WORKING PAPER 2022-28

OCTOBER 2022

Incentives for electrifying agricultural tractors in India

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Keywords: electric tractors, TCO, FAME II, incentives

Introduction and background

India has been the largest manufacturer of tractors globally since 2013, with more than one million produced in 2021 (Tractor and Mechanization Association, n.d.). The country continually ranks among the top agricultural producing countries in the world.[1] The demand for agricultural equipment, particularly tractors, is expected to increase significantly along with the country's advances in agricultural mechanization. In addition, India is a tractor exporter, with 125,000 units sold abroad in 2021.

Due to the rapid growth in their use, tractors in India also are an increasing source of carbon emissions and criteria pollutants. Powered by diesel engines in the vast majority of cases, tractors consume about 8% of India's oil annually and account for 60% of total agricultural fuel usage (The Economic Times, 2017). A 2016 ICCT study forecasted that tractors in India would emit about 25 kilotons of particulate matter (PM) and almost 300 kilotons of nitrogen oxides (NO_x) in 2020, contributing about 61% of the PM and 56% of NO_x emissions in India's off-road sector (Dallmann & Shao, 2016). In addition, tractors used an average of 7.4% of India's diesel fuel, approximately the same share as consumed by buses (9.6%) but without being subject to efficiency standards (Ministry of Petroleum and Natural Gas, 2014). With the growing market, tractors may soon become a major emissions contributor and fuel consumer in India as the road sector moves away from reliance on fossil fuel.

Leading tractor manufacturers in India have advanced tractor technology to be zero emissions. Sonalika launched India's first electric tractors in December 2020. Other manufacturers, such as Escorts, Celestial, and KAMCO, plan to launch electric models soon. These advances have occurred without direct policy mandates or financial incentives, even as India has invested in promoting zero-emission technology in the motor vehicle sector to meet various climate commitments and decarbonization goals. This highlights the great potential of accelerating zero-emission technology for the tractor sector and calls for support to encourage the adoption of electric tractors.

1 According to the Food and Agriculture Organization of the United Nations (n.d.), India is the world's largest producer of milk, pulses, and jute. The country is the second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit, and cotton.

Acknowledgments: The authors acknowledge Amit Bhatt, Ray Minjares, Shikha Rokadiya and Irem Kalayci for their guidance and constructive comments. This study was funded through the generous support of the Pisces Foundation.

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However, the price of electric tractors can be twice that of diesel versions, which could be a major barrier to phasing in electric tractors.

To evaluate the fiscal and non-fiscal incentives needed to promote electric tractors, we analyze the cost gap between electric and diesel tractors using the approach applied to India's electric vehicles and two-wheelers (Rokadiya et al., 2019; Dash et al., 2021; Rokadiya et al., 2021). We evaluate the impact of financial costs for electric tractors purchased by a farmer and used for agricultural work, transportation purposes, and other needs. In addition, we assess the impacts of proposed and hypothetical policies that would enhance the cost-competitiveness of electric tractors. The aim is to illustrate how the central and state governments of India, along with other stakeholders including power utilities and charging providers, might influence purchase decisions regarding electric tractors. The findings of this analysis could be applicable to promotion of other electric equipment in the off-road sector.

Methodology and key assumptions

To evaluate the cost impacts of financial incentives for in-field operations, we analyze the total cost of ownership (TCO) of agricultural tractors commercially available in India. The Tiger Electric tractor, a battery electric vehicle (BEV) released by Sonalika, was selected for our analysis because it was the only zero-emission tractor available for commercial purchase during the analysis. For comparison, the diesel version is the Sonalika GT 20, with similar engine power output, lift capacity, and forward speed, as shown in Table 1. The specifications of these tractors were obtained from the manufacturer's website. The electric tractors, equipped with 25.5 kWh batteries, are assumed to perform consistently as well as the diesel ones, given the manufacturer claim that the tractor can run for 8 hours with a 2-tonne trolley on a single charge.

Table 1. Models selected for analysis

Fuel type	Manufacturer	Model	HP category	No. of gears	Lift capacity (kg)	Forward speed (kmph)	Showroom price (INR Lakh)
BEV	Sonalika	Tiger Electric	20 hp /~15 kW	6F+2R	500	24.9	5.99
Diesel	Sonalika	GT 20	20 hp /~15 kW	6F+2R	650	23.9	2.85

We estimate the TCO for a 10-year period given the long lifespan of tractors in India, and we assume tractor procurement in 2022 and ownership through 2031. To compare the TCO, the study investigates the costs of equipment purchase, insurance, financing, and operation, as well as taxes and fees, as discussed below. A discount rate of 5% is applied to obtain the present value of 10-year costs, in line with previous studies (Pavlenko et al., 2019; Rokadya et al., 2019; Dash et al., 2021). Due to the limitations of real-world data and wide differences in tractor usage, the analysis discusses uncertainties in the variables to understand their impacts on the TCO.

