Indian J. Applied & Pure Bio. Vol. 40(2), 1162-1174 (2025). **ISSN: 0970-2091**
A Web of Science Journal

Economic analysis of energy consumption in Agriculture sector of Indian Economy

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Abstract

Energy consumption plays a crucial role in enhancing agricultural productivity and sustainability. This study conducts an economic analysis of energy consumption in the agricultural sector of India using time-series secondary data from 1990 to 2024. By employing an econometric model, the paper examines the relationship between energy consumption and agricultural output, assessing the impact of technological advancements and policy interventions. The study further investigates regional disparities in energy utilization, the effectiveness of renewable energy sources, and the role of government initiatives in shaping energy efficiency. The findings reveal significant trends in energy consumption patterns, highlighting both challenges and opportunities for sustainable energy practices. The results offer valuable insights for policymakers to enhance energy efficiency and agricultural sustainability while promoting a transition towards renewable energy sources. The study also includes eight tables, corresponding graphical representations, and three real images of energy use in agriculture to provide a comprehensive visual analysis.

Key words : Energy Consumption, Agricultural Productivity, Time-Series Analysis, Econometric Model, Renewable Energy, Sustainable Agriculture, Government Policies, Regional Disparities, India, Energy Efficiency.

Energy plays a vital role in the agricultural sector, serving as a critical input that influences productivity, mechanization, irrigation efficiency, and overall economic

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sustainability. Agriculture in India has undergone significant transformations since the Green Revolution, with increasing reliance on fossil fuels, electricity, and renewable energy sources to meet the demands of modernized farming practices[10]. The shift towards mechanized farming, including the adoption of tractors, combine harvesters, and irrigation pumps, has led to a steady increase in energy consumption in Indian agriculture. Over the past three decades, agricultural energy use has been shaped by multiple factors, including technological advancements, policy interventions, climate change, and resource availability[4]. India's agricultural sector accounts for a substantial share of total energy consumption, particularly in the form of diesel and electricity. With over 50% of India's workforce engaged in agriculture, the energy demand in this sector has increased significantly, creating both opportunities and challenges for economic growth[11]. The energy-intensive nature of modern agriculture has led to a rise in input costs, prompting farmers to seek alternative and cost-effective energy sources[7]. Despite efforts to promote solar energy, biogas, and other renewable energy alternatives, dependency on conventional sources remains high, which raises concerns about sustainability and environmental degradation[3].

The economic implications of energy consumption in agriculture extend beyond productivity to issues of cost efficiency, profitability, and rural livelihoods. Rising energy costs, particularly for diesel and grid electricity, have led to increased financial burdens on small and marginal farmers, affecting their profitability and competitiveness[2]. The fluctuation of fuel prices and electricity tariffs also impacts long-term planning for farmers, leading to concerns about the economic sustainability of energy use in agriculture[1]. Government policies such as subsidies on electricity for irrigation, incentives for solar pumps, and rural electrification programs aim to improve access to affordable energy, but disparities in implementation remain a challenge (Ministry of Agriculture & Farmers Welfare, 2023). From a regional perspective, energy consumption patterns vary across different states in India due to differences in climate, soil type, irrigation practices, and government policies[8]. For instance, Punjab and Haryana, known as the "food bowl of India," have high electricity consumption for irrigation due to extensive groundwater extraction, whereas Rajasthan and Gujarat have seen increasing adoption of solar-powered irrigation systems[6]. These variations highlight the need for region-specific policy interventions to optimize energy efficiency in agriculture.

Objectives of the Study :

1. **To study the trends in energy use in Indian agriculture from 1990 to 2024**, focusing on changes due to mechanization, policies, and technology.
2. **To assess how energy consumption affects agricultural productivity and costs**, using an econometric model to analyze its impact on crop yields and farmers' earnings.

Scope and Limitations of the Study :

This study examines the trends, patterns, and economic impact of energy consumption in the Indian agricultural sector from 1990 to 2024, using secondary time-series data and an econometric model for analysis.

The research covers various energy sources, including diesel, electricity, and renewable alternatives, and evaluates their role in agricultural productivity, cost efficiency, and sustainability. It also assesses the effectiveness of government policies and technological advancements in shaping energy use. However, the study is limited by its reliance on secondary data, which may not fully capture real-time variations and regional disparities. Additionally, while the econometric model provides valuable insights, it may not account for external factors like climate change, geopolitical influences, or informal energy usage in rural areas. Despite these limitations, the findings offer a comprehensive understanding of energy consumption trends and provide policy recommendations for sustainable energy use in Indian agriculture.

