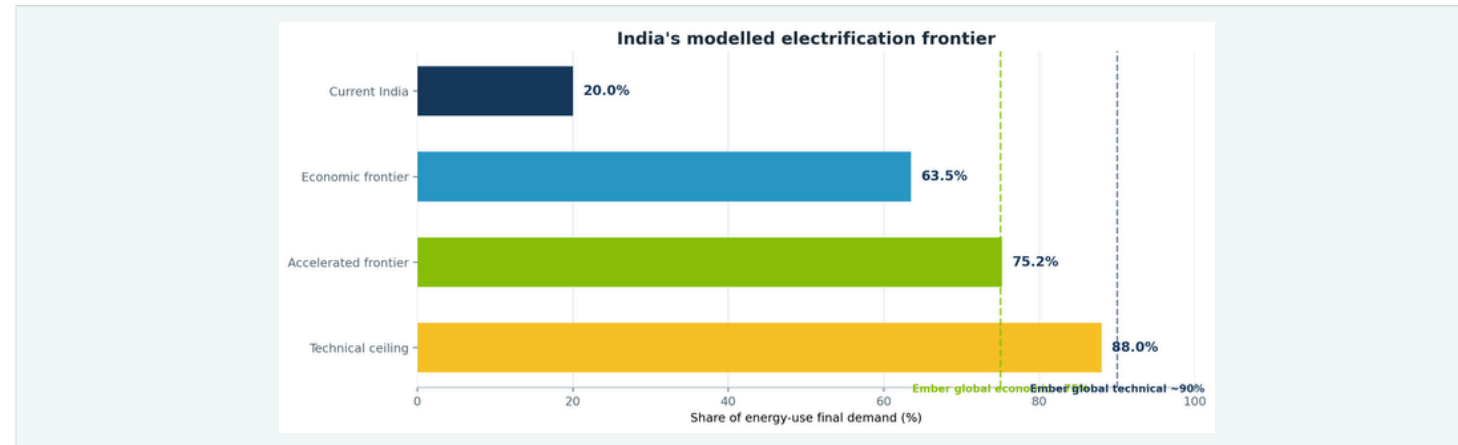


From Molecules to Electrons

Mapping India's Economic Electrification Frontier

Ember's global 75% benchmark is a useful starting point; Firstgreen rebuilds the frontier from India's own end uses and energy mix.



GLOBAL BENCHMARK The 75% question is a benchmark, not an India result

The Ember chart that triggered this analysis places global economic electrification near 75% and the technical ceiling near 90%. Firstgreen uses that as a reference, then rebuilds the frontier from Indian end uses.

Reference images supplied by user; underlying chart by Ember.

India's final-energy system is still dominated by direct use of fuels. In the BEE 2024-25 balance, electricity accounts for **140 Mtoe** of final consumption. Our assessment report energy-use basis of about **698.9 Mtoe**, that is approximately **20.0%**. The remainder is largely supplied by liquid fuels, coal, gas, biomass and other molecules consumed directly in vehicles, furnaces, kitchens, boilers and farm equipment. Electrification therefore means much more than adding renewable generation to the power grid: it means moving energy services themselves onto electricity where an electric technology can deliver the same service at acceptable cost and performance.

The Firstgreen model allocates India's final energy across 17 end uses and assigns each a current electric share, technical ceiling, economic-today share, accelerated share and an electric-equivalent efficiency factor. Those assumptions are deliberately visible and editable. On that basis, the model places India's **economic electrification frontier at about 63.5%** of today's final-energy services. Under an accelerated cost-and-infrastructure case the frontier rises to **75.2%**, close to Ember's global benchmark, while the modelled technical ceiling reaches **88.0%**.

The gap between 63.5% and 88% is economically and technically important. Rail, electric equipment, two- and three-wheelers, agricultural pumping, cars, buses and low-temperature heat are already relatively mature electrification candidates. Heavy trucking, medium-temperature heat and especially high-temperature industrial processes move later. Aviation, shipping and process chemistry retain the largest residual dependence on molecules. The frontier is therefore not a single technology story: it is the sum of many end-use decisions with different economics, duty cycles and infrastructure needs.

