



CENTRE FOR A
**People-centric
Energy Transition**

Pathways for a Low-Emission Agriculture Future in India

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About the Ashoka Centre for a People-centric Energy Transition (ACPET)

The Ashoka Centre for a People-centric Energy Transition (ACPET) is a research-focused, transdisciplinary centre within Ashoka University, India, established to drive a sustainable, equitable, and “people-centric” shift towards net-zero emissions. It bridges the knowledge gap in energy transition by collaborating with industry and government to create scalable solutions, covering areas like renewable energy, policy, and technology.

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1. Introduction

The agriculture sector remains the most critical component of the Indian economy, closing close to 45% of the total workforce and contributing approximately 16 to 18 percent of the country's Gross Value Added (GVA). In addition to its economic role, agriculture is also one of the major consumer of commercial energy reflecting the structural transformation in farming practices over the recent years. Rising irrigation intensity, expansion in farm mechanisation and increased dependence on electricity and petroleum products have significantly altered the the sector's energy demand profile.

Agriculture currently accounts for roughly **17 to 20 percent of total electricity consumption** in India, making it one of the largest electricity-consuming sectors in the economy. Electricity demand in agriculture is dominated by irrigation pumping, which relies heavily on groundwater extraction. India operates an estimated **30 to 32 million irrigation pump sets**, of which nearly **two-thirds are electrically powered**, with the remainder relying on diesel. As a result, irrigation pumping alone constitutes the bulk of electricity demand in the sector and represents a significant load on rural distribution networks.

Agriculture sector contributes to roughly 17 to 20 percent of total electricity consumption in India. The scale of irrigation related energy demand is closely linked to the expansion of groundwater-based irrigation. More than **60 percent of irrigated area** in India is now dependent on groundwater, compared to much lower shares in the early post-independence period. This expansion has enabled higher cropping intensity and increased agricultural output, but it has also resulted in steadily rising energy consumption. In many regions, the average efficiency of pump sets remains low, with wire to water efficiencies commonly estimated at **below 40 percent**. Consequently, the final energy consumed for irrigation pumping is substantially higher than the useful energy required for water lifting, amplifying the sector's overall energy demand.

In addition to electricity, agriculture remains a significant consumer of diesel. Diesel use is concentrated in mechanised field operations and in diesel powered pump sets, particularly in regions with limited or unreliable electricity access. India's tractor stock has expanded steadily and now exceeds **nine million units**, contributing materially to rural diesel consumption. Although mechanised operations consume less energy than irrigation pumping in aggregate, diesel use in agriculture accounts for a non-trivial share of total petroleum product consumption and has implications for fuel import dependence and emissions.

This report addresses these limitations by focusing exclusively on the demand side of the agriculture sector using a bottom-up analytical framework. Energy demand is derived

from physical activity indicators such as irrigation requirements, pump stock, and machinery usage, combined with technology specific efficiency assumptions. A central feature of the analysis is the explicit estimation of useful energy demand for irrigation pumping, which is subsequently converted into final energy consumption based on pump efficiency. In our analysis, useful energy demand for irrigation is estimated at **8.06 Mtoe in 2020**, increasing to **11.38 Mtoe by 2030**, highlighting the growing scale of irrigation related energy requirements.

The analysis evaluates agricultural energy demand under two scenarios that share identical activity assumptions but differ in their efficiency trajectories. By holding irrigation requirements and mechanisation levels constant, the study isolates the effect of pump efficiency improvements on total energy demand. This approach provides a transparent basis for assessing the potential of efficiency-oriented interventions to moderate growth in agricultural energy consumption.

2. Methodology and Modelling Approach

Energy consumption in the agriculture sector is estimated using a bottom up, equipment-based modelling approach. The methodology focuses on tractors and irrigation pumps, which together account for the majority of direct energy use in agricultural operations. By explicitly modelling these equipment categories, the approach captures the key drivers of energy demand arising from mechanisation and irrigation practices.

Tractor related energy demand is estimated by linking the physical stock of tractors to their utilisation characteristics and fuel or electricity consumption rates. Both diesel based and electric tractors are considered. Total energy consumption from tractors in a given year is calculated as the product of the number of tractors, the fraction of tractors by fuel type, the proportion of tractors assumed to be in active use, the fuel consumption rate or rated power of the tractor, and the average number of operating hours per year. This formulation ensures that energy demand reflects changes in equipment stock, technology composition, and usage intensity rather than being derived solely from historical fuel consumption trends.

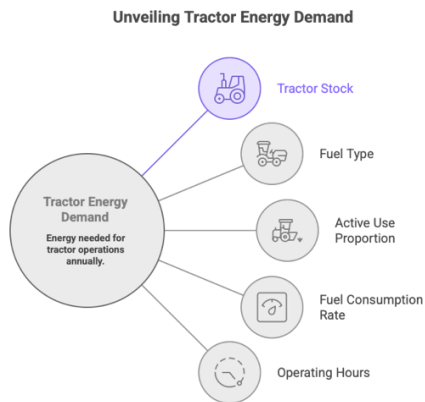


Figure 1: Parameters considered for estimation of Tractors

The number of tractors is modelled as a time varying stock that grows from a base year level according to an assumed compound annual growth rate, subject to an upper saturation limit. This saturation level represents the maximum feasible penetration of tractors in agriculture, beyond which growth slows and eventually stabilises. By imposing a saturation constraint, the model reflects the realistic evolution of mechanisation over time and avoids unconstrained growth in tractor numbers.

Once tractor stock is determined, total diesel and electricity consumption is calculated by applying technology specific shares and utilisation factors. Not all tractors are assumed to be operational at all times, and a utilisation factor is therefore used to represent the share of the tractor stock that is actively used in a given year. Fuel consumption for diesel tractors is calculated using an average litres per hour value, while electricity consumption for electric tractors is calculated using their power rating. These values are multiplied by assumed annual operating hours to obtain total energy consumption.

In addition to energy use, the methodology estimates capital and operating costs associated with tractors. Capital cost per tractor is projected over time using a cost escalation formulation that links base year and end year costs through an assumed rate of change. Total capital cost in a given year is calculated by multiplying the capital cost of a single tractor by the number of tractors sold in that year. Operating costs are estimated separately and include only maintenance costs, which are assumed to be a fixed percentage of the total capital cost of the tractor fleet. Fuel costs are excluded from operating costs, as they are accounted for separately through the energy demand calculation.