Taxes, fees, and insurance

Taxes on the sale of agricultural tractors are collected by the central government. The goods and services tax (GST) for the tractor is 12% of the base price. The selected tractors are exempted from the Tax Collected at Source (TCS), because their selling price is lower than INR 10 Lakh. Insurance is assumed to be about 2% of the purchase price, for both electric and diesel versions.

Financing costs

Financing costs are determined under a structure that is consistent for the electric and diesel versions. The down payment is set at 20% of the purchase price, with the remaining 80% of the purchase financed through a loan. The annual interest rate for the loan is about 10%, with a processing fee of 1.5% of the list price. The repayment period is ten years, because the analysis explores a 10-year TCO.

Operational costs

Operational costs vary significantly depending on tractor usage and often cover fueling costs, lubrication costs (for diesel tractors), maintenance and repair costs, and opportunity costs. The analysis assumes the same operational patterns for diesel and electric versions to ensure a consistent comparison. Sinha et al. (2017) estimated that tractors operate about 856 hours per year, 66% of which is spent in agricultural work such as tillage and threshing operations; the remaining time is devoted to customized work.

Fueling costs are calculated based on estimated energy usage and the unit price of energy. Energy usage of diesel tractors was calculated using a fuel consumption factor recommended by ASABE Standards (2011), which is widely adopted in estimating the energy consumption of diesel tractors (Edwards, 2015; Singh, 2014; Johnson, 2018). The diesel price was about INR 95 per liter in February 2022. The power needed for given duties is assumed to be the same for diesel and electric versions, but less energy is needed for electric tractors because of the greater efficiency of electric motors.[2] The study assumes a 15% charging loss for electric tractors. The electric tractors can be charged at home overnight (requiring ~10 hours with a 15-amp house socket) or charged using the "fast charging" system offered by the manufacturer, which reduces the charging time to four hours.[3] We assume that a four-hour charging system can meet 15% of a tractor's charging needs given that additional installation and costs may be needed for the charging facilities, and the rest is met using overnight residential charging for the electric tractor in this analysis. For the electricity price, we adopt the upper bound considering that the price of power varies across states and sectors; the upper bound was INR 7.19 per kilowatt-hour (kWh) (the agricultural electricity price in West Bengal) for the home charging price and INR 19.5 per kWh (the Zeon fast charging unit price) for using the manufacturer's four-hour charging system (Government of India, Central Electricity Authority, 2019; Sricharan, 2021).[4]

Lubrication costs, which are about 15% of fueling costs, are applied to the analysis of diesel tractors only (Edwards, 2015; Singh, 2014).

Edwards (2015) estimated that maintenance and repair costs would be a portion of accumulated hours performed. Given the average usage of India's tractors (~856 hours per year), the accumulated repair costs are about 19% of the purchase price over a 10-year period. For electric tractors, it is widely believed that maintenance costs will be lower; Lagnelov et al. (2021) estimated these costs to be about 72-81% of a diesel one. A maintenance cost of 81% of that of a diesel tractor was chosen for the analysis.

The analysis also includes the opportunity costs of fueling and for recharging, which depresses revenue. The opportunity costs estimate the waiting time those tractor

2 It is estimated that diesel tractors in India have an efficiency rate of 45%. Electric motors normally deliver a minimum efficiency rate of 80%, which is adopted for this analysis.

3 Due to lack of information about this "fast charging" system offered by the manufacturer, we refer the system as the "four-hour charging system" to differential from the home charging, which is around 10 hours.

4 The electricity price varies in different regions in India, so here we applied the upper limit of the price to examine the upper bound costs. This choice of the electricity price does not intend to apply to any real-world cases for the power tariff value selected, but rather evaluate the possible highest costs on fueling. This is also because that there lacks consistent data tracking the both price to understand the range of total costs. The real-world costs will probably be lower than our estimates given the various combination of agricultural and fast charging price. We will evaluate the impacts with lower power price in the later section.

drivers spent on charging considering that tractors might be used at night during busy seasons.[5] Due to the limitation in understanding the charging patterns of electric tractors and the daily performance patterns, we assume that tractors are refueled/ charged whenever needed and we do not include the driving distance/ time used for reaching the refueling/charging stations.