Most importantly, the 63.5% result is **not an official forecast** and should not be read as a target. It is a transparent scenario designed to answer a strategic question: if technologies that are already commercially available or emerging become widely adopted, how much of India's present final-energy service could plausibly shift to electricity? The next pages examine which end uses move first, how efficiency changes the size of the energy system, and what deeper electrification would imply for power-sector investment.

20.0%

63.5%

88.0%

Boundary matters. The India denominator is a BEE-derived energy-use final-demand basis of about 698.9 Mtoe, excluding estimated non-energy feedstock use. Electricity contributes 140 Mtoe.

Buildings

Cooking, cooling, appliances and heat.

Transport

Road mobility, rail and difficult freight.

Industry

Motors plus low-, medium- and high-temperature heat.

Agriculture

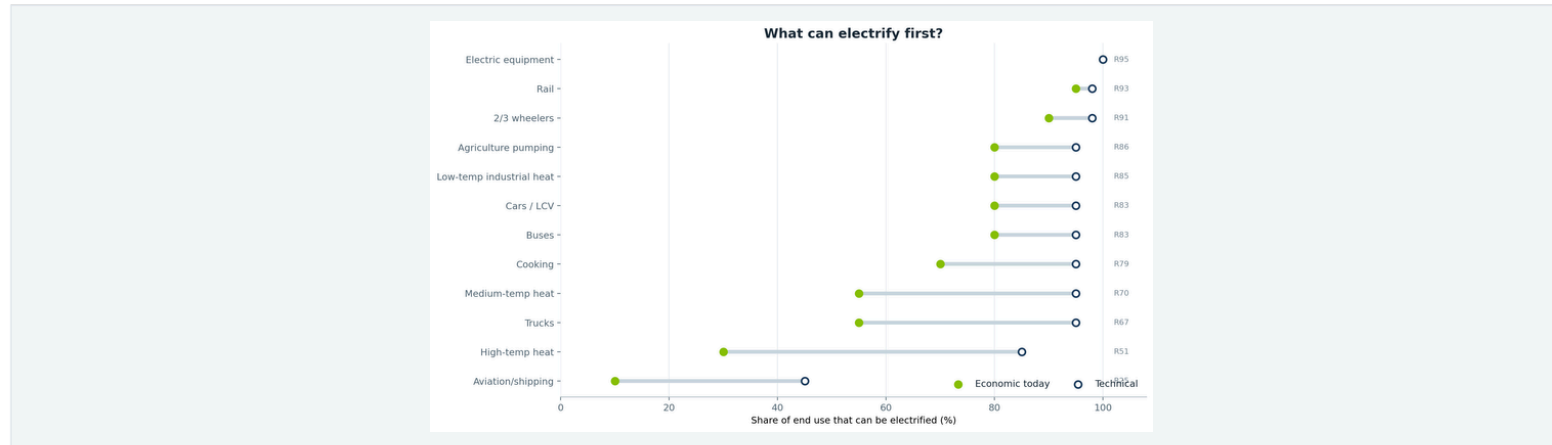
Pumping and electric equipment.

The next phase is not only about cleaner electricity - it is about where electrons can replace molecules altogether.

What can electrify first?

India's electrification frontier is an end-use ladder, not a single percentage.

The economic frontier depends on technology maturity, operating duty, infrastructure and relative lifetime cost. A motor, a truck, an induction cooktop and a cement kiln do not face the same electrification pathway.



End-use cluster	Economic	Technical
Equipment / rail	95-100%	98-100%
2/3W, cars, buses, pumps	80-90%	95-98%
Cooking / low-temp heat	70-80%	95%
Trucks / medium heat	55%	95%
High-temp heat	30%	85%
Aviation / shipping	10%	45%

Readiness score: a Firstgreen ranking based on the modelled economic share and technical maturity. It is not a market forecast.