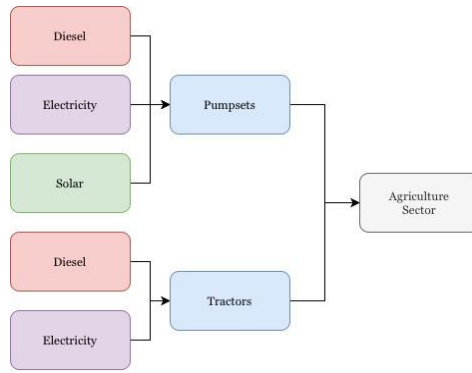


Figure 2: Technologies Considered

The evolution of tractor stock and utilisation is influenced by a range of structural drivers related to agricultural practices and rural economic conditions. These include precipitation patterns that affect cropping intensity, average landholding sizes, availability of farm labour, access to institutional credit, and the relative costs of mechanised versus manual or animal based operations. The potential to generate additional income through renting tractors for non agricultural uses, such as transport or construction, also contributes to higher utilisation rates. Policy measures that promote farm mechanisation are implicitly reflected in the assumed growth trajectories.

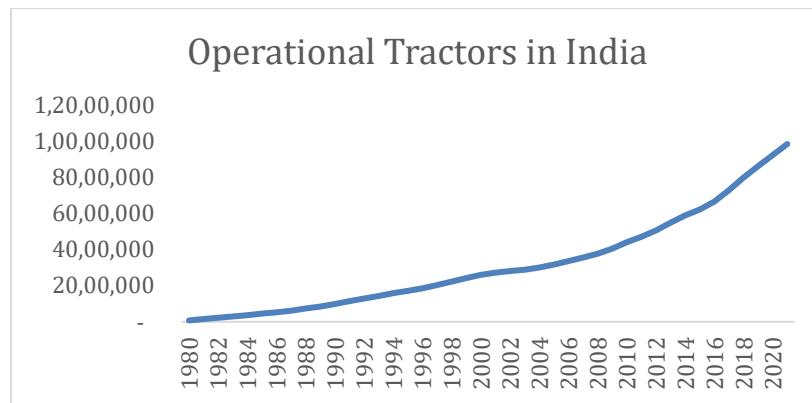


Figure 3: Demand for tractors in India

The modelling framework is underpinned by a set of explicit assumptions. Tractor density is assumed to be 50 tractors per thousand hectares, with net sown area taken as 140.02 million hectares. Based on official agricultural statistics, the number of tractors in operation in 2020 is estimated at approximately 7.77 million units. Of the total stock, 60 percent is assumed to be in active use in a given year. Average fuel consumption for an efficient diesel tractor is assumed to be 4.5 litres per hour. The average operational lifetime of a tractor is taken as 13 years. Tractor size is assumed to average 35 horsepower and is

held constant over time, including under more intensive cultivation scenarios. Annual utilisation is assumed to be 500 hours per tractor, consistent with observed usage ranges in Indian agriculture.

This methodology provides a transparent and physically grounded representation of tractor related energy demand in agriculture. By explicitly linking equipment stock, utilisation, and fuel intensity, the approach allows energy consumption to respond coherently to changes in mechanisation patterns, technology mix, and long-term structural drivers within the sector.

3. Scenario Definition and Design

The analysis of agricultural energy demand is undertaken using two contrasting scenarios that are designed to isolate the impact of technology efficiency on energy consumption. Both scenarios share a common structural framework, activity representation, and base year calibration. Agricultural activity levels, mechanisation pathways, and irrigation requirements are held identical across scenarios. This ensures that differences in energy demand outcomes arise solely from changes in technology performance rather than from variations in agricultural output or structural assumptions.

The **Business as Usual (BAU) scenario** represents the continuation of current practices in the agriculture sector. Under this scenario, the evolution of energy demand is driven by projected growth in farm mechanisation and sustained irrigation activity, while technology efficiency remains at baseline levels. Tractor fuel consumption per hour, pump efficiencies, utilisation rates, and equipment lifetimes follow existing patterns without any additional efficiency gains beyond those implicitly captured through normal equipment turnover. As a result, increases in final energy demand in the BAU scenario are primarily attributable to greater mechanisation intensity and continued reliance on irrigation pumping.

In the BAU scenario, energy demand from farm mechanisation increases in line with growth in tractor stock and utilisation. Diesel consumption per hour for tractors remains unchanged, and electricity consumption for electric tractors reflects current power ratings. Similarly, irrigation pumping energy demand increases proportionally to the useful energy required to lift water, with pump efficiencies held constant. This scenario therefore provides a reference trajectory against which the impact of alternative efficiency assumptions can be assessed.

The **Ambitious scenario** explores the potential to moderate agricultural energy demand through improved technological performance. In this scenario, all energy-using technologies in the agriculture sector are assumed to achieve a **10 percent improvement in efficiency** relative to the BAU case. This improvement is applied across the full range of

technologies considered in the analysis, including diesel tractors, electric tractors, and irrigation pump sets. The efficiency enhancement reduces energy consumption per unit of activity while maintaining the same level of agricultural service delivery.

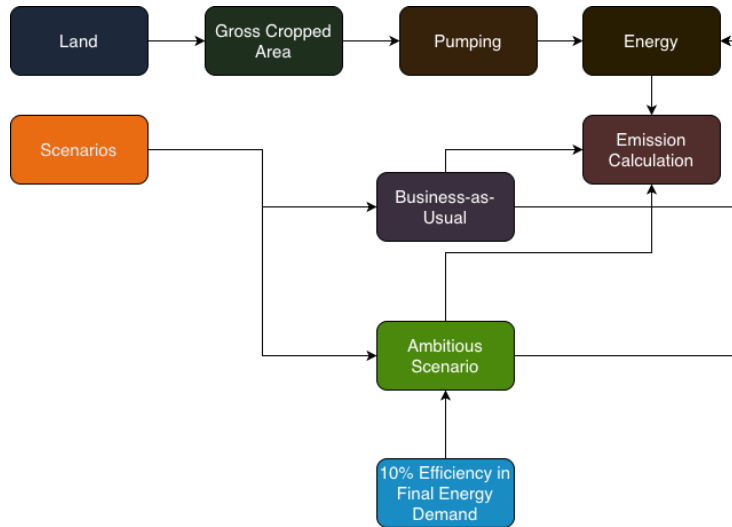


Figure 4: Methodology for Agriculture Demand Estimation

For farm mechanisation, the 10 percent efficiency improvement is implemented as a reduction in fuel consumption per hour for diesel tractors and a corresponding reduction in electricity consumption for electric tractors. Annual operating hours, tractor stock, and the share of tractors in active use remain unchanged. Consequently, total energy demand from mechanised operations declines relative to the BAU scenario purely due to improved efficiency.