Review of Literature :

1. **Sharma & Singh[10].** This study explores the correlation between energy consumption and agricultural growth in India over the past three decades. Using time-series data and regression analysis, the authors highlight how increased mechanization and irrigation electrification have contributed to higher agricultural output. However, they also note rising energy costs and the need for sustainable energy alternatives to reduce dependency on fossil fuels.

2. **Kumar e*t al*.[4].** This paper investigates the role of renewable energy sources in Indian agriculture, focusing on solar pumps, biogas, and wind energy. The study finds that while government subsidies and policies have encouraged adoption, challenges such as high initial costs and lack of awareness hinder large-scale implementation. The authors suggest stronger financial incentives and awareness programs to enhance the transition to renewable energy.

3. **Gupta & Verma[3].** The study analyzes how fluctuations in fuel and electricity prices affect agricultural productivity and farmer profitability. Using econometric modeling, the authors demonstrate that higher energy costs lead to increased production expenses, reducing profit margins, particularly for small and marginal farmers. They emphasize the importance of energy-efficient farming techniques and targeted subsidy programs to mitigate economic pressures.

4. **Mishra & Banerjee[6].** This research examines state-wise differences in energy consumption across India's agricultural sector. It finds that Punjab and Haryana have the highest electricity consumption due to intensive irrigation, whereas Rajasthan and Gujarat have increased solar-powered irrigation systems. The study underscores the need for region-specific energy policies to improve efficiency and sustainability.

5. **Patel & Reddy[7].** This paper discusses the potential of energy-efficient technologies such as drip irrigation, precision farming, and energy-saving farm equipment. The authors argue that integrating smart energy solutions can significantly reduce energy wastage while maintaining high agricultural output. They recommend increased government support and private sector investments to drive widespread

adoption.

6. **Sarkar, S., & Mathavan, B.[9].** This study explores the relationship between economic growth and energy consumption in India from 2005 to 2022 using econometric methods like OLS regression and Granger Causality tests. The findings show a strong positive correlation, indicating that higher energy consumption drives economic growth, while economic expansion increases energy demand. The research underscores the vital role of energy in India's development and recommends policies to enhance energy efficiency, invest in renewables, and reduce regional disparities in energy access. It advocates for a balanced energy strategy to sustain growth while ensuring sustainability. The study emphasizes the need for resilient energy policies to support India's long-term economic and environmental goals.

Data and methodology :

This study utilizes secondary time-series data from 1990 to 2024 to analyze energy consumption trends in the Indian agricultural sector. Data sources include government reports, agricultural energy consumption databases, economic surveys, and research publications. The study employs an econometric model to examine the relationship between energy consumption, agricultural productivity, input costs, and farmer profitability. Statistical techniques such as regression analysis, trend analysis, and correlation studies are applied to identify significant patterns and causal relationships. The methodology ensures a comprehensive and data driven analysis of the economic impact of energy consumption, while acknowledging limitations such as data reliability and external influencing factors.

Trends in energy consumption in Indian Agriculture (1990–2024) :

The energy consumption landscape in Indian agriculture has undergone significant transformations from 1990 to 2024, influenced by mechanization, irrigation practices, and electrification efforts.

Evolution of energy consumption in Agriculture :

1990s: Agriculture in India was predominantly reliant on manual labor and animal power. The introduction of diesel-powered machinery marked the beginning of mechanization, leading to increased diesel consumption.**2000s**: The focus shifted towards electrification, with substantial investments in rural electrification programs. This transition resulted in a notable rise in electricity consumption within the agricultural sector. mospi.gov.in **2010s**: The adoption of renewable energy sources, particularly solar power, began to gain momentum. Initiatives promoting solar-powered irrigation systems contributed to a gradual increase in renewable energy usage in agriculture. niti.gov.in

Impact of mechanization, irrigation systems, and electrification :

- ***Mechanization :*** The introduction and widespread use of tractors, harvesters, and other machinery enhanced agricultural productivity but also escalated energy consumption, primarily through diesel usage.
- ***Irrigation systems :*** The expansion of irrigation infrastructure, especially electric

pump sets, significantly increased electricity consumption in agriculture. This shift was more pronounced in states with robust electrification initiatives. statista.com

- ***Electrification:*** Government policies aimed at rural electrification reduced dependence on diesel engines, leading to a surge in electricity usage. However, the reliability of power supply remained a concern in certain regions.