Fast movers

Motors, rail, 2/3W and pumps already have mature electric routes.

Scale next

Cars, buses, cooking and low-temperature heat depend increasingly on economics and infrastructure.

Harder heat

Medium- and high-temperature industrial heat has more site-specific economics.

Residual molecules

Aviation, shipping and process chemistry retain larger technical and economic gaps.

Firstgreen's sectoral analysis provides a differentiated result rather than one national percentage. Electric equipment and rail sit close to the frontier; two- and three-wheelers, cars, buses and agricultural pumping show roughly 80-90% economic potential; cooking and low-temperature heat 70-80%; trucks and medium-temperature heat about 55%; high-temperature heat about 30%, while aviation and shipping remain the least-ready end uses.

The next tier is larger and more heterogeneous. The model assigns an **80% economic-today share** to cars, light commercial vehicles, buses, agricultural pumping and low-temperature industrial heat. These are not identical opportunities. Road transport requires vehicles, charging, financing and duty-cycle fit. Low-temperature heat depends on electricity-to-fuel prices, process integration and whether heat pumps or electric boilers suit the temperature and steam requirements. Cooking reaches a modelled 70% economic share, reflecting the fact that induction can be technically straightforward while household economics, appliance turnover, kitchen practices and electricity reliability determine adoption.

The difficult frontier begins where energy density, continuous duty and process temperature become more demanding. Medium-temperature industrial heat and heavy trucking are assigned **55% economic shares** today even though their technical ceilings are much higher. High-temperature industrial heat falls to 30% economically in the model. Cement, metals, kilns and other processes may require resistance heating, electric furnaces, plasma, hydrogen or redesigned production routes rather than simple equipment substitution.

Aviation, shipping and process chemistry sit furthest from direct electrification. Batteries are constrained by weight and energy density, while some industrial uses require molecules as feedstocks rather than merely as energy carriers. The purpose of the frontier is not to force every energy service onto electricity. It is to identify where direct electrification is the efficient first choice and where other clean molecules or process changes may remain necessary. For investors and policy makers, the ladder suggests a sequencing principle: focus first on large end uses where electric technologies are mature, efficient and commercially close, then use infrastructure, pricing reform and innovation to move the middle of the ladder.

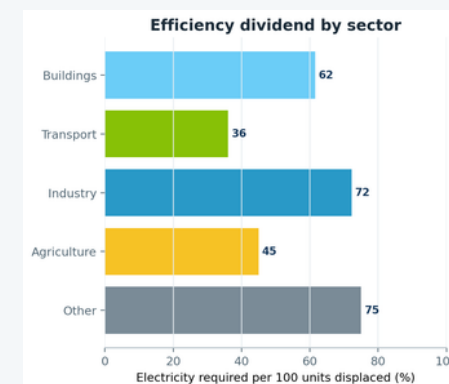
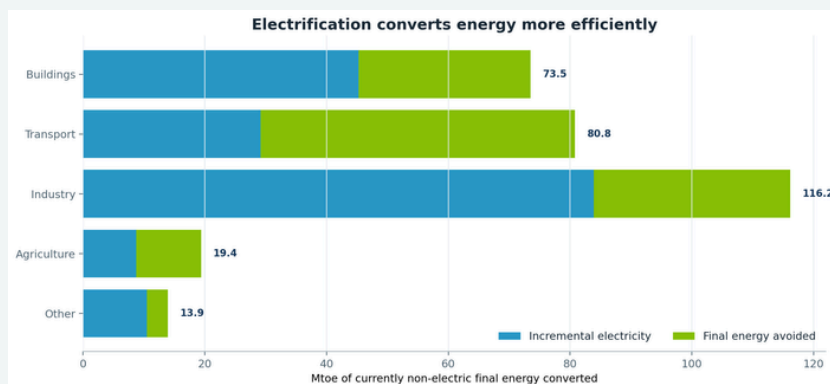
Electrification is not one market - it is a portfolio of end-use transitions moving at different speeds.