Results

An estimated 10-year TCO is presented in Figure 1 for the electric and diesel agricultural tractors. Applying the assumption highlighted above, the 10-year TCO of the electric tractor is about INR 31.1 Lakh while that of the diesel version is less than 30.2 INR Lakh. Fueling costs are the largest cost component of both tractors, followed by vehicle purchase and financing costs. Even though electric tractors require much higher purchase costs, the TCO analysis shows that the cost gap over a ten-year period is minor even when electricity costs and opportunity costs are assumed to be at the upper bound. Thus, electric tractors could be very cost-competitive if some incentives can be provided.

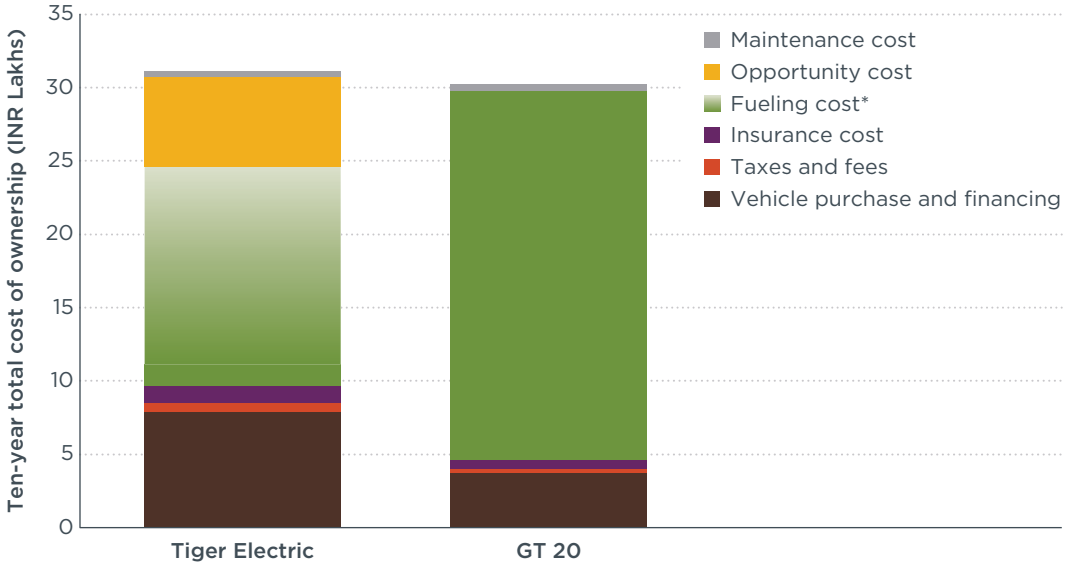

Figure 1. 10-year TCO of an electric versus a diesel tractor

* The green gradient shade provides the range of fueling costs when estimated using different agricultural electricity prices.

Here we introduce several policies and actions, most adopted in the motor vehicle sector, that could be applied to the tractor sector to enhance the cost competitiveness of electric tractors. The following adaptations are analyzed as opportunities to bridge the price differential and to position electric tractors to be even cheaper in the long term.

» **Upfront purchase incentives from the central government.** India launched the Faster Adoption and Manufacturing of Electric and Hybrid Vehicles (FAME) scheme in 2015. It was extended in 2019 to steadily reduce the use of fossil fuel-powered vehicles and boost the development of electric vehicles. The current subsidy is about INR 15,000 per kWh of the battery or up to 40% of the vehicle's total cost (Department of Heavy Industries, 2019). However, zero-emission tractors and other clean off-road equipment are not yet covered in the existing FAME scheme. Considering that the FAME policy is intended to subsidize zero-emission technology, we assume that the subsidy could be applied to tractors with a

5 The assumption will overestimate opportunity costs given limited information available for (electric) tractors' performance and charging needs. We will discuss the uncertainty of opportunity costs in the Uncertainty section.

consistent rule. Hence, an upfront purchase subsidy of INR 2.4 Lakh is used for the electric tractor analyzed in the study (40% of the tractor's base price).