For irrigation pumping, the efficiency improvement is reflected as an increase in pump efficiency. Useful energy demand for water lifting remains identical across scenarios, but final energy demand is reduced in the Ambitious scenario as less electricity or diesel is required to deliver the same irrigation service. This formulation ensures that efficiency improvements directly translate into lower final energy consumption without altering irrigation activity levels.

The Ambitious scenario does not assume structural shifts such as changes in cropping patterns, reductions in irrigated area, or accelerated electrification beyond existing trends. By limiting the scope of intervention to efficiency improvements alone, the scenario provides a conservative estimate of the potential energy savings achievable through improved technology performance.

Together, the two scenarios establish a clear analytical contrast. The BAU scenario reflects a continuation of existing trends in agricultural energy use, while the Ambitious scenario illustrates the extent to which efficiency improvements across all major technologies can moderate growth in energy demand. This scenario design enables

transparent comparison and provides a robust basis for evaluating the role of efficiency-oriented interventions in shaping future agricultural energy consumption.

3.1. Farm Mechanisation Energy Demand Requirements

Farm mechanisation has emerged as a central driver of energy demand in Indian agriculture, reflecting a long-term transition away from human and animal labour towards machine-based operations. This transition is evident in the steady increase in farm power availability over the past five decades. Total farm power availability has risen from **0.37 kW per hectare in 1971–72 to 3.05 kW per hectare in 2021–22**, representing a compound annual growth rate of approximately **4.3 percent**. This increase has been driven almost entirely by mechanised sources, particularly tractors, diesel engines, and electric motors, while the contribution of draught animals has declined sharply over the same period .

The expansion of mechanisation has fundamentally altered the composition of energy demand in agriculture. Tractors have become the dominant source of mobile farm power, with their contribution increasing from **0.02 kW per hectare in the early 1970s to nearly 1.93 kW per hectare by 2021–22**. At the same time, the contribution of diesel engines and electric motors used for stationary operations, including pumping and post-harvest activities, has increased to **0.37 kW per hectare and 0.57 kW per hectare**, respectively. This shift highlights the growing dependence of agricultural operations on commercial energy sources and explains the rising share of diesel and electricity in total agricultural energy consumption.

The increase in mechanised power availability has been closely associated with higher cropping intensity and productivity. Cropping intensity increased from **120 percent in the mid-1970s to over 141 percent by 2021–22**, while food grain productivity rose from **0.94 tonnes per hectare to 2.27 tonnes per hectare** during the same period. Importantly, this intensification has been accompanied by a substantial rise in energy use per unit of output, with farm power per unit of food grain production increasing from **0.46 kW per tonne to 1.34 kW per tonne**. These trends indicate that improvements in agricultural output have increasingly relied on energy-intensive mechanised inputs rather than on land expansion alone.

Despite these advances, mechanisation remains uneven across agricultural operations, with important implications for energy demand growth. Overall mechanisation levels are estimated at **40 to 45 percent**, with relatively high penetration in land preparation and harvesting for major cereals, but much lower adoption in operations such as sowing, weeding, and harvesting for non-cereal crops. As these under-mechanised operations

expand, particularly among small and marginal farmers, additional demand for tractor-mounted and self-propelled machinery is expected, leading to further increases in diesel and electricity consumption.

Farm size dynamics also play a critical role in shaping mechanisation-related energy demand. The net sown area per tractor has declined sharply from **487 hectares per tractor in 1975–76 to around 15 hectares per tractor by 2021–22**, indicating a much denser deployment of machinery. While this has improved timeliness of operations, it has also raised aggregate energy consumption, as a larger number of machines operate over smaller landholdings. The increasing prevalence of custom hiring models has further increased utilisation rates of tractors and other machinery, intensifying fuel and electricity use per unit of equipment stock.

Looking ahead, mechanisation is expected to deepen further, driven by labour shortages, declining average landholdings, and policy support for farm machinery adoption. The agricultural machinery market in India is projected to grow at a compound annual rate of **8.5 percent**, significantly faster than global averages, with increasing emphasis on non-tractor machinery such as power tillers, planters, harvesters, and precision equipment. This evolution suggests that energy demand from farm mechanisation will continue to grow, not only through an expansion of tractor stock but also through the diversification of mechanised operations that rely on both diesel and electricity.

In this context, energy demand associated with farm mechanisation is best understood as a function of equipment stock, utilisation intensity, and power ratings rather than as a fixed proportion of agricultural output. Explicitly accounting for these drivers is therefore essential for accurately estimating current and future energy requirements of the agriculture sector. The methodology adopted in this report reflects this perspective by linking mechanisation trends directly to fuel and electricity demand through physical activity and equipment-based parameters.

3.2. Modelling Tool Implementation

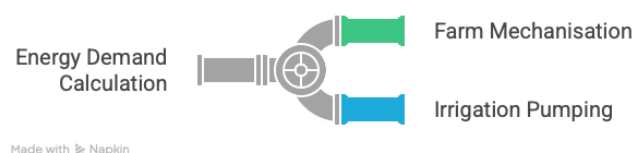
The modelling framework is implemented using a bottom-up, accounting-based energy demand modelling tool that allows explicit representation of agricultural activities, equipment stocks, and technology-specific energy intensities. The tool is designed to translate physical activity drivers into final energy demand through transparent and internally consistent calculations, making it well-suited for analysing sectors such as agriculture, where energy use is closely tied to equipment utilisation and service delivery.

Agricultural energy demand is represented using a hierarchical structure that disaggregates consumption by end use and equipment type. Farm mechanisation is modelled explicitly through tractor stock and utilisation, while irrigation-related demand is captured through pumping stock, useful energy demand for pumping and efficiency parameters of different types of pump sets. This structure ensures that the major source of energy demand is linked to the physical processes that generate it, rather than inferred from aggregate energy statistics.