Source: Firstgreen's internal technical analysis - sectoral end-use mapping and electrification-readiness assessment. Economic shares are model assumptions and should be stress-tested.

Electrification can make the energy system smaller

More electricity does not necessarily mean more final energy.

Electric motors, EV drivetrains and heat pumps can deliver the same useful service with far less final energy than combustion.



304 Mtoe

Currently non-electric final energy converted at the economic frontier

177 Mtoe

Incremental electricity required to replace it

~126 Mtoe

Modelled efficiency dividend - final energy no longer required

The most important arithmetic in the electrification transition is not one-for-one substitution. Replacing 100 units of petrol, diesel, gas or coal with an electric technology does not necessarily require 100 units of electricity. The Firstgreen economic-frontier case converts about **304 Mtoe** of currently non-electric final energy but requires only about **177 Mtoe** of incremental electricity. The difference - roughly **126 Mtoe** - is the modelled efficiency dividend.

The sectoral results also quantify the efficiency dividend. Transport converts about 80.8 Mtoe of non-electric energy with only 29.1 Mtoe of additional electricity, avoiding 51.6 Mtoe. Industry is the largest convertible block at 116.2 Mtoe, buildings contribute 73.5 Mtoe and agriculture 19.4 Mtoe. Scale and efficiency benefit therefore differ materially by sector.

Buildings also benefit, especially where heat pumps can replace combustion for water and space heating. In the model, 73.5 Mtoe of non-electric building energy becomes about 45.2 Mtoe of incremental electricity, reducing final energy by 28.3 Mtoe. The precise result depends on climate, appliance efficiency, temperature lift and the mix between heat pumps, direct resistance and induction, but the direction is important: an electrified building can consume more electricity while consuming less total final energy.

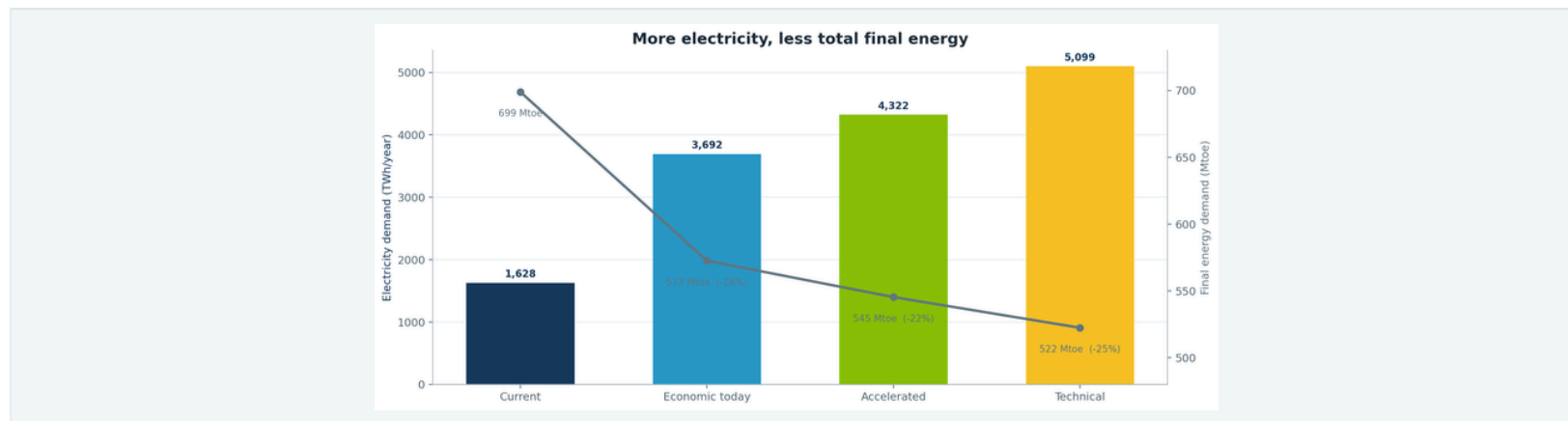
Industry is more nuanced. The model converts 116.2 Mtoe of industrial fossil energy with about 83.9 Mtoe of new electricity, producing a smaller but still material 32.3 Mtoe reduction. Low-temperature heat can show large savings when heat pumps are feasible. Electric boilers and resistance heating are closer to one-for-one conversion, so the wedge narrows as process temperatures rise. At the economic frontier, electricity demand reaches about **3,692 TWh/year**, yet total final-energy demand falls by about **18.1%**. The relevant question is therefore not only how much electricity grows, but how much fossil final energy disappears at the same time.