» **Purchase incentives from the state level.** Many states match the subsidies given by the central government to electric motor vehicles. The form of subsidy varies (Ahmed, 2021). For example, states such as Kerala, Tamil Nadu, and Madhya Pradesh offer a waiver of the road tax, with discounted rates of between 50% and 100%. Other states, including Delhi, Gujarat, and Maharashtra Rajasthan, add direct cash incentives in addition to the road tax waiver, using an approach similar to the one seen in the FAME II, which sets a fixed value per kWh based on battery capacity and a cap with a maximum subsidy amount. The per kWh incentive ranges from INR 2,500 to INR 10,000, and the subsidy cap ranges from INR 0.6 Lakh to INR 2.5 Lakh. For this analysis, we apply a subsidy equaling INR 1.5 Lakh for electric tractors considering this is the cap used in many states such as Delhi, Gujarat, and West Bengal.

» **5% GST incentives and discounted insurance rates.** A powerful incentive that promotes the adoption of electric motor vehicles was the reduction in the GST. The rate was lowered from 12% to 5% in 2019 (Ministry of Finance, 2019). Our previous analysis confirmed that India's cut to the GST can effectively lower the consumers' ownership cost of electric vehicles and help reach cost parity with internal combustion engine vehicles (Chen et al., 2022)**.** Similarly, India proposes a 15% discount on the motor third-party premium rates of electric vehicles, which could also be extended to electric tractors (Ministry of Road Transport and Highways, 2022). Thus, we assume that a 5% GST and a 15% discount on insurance will apply to electric tractors.

» **Reduced electricity tariffs in the agricultural sector.** India has a history of subsidizing agricultural electricity dating back to the 1960s and 70s. States such as Karnataka, Tamil Nadu, and Punjab offer free agricultural electricity. Others, such as Bihar, Gujarat, Haryana, and Maharashtra, provide an un-metered, fixed monthly power rate (Government of India, Central Electricity Authority, 2019). The cheap power price was initially designed to encourage the use of irrigation systems. Still, it could be powerful in promoting the use of electric tractors as the discounted agriculture power rates can reduce the fueling costs of electric tractors. However, the free electricity will result in a substantial financial burden for the government and could potentially lead to overuse based on India's experience (Deshpande, 2022). Instead, a discounted power price or a fixed amount of free electricity would be healthier, fiscally. For modeling purposes only, we assume that free electricity will be offered to model electric tractors' maximum cost reduction potential to explore the full impacts of reduced electricity tariffs.

» **Support for charging system infrastructure deployment.** The installation of the four-hour charging system adds an additional financial burden. However, the reliance on overnight residential charging will increase charging time and the potential loss of revenue due to waiting, particularly in busy seasons, when tractors may be used into the night. The lack of four-hour charging system infrastructure might affect the performance of electric tractors, although this is not fully addressed in this analysis. In addition, the current charging price could be high due to limited capacity, while the expansion of the charging system could potentially reduce the unit price. Hence, we assume more four-hour charging system (~30%) will be used with more charging facilities offered to ensure the performance of tractors along with a reduced supply tariff of INR 5.5 per unit in this analysis (Haryana Electricity Regulatory Commission, 2021). The suggested supply tariff is used in the modeling to evaluate the potential impacts; however, there will be an additional service charge from the charging station/facility operators to ensure the viability, which is not captured here.

» **Agricultural loans with reduced interest rates.** Because the upfront cost associated with the procurement of electric tractors is double that of diesel ones, financing incentives can be helpful in lowering the threshold. Almost 95% of tractors in India were purchased using bank credits (Gulati, 2020). India has provided various agricultural loans to fund farming operations and activities, starting at a 7% annual interest rate and with processing fees ranging from 0% to 4% of the loan amount. Our analysis assumes that a 7% annual interest rate with 0% processing fees can be obtained for electric tractors.

Figure 2 illustrates the incremental effects of the policy measures discussed above on the 10-year TCO of the electric tractors by estimating the net impact of each additional policy on relative costs, shown using the blue bars. The brown bar represents the existing additional TCO of electric tractors compared to diesel tractors. After factoring in all proposed additional measures, the red bar indicates the net improvement. The results in Figure 2 confirm that the combined policy measures and incentives above can bridge the gap between the TCO of the electric and the diesel tractors and make electric tractors even cheaper over the long term.