All the key drivers of energy demand are implemented as time-varying parameters. Equipment stocks, such as the number of tractors and pumpsets, are represented as physical quantities that evolve based on growth and saturation assumptions. Utilisation parameters, including the share of different equipment in active use and annual operating hours, are applied to convert equipment stocks into activity levels. Technology characteristics, such as fuel intensity and efficiency, are specified separately for different equipment types, allowing endogenous calculation of fuel-specific energy demand.

Energy demand calculations follow a consistent accounting logic across all end uses. For farm mechanisation, total energy consumption is calculated by multiplying equipment stock, utilisation rates, fuel shares, and energy intensity parameters. For irrigation pumping, useful energy demand is specified independently and converted into final energy demand by applying average pump efficiencies. This distinction between useful and final energy ensures that efficiency improvements reduce energy consumption without altering the underlying level of agricultural service delivered.

Energy Demand Calculation Methods



Scenario analysis is implemented by maintaining a fixed model structure and selectively modifying input assumptions. Activity drivers such as tractor stock growth, utilisation rates, and irrigation requirements are held constant across scenarios unless explicitly altered. Differences between scenarios arise from changes in technology performance parameters, particularly efficiency trajectories. This approach ensures that

variations in model outputs can be traced directly to changes in clearly defined assumptions rather than to structural changes in the model.

The modelling tool aggregates end use level energy demand across equipment types and fuels to generate total agricultural energy consumption by fuel and by activity. Outputs are produced as time series, enabling comparison across years and scenarios. The accounting structure ensures full transparency, allowing intermediate results such as equipment activity levels and efficiency adjusted energy use to be examined alongside aggregated outcomes.

Overall, the implementation of the modelling tool provides a robust and interpretable platform for analysing agricultural energy demand. By grounding calculations in physical drivers and equipment characteristics, the framework supports consistent scenario comparison and enables clear attribution of changes in energy demand to mechanisation trends, efficiency improvements, and technology adoption patterns.

4. Comparison of Scenarios and Energy Savings

The comparison between the Business as Usual (BAU) and Ambitious scenarios highlights the extent to which improvements in technology efficiency can moderate growth in agricultural energy demand, even when underlying agricultural activity and mechanisation levels remain unchanged. Since both scenarios share identical assumptions on tractor stock, utilisation, and irrigation requirements, the observed differences in energy demand are attributable solely to efficiency improvements.

Under the BAU scenario, total final energy demand in agriculture increases steadily over time, driven by rising mechanisation and sustained irrigation requirements. Total agricultural energy demand rises from **32.3 Mtoe in 2020** to **43.6 Mtoe by 2030** and continues to increase thereafter. This growth reflects the combined effects of expanding tractor use and increasing energy requirements for irrigation pumping, with efficiency parameters remaining at baseline levels.

In contrast, the Ambitious scenario demonstrates a markedly lower energy demand trajectory. With a uniform **10 percent improvement in efficiency across all agricultural technologies**, total energy demand rises more slowly, reaching **36.1 Mtoe in 2030**. This represents an absolute reduction of approximately **7.4 Mtoe in 2030** relative to the BAU scenario. The magnitude of this difference underscores the sensitivity of agricultural energy demand to technology performance, particularly in energy intensive activities such as irrigation pumping and mechanised field operations.

Agricultural Energy Demand Scenarios

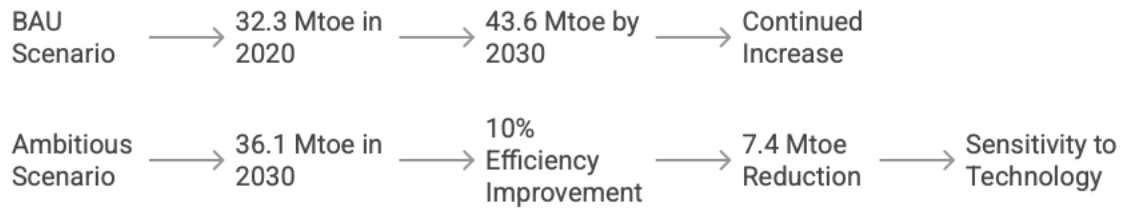


Figure 5: Different Agriculture Scenarios

The energy savings in the Ambitious scenario accumulate progressively over time. While the difference between scenarios is modest in the early years, it widens as agricultural activity scales up. By the mid-term, efficiency improvements lead to substantial reductions in final energy demand, even though the same level of irrigation service and mechanised output is delivered in both scenarios. This indicates that efficiency improvements not only reduce energy consumption in absolute terms but also dampen the rate of demand growth over the long run.

A large share of the observed savings arises from reduced electricity and diesel consumption associated with irrigation pumping. Because irrigation demand is modelled in terms of useful energy requirements, improvements in pump efficiency directly translate into lower final energy consumption without affecting water delivery. Similarly, reductions in fuel consumption per hour for tractors contribute to lower diesel demand from farm mechanisation, although the absolute impact is smaller than that of irrigation because pumping dominates total agricultural energy use.

By design, the Ambitious scenario does not assume changes in cropping patterns, reductions in irrigated area, or shifts in mechanisation intensity. As a result, the energy savings identified here can be interpreted as conservative estimates of the potential achievable through efficiency improvements alone. The results clearly demonstrate that even modest, uniform efficiency gains across technologies can yield significant reductions in aggregate agricultural energy demand.

Overall, the comparison of scenarios highlights the central role of efficiency in shaping future agricultural energy use. While mechanisation and irrigation requirements continue to drive demand upward in both scenarios, efficiency improvements significantly reduce the scale of this increase. These findings provide a strong quantitative basis for prioritising efficiency-oriented interventions in the agriculture sector, particularly in

irrigation pumping and farm machinery, as part of broader energy planning and demand management strategies.

5. Food-Energy-Water (FEW) Nexus for Strategic Crop Substitution

The current landscape of Indian agriculture is defined by a deep and often strained relationship between food production, energy consumption, and water availability. As our preceding analysis established, the sector's energy appetite, accounting for 17% to 20% of the nation's total electricity, is largely driven by a single, relentless activity: the extraction of groundwater for irrigation. While the "Ambitious Scenario" demonstrates how technical efficiency can mitigate this load, a more fundamental transformation emerges when we look beyond the machinery and toward the crops themselves. By strategically substituting water-intensive rice with climate-resilient millets, we can address the root cause of resource depletion at the source.