100 units of fossil final energy displaced does not mean 100 units of new electricity - efficiency is the hidden dividend.

More electricity. Less final energy.

Three frontiers show why electrification changes both sides of India's energy balance.

The model is a static service-based screen: it isolates technology substitution rather than forecasting India's future economic growth.

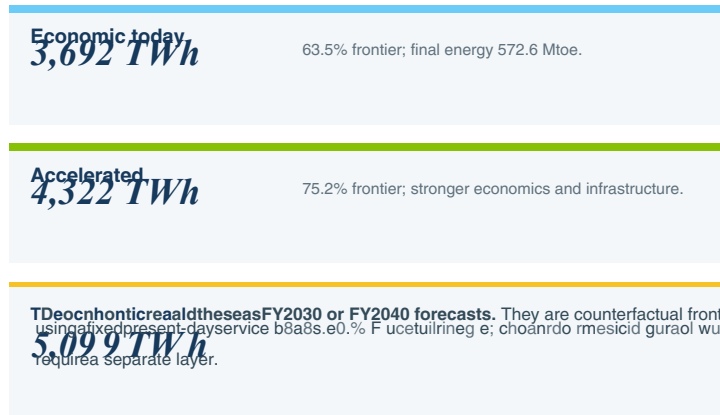


The scenario results show why electrification cannot be analysed by looking only at electricity demand. Today's modelled energy-use baseline is approximately **698.9 Mtoe**, of which electricity represents 140 Mtoe or roughly **1,628 TWh**. Moving to the economic frontier raises electricity consumption to about **3,692 TWh/year**. Yet total final energy falls to about **572.6 Mtoe** because electric technologies use less input energy to deliver many of the same services.

The accelerated case takes the modelled electrification frontier to **75.2%**. Electricity demand rises further to around **4,322 TWh/year**, while final energy falls to approximately **545.3 Mtoe**, a reduction of about 22% from the current service-basis energy total. The technical case pushes the frontier to **88.0%**; electricity approaches **5,099 TWh/year** and total final energy falls to about **522.4 Mtoe**, roughly 25% below the starting level.

These numbers are deliberately not presented as a timeline. Transition speed would depend on equipment replacement cycles, relative electricity and fossil-fuel prices, financing, grid availability, charging infrastructure, industrial plant turnover and consumer preferences. Heat pumps, EVs and industrial electric equipment can be economic on a lifetime-cost basis while still facing high upfront costs or infrastructure barriers. Conversely, cheap electricity alone does not make every high-temperature process or transport duty immediately electrifiable.

The structural implication is clear: India can become much more electricity-intensive without becoming more energy-intensive. Direct electrification moves energy conversion away from millions of combustion devices and toward the power system. Reliability, clean generation, transmission, distribution capacity, storage and flexible demand therefore become more central to energy security. Annual TWh is also only part of the picture: a 4,000-5,000 TWh system could have very different peak needs depending on when EVs charge, when industrial heat operates and how much flexible demand aligns with solar output. Those questions need an hourly or representative-time-slice model.

