to adopt energy management strategies such as shifting production to Off-Peak Load Time (OLT) or Normal Load Time (NLT) to reduce costs. Implementing energy-efficient technologies and conducting regular energy audits can further improve profitability and sustainability. Furthermore, policy interventions to support these transitions, including technical assistance and incentives, could enhance energy efficiency across the seafood processing sector, contributing to both economic and environmental goals.

In conclusion, optimizing energy use through TOD tariff alignment and equipment upgrades, particularly for smaller units, is crucial for enhancing the operational efficiency and sustainability of seafood processing in Kerala. Future research should explore the influence of external factors such as seasonal supply and market demand on energy consumption patterns, as these variables were not considered in this study.

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