5.1. *The Cycle of Thirst and Power*

At the heart of the current crisis is the staggering resource requirement of traditional paddy cultivation. In our current model, producing just one kilogram of rice demands approximately 3,000 liters of water a requirement that forces farmers to keep irrigation pumps running for extended periods. This demand is further compounded by a 60% irrigation dependency for rice, which places a heavy, consistent load on rural distribution networks.

When we consider that the average pump set operates at a "wire-to-water" efficiency of less than 40%, the story becomes one of systemic waste. We are not just lifting water; we are consuming massive amounts of electricity to lift water that the crop consumes at an unsustainable rate. If left unchecked, this cycle is projected to drive agricultural electricity demand to 18.6 Mtoe by 2047. However, the introduction of millets changes this narrative entirely.

5.2. *Millets: The Structural Intervention*

Millets represent a fundamental shift in the Food-Energy-Water nexus. Often called "Future Smart Crops," millets require only 350 liters of water per kilogram produced a staggering 88% reduction in water footprint compared to rice. This "volumetric saving" of 2,650 liters per kilogram does more than just save water; it acts as a structural demand-side management tool for the power grid.

Millet as a Structural Intervention in the FEW Nexus

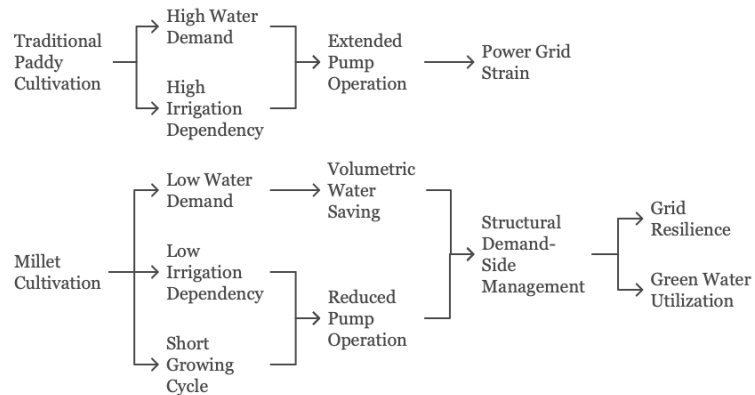


Figure 6: Millets as a Structural Intervention

Because millets have a significantly lower irrigation dependency (only 15%) and a much shorter growing cycle, averaging 75 days, compared to the 150 days required for rice, the total operating hours for pump sets are slashed. This reduction in pumping time is arguably the most effective way to bypass the inherent inefficiencies of the current pump stock. A shift toward millets doesn't just make the grid more resilient; it prevents the need for energy consumption altogether by utilizing "green water" (rainfall) more effectively.

5.3. Beyond the Pump: The Carbon and Chemical Footprint

The story of the FEW nexus extends beyond the immediate pull of electricity. The energy intensity of our food is also "embedded" in the chemicals and carbon we release during production. Rice cultivation is an energy-intensive process that leaves a heavy footprint, estimated at 3.5 kg CO₂eq per kilogram of grain. Much of this is tied to the 250 kg/ha of NPK fertilizers required to sustain high-yield paddy fields a chemical input that is itself a product of high-energy industrial manufacturing.

Transitioning to Millets for Energy Security

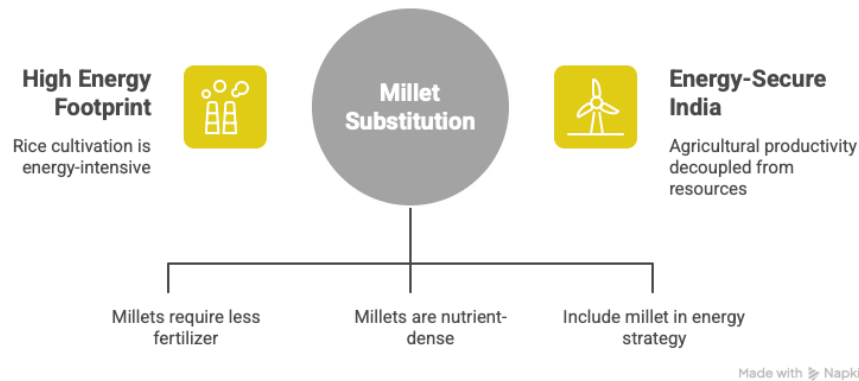


Figure 7: Transitioning to Millets

Millets offer a cleaner alternative, requiring only 50 kg/ha of fertilizer and emitting just 0.5 kg CO₂eq per kilogram. By making this transition, the agricultural sector achieves a six-fold reduction in greenhouse gas emissions while simultaneously improving nutritional outcomes. Millets provide superior protein, fiber, and micronutrient density, ensuring that every unit of energy and water invested in the field yields a higher "nutritional return" for the population.