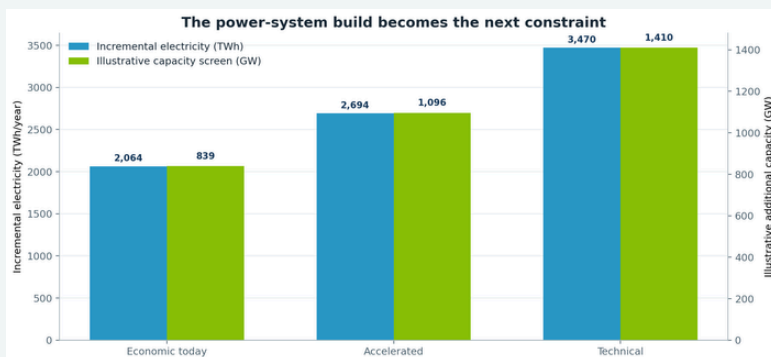


Electrification can make India's power system much bigger while making its total final-energy system materially smaller.

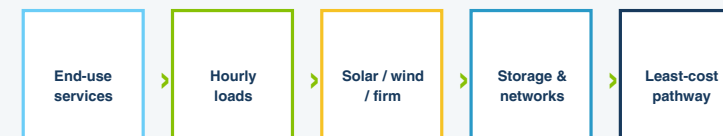
The next question is how to supply it

Electrification moves the analytical problem from end-use technology to whole-system optimisation.

Deeper electrification shifts the question to renewables, firm clean supply, storage, networks and flexibility - assessed as one system.



From end-use frontier to system model



OSeMOSYS next step: add technology costs and lifetimes, fuel prices, resource constraints, storage, transmission expansion, seasonal/hourly demand, industrial heat and transport flexibility.

+2,064 TWh

Incremental electricity at the economic frontier

+236 GW

Average incremental load equivalent

~839 GW

Illustrative additional clean-capacity screen



SUPPLY ARCHITECTURE

A more electrified economy increases the value of coordination

Solar, wind, firm clean supply, storage, transmission and flexible demand must be built as one system. The right mix depends on hourly demand and resource economics, not annual TWh alone.

Illustrative image from supplied Firstgreen magazine template.

The economic-frontier scenario adds about **2,064 TWh/year** of electricity relative to the workbook's current final-electricity baseline. Spread evenly across the year that is an average additional load of roughly **236 GW**. The accelerated and technical cases raise the increment to about **2,694 TWh** and **3,470 TWh**, equivalent to average loads of approximately 308 GW and 396 GW. Those figures illustrate the scale of the supply challenge, but they say little about the optimal generation portfolio on their own.

The workbook therefore includes only a screening calculation. It assumes that incremental energy is supplied 50% by solar, 30% by wind and 20% by firm clean resources, using simple capacity-factor assumptions. Under that illustrative mix, the economic-frontier increment corresponds to roughly **839 GW** of additional solar, wind and firm capacity; the accelerated case to about 1,096 GW; and the technical case to about 1,410 GW. These values are intentionally labelled **screening**, because they ignore chronology, curtailment, storage losses, network constraints, resource quality and least-cost substitution.

This is where a model such as **OSeMOSYS** becomes useful. The end-use workbook already defines the service categories and technology pathways. A capacity-expansion model can add capital costs, operating costs, fuel prices, efficiency, asset lives, resource limits, transmission, storage and representative hourly or seasonal demand. It can then test whether deeper electrification is best served by more daytime solar, more wind, batteries or pumped storage, firm clean generation, flexible industrial loads, managed EV charging or combinations of these resources.

The modelling must preserve the difference between **flexible and inflexible electrification**. EV charging can often shift within a day. Some industrial heat can use thermal storage. Water heating can pre-heat, and agricultural pumping can align with solar hours. Other processes need continuous electricity and high reliability. The strategic conclusion is therefore broader than a capacity number: moving from molecules to electrons makes the power system the central platform of the energy economy. The next research step is a fully constrained optimisation that asks not only how much can electrify, but what is the least-cost reliable pathway for supplying it.

The electrification frontier is only half the story - the real system question is how to supply the new electrons reliably and cleanly.

Source: Firstgreen's internal technical analysis - grid-implication screening and power-system scenario assessment. Illustrative supply mix is a screening case, not a least-cost optimisation result.