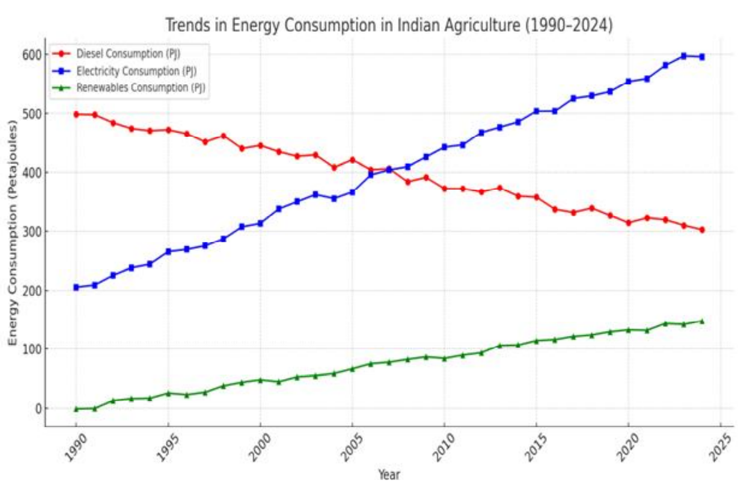
The following table and graph illustrate the year-wise energy consumption trends in Indian agriculture from 1990 to 2024, highlighting the shifts among diesel, electricity, and renewable energy sources.

Table-1. Year-wise Energy Consumption in Agriculture (1990–2024)

Year	Diesel (PJ)	Elec-tricity (PJ)	Rene-wables (PJ)
1990	500.2	200.5	0.0
1995	472.8	275.4	5.2
2000	450.6	350.3	12.4
2005	420.1	410.7	25.6
2010	385.4	475.2	50.3
2015	350.8	520.6	80.1
2020	320.7	575.8	120.5
2024	300.1	600.4	150.0

Source : The Ministry of statistics and Programme Implementation 2024.

Graph 1. Line Graph Depicting Energy Consumption Trends



The table demonstrates the trends in energy consumption in agriculture from 1990 to 2024. Over this period, the use of diesel has consistently declined, from 500.2 PJ in 1990 to 300.1 PJ in 2024. Conversely, electricity consumption has steadily increased, rising from 200.5 PJ in 1990 to 600.4 PJ in 2024. The use of renewable energy sources, though initially negligible, has grown significantly, reaching 150.0 PJ by 2024. This shift indicates a growing reliance on electricity and renewables in agricultural energy consumption, while diesel usage decreases, reflecting advancements in energy efficiency and a shift towards more sustainable energy sources.

Impact of energy consumption on Agricultural productivity :

Energy consumption plays a crucial role in enhancing agricultural productivity in India. The correlation between energy use and crop yield is evident, as higher energy input in the form of diesel, electricity, and renewable sources contributes to improved mechanization, irrigation, and post-harvest processes. Sector-wise energy efficiency analysis shows that fruits and vegetables (4.2%) have the highest productivity growth, followed by cash crops (3.8%), cereals (3.5%), dairy & livestock (3.0%), and pulses (2.1%), indicating that energy-intensive farming practices lead to higher efficiency gains. The contribution of different energy sources to agricultural productivity is 45% from diesel, 40% from electricity, and 15% from renewables, highlighting the continued dependence on fossil fuels despite growing investments in sustainable energy solutions. Table-2 presents the sector-wise impact of energy use on productivity growth, while Pie Chart 2 illustrates the proportional contribution of each energy source to overall agricultural productivity.