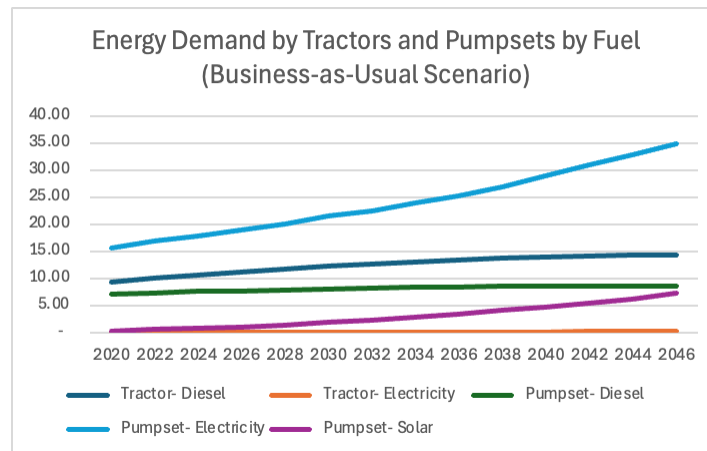
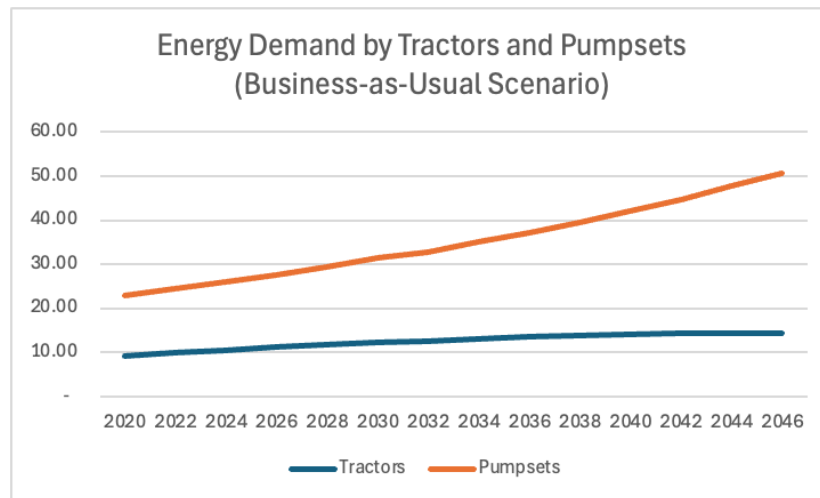
Integrating millet substitution into the national energy strategy is not merely an agricultural recommendation; it is a prerequisite for long-term energy security. While we must continue to pursue the 10% technical efficiency gains outlined in the Ambitious Scenario, crop diversification offers a path to address the *root cause* of energy stress. By fundamentally reducing the volume of water that needs to be lifted, the FEW Nexus approach provides a roadmap to a future where agricultural productivity is decoupled from resource exhaustion, ensuring a climate-resilient and energy-secure India.

6. Results

This section presents the results of the agricultural energy demand analysis under the Business-as-Usual (BAU) and Ambitious scenarios. Results are reported in terms of total final energy demand, fuel wise composition, and end use contributions, with particular emphasis on farm mechanisation and irrigation pumping. All values are expressed in million tonnes of oil equivalent.

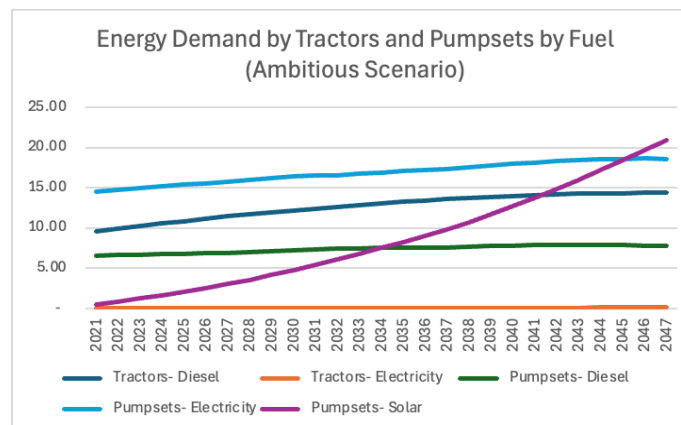
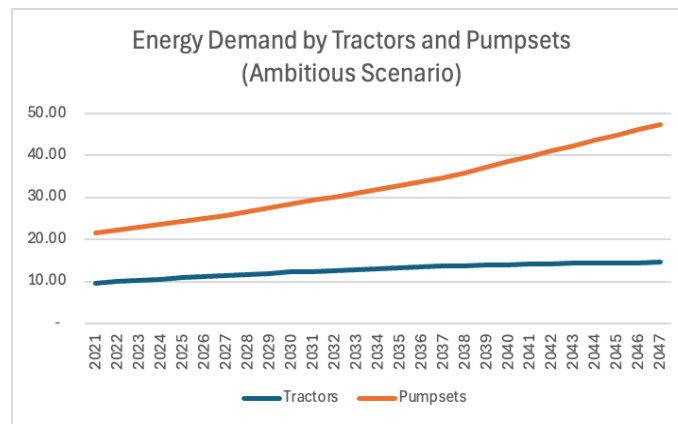
6.1. Total Agricultural Energy Demand

Under the BAU scenario, total final energy demand in the agriculture sector increases substantially over the projection period. In 2020, total agricultural energy demand is estimated at **32.29 Mtoe**, of which **9.26 Mtoe** is attributable to tractors and **23.03 Mtoe** to irrigation pump sets. Energy demand continues to rise steadily, reaching **43.59 Mtoe by 2030** and further increasing to **61.81 Mtoe by 2047**. This growth reflects rising mechanisation intensity and increasing irrigation energy requirements, with no additional efficiency improvements assumed beyond baseline conditions.



In contrast, the Ambitious scenario exhibits a significantly moderated growth trajectory. With a uniform **10 percent improvement in efficiency across all agricultural technologies**, total energy demand in 2020 is **29.06 Mtoe**, already lower than the BAU case due to immediate efficiency gains. By 2030, total energy demand under the Ambitious scenario reaches **36.15 Mtoe**, compared to **43.59 Mtoe** in the BAU scenario. By 2047, total

energy demand in the Ambitious scenario is **55.24 Mtoe**, representing an absolute reduction of approximately **6.57 Mtoe** relative to the BAU scenario.



6.2. End-use Contributions

Irrigation pumping dominates agricultural energy demand in both scenarios. In the BAU case, energy consumption from pump sets increases from **23.03 Mtoe in 2020** to **31.72 Mtoe in 2030**, and further to **47.28 Mtoe by 2047**. Electricity constitutes the largest share of pumping energy demand, accounting for **15.67 Mtoe in 2020**, increasing to **18.60 Mtoe by 2047**, while diesel use for pumping remains significant at **7.13 Mtoe in 2020** and **7.75 Mtoe by 2047**. A small but growing contribution from solar pumping is also observed, rising from **0.22 Mtoe in 2020** to **20.93 Mtoe by 2047**.

In the Ambitious scenario, pump set energy demand is consistently lower across all years. Total pumping energy demand in 2020 is **21.03 Mtoe**, increasing to **27.34 Mtoe in 2030** and **41.42 Mtoe by 2047**. The reduction relative to BAU arises from higher pump efficiency, which reduces final energy consumption for the same level of useful energy

required for water lifting. Electricity demand for pumping is reduced substantially, while diesel and solar contributions follow similar trajectories but at lower absolute levels.

Agricultural Energy Demand Scenarios

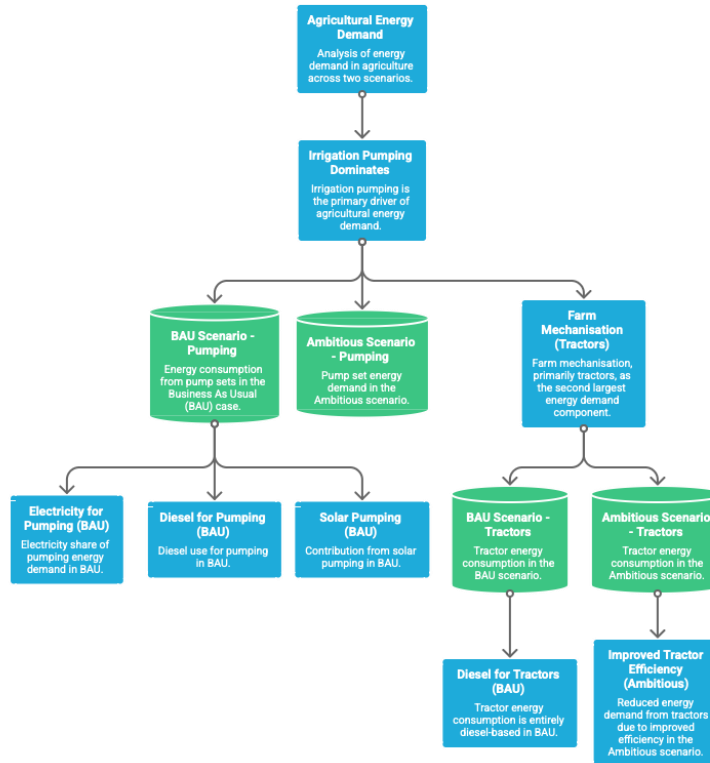


Figure 8: End Use Flow

Farm mechanisation, represented primarily by tractors, forms the second largest component of agricultural energy demand. Under BAU, tractor energy consumption in 2020 is **9.26 Mtoe**, entirely diesel based. This increases steadily over time, reaching **11.87 Mtoe in 2030** and **14.53 Mtoe by 2047**, reflecting growth in tractor stock and utilisation. Electricity use from tractors remains negligible in the BAU scenario.

In the Ambitious scenario, energy demand from tractors is reduced due to improved efficiency. Tractor energy consumption in 2020 is **8.03 Mtoe**, rising to **8.81 Mtoe in 2030** and **10.96 Mtoe by 2047**. The difference relative to BAU widens over time, highlighting the cumulative impact of efficiency improvements on mechanisation related energy demand.

6.3. Fuel-wise Energy Demand

Electricity and diesel dominate agricultural energy use across both scenarios. In the BAU scenario, electricity demand grows rapidly due to increasing reliance on electric pump sets, reaching **18.60 Mtoe by 2047**. Diesel consumption also increases steadily, driven by both tractors and diesel pump sets, reaching **14.38 Mtoe by 2047**. Solar energy contributes an increasing share in later years, reflecting gradual adoption of solar pumping technologies.

In the Ambitious scenario, electricity and diesel demand are both lower across the projection period. Electricity consumption for irrigation pumping declines relative to BAU due to higher efficiency, while diesel demand from tractors is reduced due to lower fuel consumption per hour. Solar energy follows a similar expansion path as in BAU but contributes to a lower total energy requirement due to efficiency gains in conventional technologies.

7. Scenario Comparison and Energy Savings

The divergence between the BAU and Ambitious scenarios becomes more pronounced over time. By 2030, the Ambitious scenario delivers an absolute energy saving of approximately **7.44 Mtoe**, representing a reduction of nearly **17 percent** relative to the BAU scenario. By 2047, cumulative energy savings increase further, with the Ambitious scenario consuming **over 10 percent less energy** than BAU despite delivering the same level of agricultural services.

Which energy scenario offers greater savings?

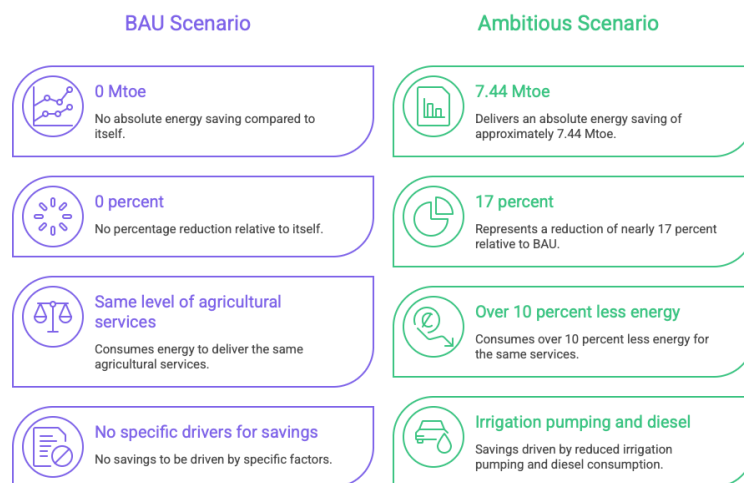


Figure 9: Scenarios for Energy Saving

These savings are driven predominantly by reductions in irrigation pumping energy demand, followed by lower diesel consumption from farm mechanisation. Because underlying agricultural activity, equipment stock, and utilisation assumptions are identical across scenarios, the results demonstrate that efficiency improvements alone can significantly moderate the growth of agricultural energy demand.

8. Key Insights

The results clearly indicate that agricultural energy demand is highly sensitive to technology efficiency. Irrigation pumping remains the dominant driver of energy consumption, and improvements in pump efficiency yield large reductions in final energy demand. Farm mechanisation contributes a smaller but steadily growing share of energy use, and efficiency improvements in tractors provide meaningful cumulative savings. Together, these findings highlight the critical role of efficiency-oriented interventions in shaping future agricultural energy demand trajectories.

8.1. Implications for Energy Planning and Policy

The results of the agricultural energy demand analysis have important implications for energy planning, infrastructure development, and sector specific policy design. The magnitude and composition of agricultural energy demand, as well as the sensitivity of demand to technology efficiency, underscore the need for targeted interventions that address the physical drivers of energy use in agriculture rather than relying on aggregate demand management approaches.