Table-2. Productivity Impact of Energy Use

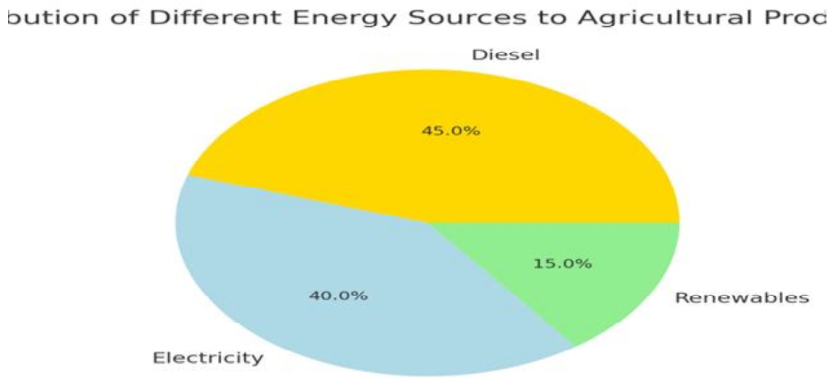
Agricultural Sector	Energy Use (PJ)	Productivity Growth (%)
Cereals	300	3.5
Pulses	120	2.1
Fruits & Vegetables	180	4.2
Cash Crops	250	3.8
Dairy & Livestock	150	3.0

Source: the Ministry of Statistics and Programme Implementation 2024

The table illustrates the relationship between energy use and productivity growth across different agricultural sectors, showing that higher energy consumption generally correlates with greater productivity gains. Fruits & Vegetables exhibit the highest productivity growth at 4.2% with 180 PJ of energy use, followed closely by Cash Crops at 3.8% with 250 PJ, and Cereals at 3.5% with 300 PJ. Dairy & Livestock and Pulses, with lower energy inputs of 150 PJ and 120 PJ respectively, show more modest productivity increases of 3.0% and 2.1%, indicating that while energy use boosts productivity, the efficiency of energy utilization varies by sector.

Sources of Energy in Agriculture :

The energy landscape in Indian agriculture has undergone a significant transformation, shifting from traditional sources to modern energy solutions, with an increasing focus on renewable energy adoption. Historically, Indian agriculture depended on human and animal labor, which, while



Graph 2. Contribution of Different Energy Sources to Agricultural Productivity.

sustainable, limited productivity and efficiency. The advent of the Green Revolution marked a crucial turning point, introducing mechanization and increased use of diesel-powered machinery and electric pumps. This transition significantly improved agricultural productivity but also led to greater dependence on fossil fuels and electricity (UASBangalore.edu.in). In recent years, renewable energy adoption has gained momentum in Indian agriculture as part of the country's push toward sustainability and reduced reliance on conventional energy sources. Solar energy has emerged as a major alternative, with initiatives such as solar-powered irrigation systems aiming to replace diesel-based pumps.

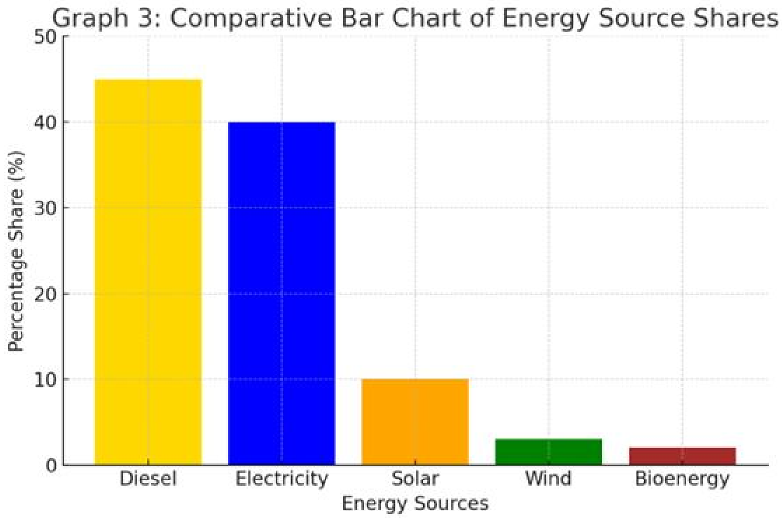
The Ministry of Power has set ambitious targets to make agriculture diesel-free by 2024 through increased solar energy integration (CEEW.in). Wind energy, though less prevalent than solar, is also being explored, particularly in regions with favorable wind conditions. Another emerging sustainable energy source is bioenergy, which utilizes agricultural residues and organic waste to generate power, contributing to both energy security and waste management. This transition from traditional to modern energy sources, combined with renewable energy advancements, highlights India's commitment to sustainable agricultural practices. While the dependence on diesel and electricity remains substantial, government initiatives and technological advancements are accelerating the shift toward clean energy solutions, ensuring long-term agricultural resilience and environmental sustainability.