8.2. Implications for Electricity Planning and Rural Infrastructure

Irrigation pumping emerges as the dominant source of agricultural energy demand, accounting for the majority of electricity consumption in both scenarios. Under the BAU trajectory, agricultural electricity demand increases sharply, driven by rising irrigation requirements and unchanged pump efficiencies. By 2047, electricity demand from irrigation pumping alone reaches close to **18.6 Mtoe**, placing sustained pressure on rural distribution networks. This growth has direct implications for feeder capacity, transformer sizing, and system reliability, particularly during peak irrigation seasons.

The Ambitious scenario demonstrates that efficiency improvements can significantly reduce electricity demand without compromising irrigation services. By 2030, efficiency driven reductions of over **7 Mtoe** in total agricultural energy demand translate into

substantial reductions in electricity load growth. For planners, this highlights that demand side efficiency in agriculture can act as an effective alternative to costly supply side investments in rural electricity infrastructure.

8.3. Implications for Fuel Demand and Energy Security

Diesel consumption remains a significant component of agricultural energy use, driven primarily by farm mechanisation and diesel based pump sets. Under BAU, diesel demand increases steadily through the projection period, contributing to higher petroleum product consumption in rural areas. In the Ambitious scenario, improved efficiency reduces diesel demand from both tractors and pumps, leading to cumulative fuel savings.

These reductions have implications beyond the agriculture sector. Lower diesel demand contributes directly to reduced fuel import requirements and enhances energy security. Given that diesel consumption from agriculture is relatively inelastic to short term price signals, efficiency improvements offer a more reliable pathway for moderating long term fuel demand growth.

8.4. Role of Efficiency as a Planning Instrument

The comparison of scenarios demonstrates that even a uniform **10 percent improvement in efficiency across agricultural technologies** yields large absolute energy savings. Importantly, these savings are achieved without altering agricultural activity levels, mechanisation intensity, or irrigation requirements. This suggests that efficiency improvements represent a low risk and high impact intervention from a planning perspective.

For irrigation pumping, improving pump efficiency reduces electricity consumption directly and also mitigates the impacts of declining groundwater tables on energy demand. For farm mechanisation, improved tractor efficiency lowers diesel consumption per unit of output, moderating the energy implications of rising mechanisation.

8.5. Integration with Agricultural and Energy Policy

The results highlight the importance of aligning agricultural policy with energy planning objectives. Policies that promote mechanisation and irrigation expansion must be accompanied by measures that improve equipment efficiency to avoid unintended increases in energy demand. Efficiency-oriented standards, performance-based incentives, and targeted replacement programmes for inefficient pump sets and tractors can play a central role in this regard.

The growing contribution of solar energy in irrigation pumping also has planning implications. While solar pumping reduces grid electricity demand, it does not eliminate the importance of efficiency. Inefficient solar pump sets can still lead to excessive water extraction and higher system costs. Integrating efficiency criteria into renewable energy deployment programmes is therefore essential.

8.6. Implications for Long-Term Demand Management

From a long-term perspective, the results indicate that agricultural energy demand growth is not inevitable. While structural drivers such as mechanisation and irrigation expansion will continue to increase energy requirements, efficiency improvements can substantially moderate this growth. Incorporating explicit efficiency assumptions into energy planning models is therefore critical for producing realistic demand projections.

Overall, the findings suggest that agricultural energy demand should be addressed through a combination of demand side efficiency measures and coordinated planning across the energy and agriculture sectors. Efficiency improvements in irrigation pumping and farm mechanisation emerge as priority areas for intervention, offering significant energy savings while supporting agricultural productivity and resilience.

9. Conclusion and Way Forward

This report has examined the evolution of energy demand in the agriculture sector using a demand side, equipment based analytical framework. By explicitly linking energy consumption to physical drivers such as irrigation requirements, mechanisation intensity, and technology performance, the analysis provides a transparent and internally consistent representation of agricultural energy use. The results underscore the central role of irrigation pumping and farm mechanisation in shaping current and future energy demand in agriculture.

Under the Business-as-Usual scenario, agricultural energy demand increases steadily over the projection period, driven by rising mechanisation and sustained irrigation requirements. Electricity demand from irrigation pumping and diesel consumption from tractors together account for the bulk of this growth. Without targeted interventions, these trends imply increasing pressure on rural electricity infrastructure, higher fuel consumption, and rising system costs.

The Ambitious scenario demonstrates that efficiency improvements can significantly moderate this growth. A uniform 10 percent improvement in efficiency across tractors and irrigation pump sets delivers substantial reductions in total energy demand, amounting to

several million tonnes of oil equivalent by 2030 and growing thereafter. Importantly, these savings are achieved without reducing agricultural output, mechanisation levels, or irrigation services. This finding, highlights efficiency as a powerful and low risk instrument for managing agricultural energy demand.

The analysis also illustrates the importance of distinguishing between useful energy demand and final energy consumption, particularly in irrigation pumping. Improvements in pump efficiency directly reduce electricity and diesel consumption while maintaining the same level of water delivery. Similarly, efficiency gains in tractors reduce fuel use per hour of operation, dampening the energy implications of increasing mechanisation. Together, these effects show that technology performance plays a decisive role in determining long term energy demand trajectories in agriculture.

Looking ahead, the findings point to several priorities for future action. First, efficiency-oriented interventions in irrigation pumping and farm mechanisation should be elevated as central elements of agricultural and energy policy. Second, demand side efficiency should be explicitly integrated into energy planning processes to avoid over investment in supply side infrastructure. Third, future modelling efforts should extend the analysis to include additional agricultural end uses such as post-harvest processing and emerging technologies, as well as regional disaggregation to capture spatial heterogeneity in energy use.

Further work can also explore the interaction between efficiency improvements and renewable energy deployment, particularly in the context of solar powered irrigation. While renewable technologies can reduce dependence on grid electricity and fossil fuels, their energy and water use implications depend critically on efficiency and system design. Integrating these dimensions into future analyses will be essential for developing balanced and sustainable agricultural energy strategies.

In conclusion, agricultural energy demand need not follow a high growth trajectory. By grounding energy planning in physical drivers and prioritising efficiency improvements across key technologies, it is possible to support agricultural productivity while containing energy demand growth. The framework and results presented in this report provide a robust foundation for informed decision-making and future policy development in the agriculture and energy sectors.

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