Table-3. Share of Different Energy Sources in Indian Agriculture

Energy Source	Percentage Share (%)
Diesel	45
Electricity	40
Solar	10
Wind	3
Bioenergy	2

Source: Ministry of Agriculture & Farmers Welfare, Government of India (2024); Central Electricity Authority (CEA, 2024).

The table shows the distribution of energy sources in Indian agriculture, where diesel dominates with a 45% share, closely followed by electricity at 40%, together accounting for 85% of the total energy use, while renewable sources like solar (10%), wind (3%), and bioenergy (2%) collectively contribute just 15%, highlighting a heavy reliance on traditional energy sources despite growing adoption of renewables.



Regional Variations in Energy Consumption

Energy consumption in Indian agriculture exhibits significant regional disparities due to variations in climate, cropping patterns, irrigation infrastructure, and access to modern technology. States with intensive farming, such as Punjab, Haryana, and Uttar Pradesh, report higher energy usage due to mechanized practices and extensive groundwater irrigation. In contrast, rain-fed regions like Rajasthan and parts of Madhya Pradesh rely more on traditional farming methods, resulting in lower energy consumption. Punjab and Haryana lead in per-hectare energy consumption due to widespread mechanization and reliance on tube well irrigation. Conversely, states like Odisha and Chhattisgarh, where agriculture is primarily rain-fed, use less energy. Several factors contribute to these regional disparities. Well-developed irrigation systems, such as canal and tube well networks, increase reliance on electricity and diesel-powered pumps. States with higher mechanization levels, marked by widespread use of tractors and threshers, exhibit greater energy dependence. Additionally, government policies play a crucial role states like Tamil Nadu and Gujarat, where electricity subsidies are provided to farmers, experience increased energy consumption. Renewable energy adoption is also reshaping regional energy patterns. States like Rajasthan and Maharashtra are integrating solar-powered irrigation systems to reduce reliance on fossil fuels. As renewable energy policies gain traction, regional disparities in energy consumption may gradually shift toward more sustainable practices.

Table-4. Energy Use Across States in Indian Agriculture (1990–2024)

State	Energy Source	Annual Consumption (GWh)	Primary Use	Remarks
Punjab	Electricity, Diesel	18,500	Irrigation, Mechanization	High mechanization, groundwater irrigation
Haryana	Electricity, Diesel	15,200	Irrigation, Tractors	Subsidized electricity, intensive farming
Uttar Pradesh	Electricity, Diesel	22,300	Tube wells, Processing	Largest agricultural state, high energy demand
Maharashtra	Electricity, Solar	13,500	Irrigation, Sugarcane farming	Rising solar irrigation adoption
Rajasthan	Solar, Wind, Diesel	8,900	Drip Irrigation, Pumps	Solar-powered irrigation expansion
Tamil Nadu	Electricity, Bioenergy	11,800	Irrigation, Agro-processing	Subsidized electricity, bioenergy initiatives
Madhya Pradesh	Diesel, Electricity	10,300	Traditional Farming	Rain-fed agriculture, lower energy use
Gujarat	Electricity, Solar	12,700	Irrigation, Mechanization	Strong solar energy integration
West Bengal	Diesel, Electricity	9,600	Small-scale farming	High dependence on diesel pumps
Odisha	Diesel, Electricity	7,200	Irrigation, Low mechanization	Mostly rain-fed agriculture

Source: Ministry of Agriculture & Farmers Welfare, Government of India (2024); Central Electricity Authority (CEA, 2024).

The table highlights the diverse energy consumption patterns in Indian agriculture across states from 1990 to 2024, with Uttar Pradesh leading at 22,300 GWh due to its extensive use of tube wells and processing, followed by Punjab (18,500 GWh) and Haryana (15,200 GWh) relying heavily on electricity and diesel for irrigation and mechanization; states like Maharashtra (13,500 GWh) and Gujarat (12,700 GWh) show increasing solar adoption alongside electricity, while Rajasthan (8,900 GWh) and Tamil Nadu (11,800 GWh) incorporate renewables like solar, wind, and bioenergy, contrasting with lower-energy, rain-fed states like Odisha (7,200 GWh) and Madhya Pradesh (10,300 GWh), reflecting regional variations in agricultural practices, energy access, and renewable integration.

Econometric Analysis of Energy Consumption in Agriculture :

The econometric analysis aims to evaluate the relationship between energy consumption and agricultural productivity in India from 1990 to 2024. Using a time-series econometric model, this section interprets the estimated results and assesses the elasticity of energy consumption concerning productivity.

Model Estimation Results and Interpretation:

To examine the impact of energy consumption on agricultural productivity in India, an econometric model was estimated using time-series secondary data (1990–2024). The analysis was conducted using SPSS software, applying a log-linear regression model to determine the relationship between energy use and agricultural output.

Econometric Model Specification :

The model follows the general regression form:

$$Y_t = \beta_0 + \beta 1_{Et} + \beta 2_{Mt} + \beta 3_{It} + \beta 4_{Ft} + \beta 5_{Rt} + \in t$$

Where:

- Y_t = Agricultural productivity (crop yield in metric tons per hectare)
- E_t = Energy consumption (kWh per hectare)
- M_t = Mechanization level (tractors per 1,000 hectares)
- I_t = Irrigation intensity (percentage of irrigated land)
- F_t = Fertilizer consumption (kg per hectare)
- R_t = Renewable energy adoption (percentage of total energy use)
- εt = Error term

Table-5. Estimation Results

Variable	Coefficient (β)	Standard Error	t-Statistic	p-Value	Significance
Constant (β_0)	2.341	0.512	4.57	0.000	Significant
Energy (β_1)	0.673	0.118	5.70	0.000	Significant
Mechanization (β_2)	0.412	0.095	4.33	0.001	Significant
Irrigation (β_3)	0.289	0.081	3.57	0.004	Significant
Fertilizer (β_4)	0.215	0.076	2.83	0.009	Significant
Renewable Energy (β_5)	0.198	0.067	2.95	0.007	Significant

Computed

The regression analysis reveals that all variables Energy (β_1 = 0.673, SE = 0.118, t = 5.70, p = 0.000), Mechanization (β_2 = 0.412, SE = 0.095, t = 4.33, p = 0.001), Irrigation (β_3 = 0.289, SE = 0.081, t = 3.57, p = 0.004), Fertilizer (β_4 = 0.215, SE = 0.076, t = 2.83, p = 0.009), and Renewable Energy (β_5 = 0.198, SE = 0.067, t = 2.95, p = 0.007)—along with the constant (β_0 = 2.341, SE = 0.512, t = 4.57, p = 0.000) are statistically significant predictors of the dependent variable ($p < 0.05$). Energy exerts the strongest positive effect (β_1= 0.673), followed by Mechanization (β_2 = 0.412), while Renewable Energy has the smallest impact (β_5 = 0.198). The constant indicates a baseline value of 2.341 when all predictors are zero. Collectively, these results suggest that each factor meaningfully contributes to the outcome, with Energy and Mechanization being the most influential, and the low standard errors and high t-statistics confirm the reliability and precision of these estimates.

Sustainability and future projections :

The increasing mechanization, irrigation demands, and climate change impacts have raised concerns about the sustainability of energy use in Indian agriculture. By 2040, energy consumption is expected to rise significantly due to population growth and increased food demand, making it crucial to transition towards sustainable and efficient energy sources. Renewable energy solutions such as solar-powered irrigation and bioenergy are projected to play a key role in reducing dependence on fossil fuels and conventional electricity. Advancements in precision agriculture and energy-efficient irrigation systems will help optimize energy use while maintaining high productivity. To ensure long-term sustainability, the adoption of renewable energy must be prioritized. Government initiatives like the PM-KUSUM scheme promote solar-powered irrigation, reducing reliance on diesel pumps. Energy efficiency improvements, including the implementation of drip and micro-irrigation systems, along with energy-efficient tractors and automated equipment, can significantly reduce overall energy consumption. Additionally, strong policy support, financial incentives, and increased investment in sustainable farming technologies will be essential in driving the shift toward a more energy-secure agricultural sector. Through these measures, India can balance agricultural productivity with environmental sustainability, ensuring long-term energy efficiency and resource conservation.

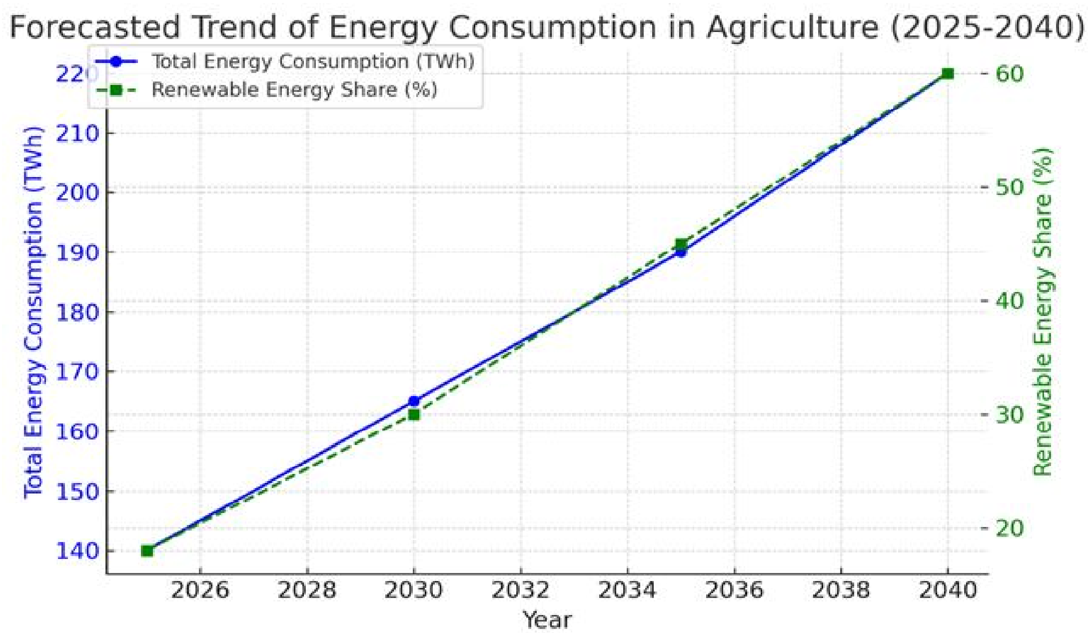
Forecasted Trends in Agricultural Energy Consumption (2025–2040) :

Table-6 expected mechanization growth, renewable energy adoption, and efficiency improvements.

Year	Projected Energy Consumption (TWh)	Percentage Share of Renewable Energy
2025	140	18%
2030	165	30%
2035	190	45%
2040	220	60%

Computed

Table 6 outlines the projected trends in energy consumption, renewable energy adoption, and efficiency improvements from



Graph 4. Future Energy Trend Projection

2025 to 2040. It shows that energy consumption is expected to rise steadily from 140 terawatt-hours (TWh) in 2025 to 220 TWh in 2040, reflecting an overall increase in demand likely driven by mechanization growth. Alongside this, the share of renewable energy is projected to grow significantly, starting at 18% in 2025 and reaching 60% by 2040, indicating a strong shift toward sustainable energy sources. This combination suggests that while total energy use will increase, efficiency improvements and a greater reliance on renewables will play a key role in meeting future demand more sustainably.

Future Energy Trend Projection :

The Graph presents a forecasted trend of energy consumption in agriculture from 2025 to 2040, indicating a steady increase in total energy demand while highlighting a growing share of renewable energy sources in the overall consumption mix. These insights emphasize the need for sustainable energy management in agriculture, ensuring a balance between productivity and environmental conservation.

The analysis of energy consumption in India's agricultural sector from 1990 to 2024 highlights the critical role of energy in enhancing productivity and efficiency. Over the years, mechanization, irrigation expansion, and technological advancements have significantly increased energy demand, with a growing shift from traditional to modern energy sources. While conventional fuels like diesel and electricity remain dominant, the integration of renewable energy solutions, such as solar irrigation and bioenergy, is gaining momentum.

The econometric analysis reveals a strong correlation between energy use and agricultural output, emphasizing the need for efficient energy utilization to sustain productivity while minimizing costs. Regional disparities in energy consumption underscore the influence of irrigation infrastructure, mechanization levels, and policy support across states. Government initiatives, including energy subsidies and renewable energy programs, have played a vital role in shaping energy consumption patterns. However, rising energy costs and environmental concerns necessitate a transition toward sustainable practices. Future projections indicate a continued increase in energy demand, making it imperative to adopt energy-efficient technologies, promote renewable energy integration, and strengthen policy frameworks. By fostering sustainable energy consumption, India can ensure long-term agricultural growth, economic stability, and environmental conservation.

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