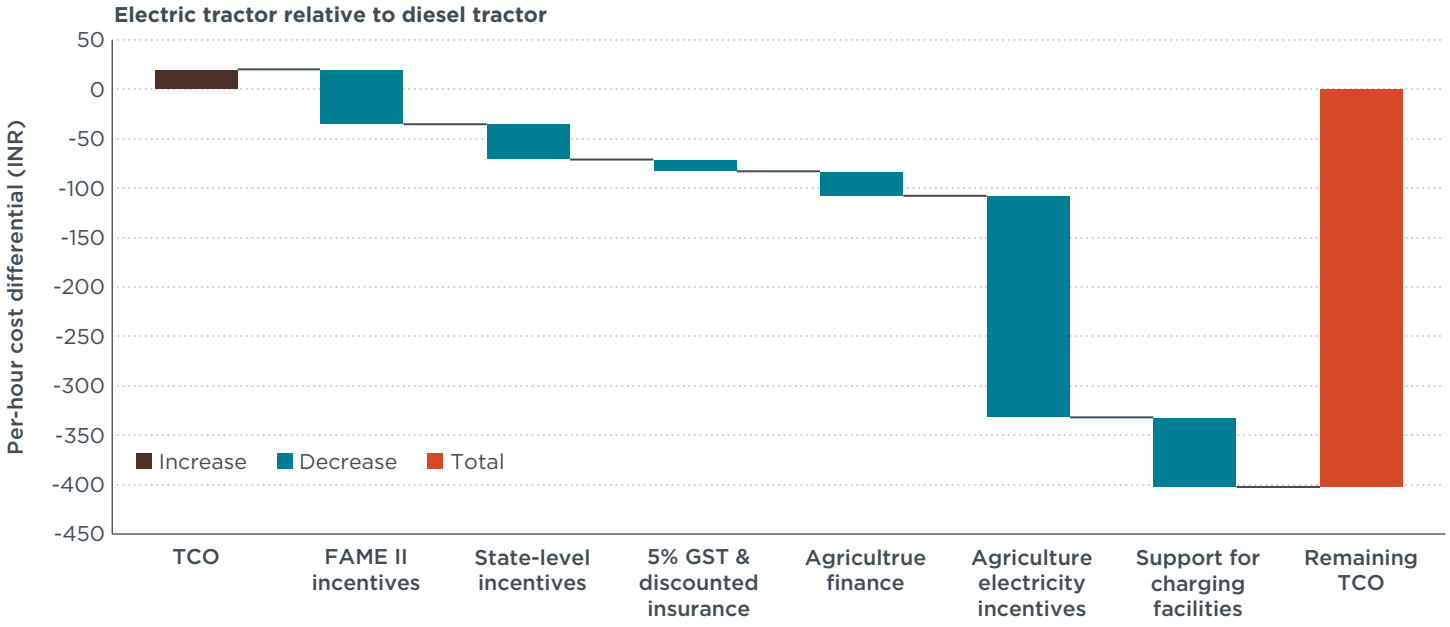

Figure 2. Impact of potential incentive mechanisms and policy actions in bridging the TCO differential between electric and diesel tractors

Several of these actions and incentives can bridge the entire gap between the TCOs of electric and diesel tractors. The largest reduction comes from the subsidized agricultural rate. Fully subsidized agricultural power can achieve the highest saving and will potentially result in unexpected impacts. However, the chart indicates that discounted power price is a power tool that can ensure the cost competitiveness of electric tractors and lead to net improvement. The support for deploying a four-hour charging system can remove the cost gap as well, although it will require additional investment in infrastructure, which is not captured here. Similarly, upfront incentives from central and state levels combined will also have a substantial impact on reducing total costs. All policies and incentives considered, the subsidies can bridge more than 100% of the gap between electric and diesel tractors. The per-hour cost difference between the electric and diesel tractor can be reduced from INR 20 to INR -400.

Because the upfront procurement associated with the electric tractors is more than double that of diesel tractors, purchase incentives and discounts from the central and local states can substantially improve cost competitiveness. FAME II alone can greatly

reduce the TCO price difference among all upfront incentives. The same is true for the state incentives. Using fiscal incentives consistent with those used for electric vehicles can remove the cost gap of purchasing electric tractors, and even make it cheaper to own and use electric tractors in the long term. The reduced 5% GST rate and discounted insurance will bridge the gap by about 50%. Finally, the discounted interest rate and process fees offer an almost 100% reduction in the cost difference. Adopting one or several of these incentives can remove the cost gap of the 10-year TCO, presenting electric tractors as cost-effective options.

Because fuel is the largest cost component for electric tractors, subsidized energy prices can significantly reduce overall costs. Offering discounted electricity can entirely bridge the TCO difference between electric and diesel tractors. It is worth mentioning that the analysis of free electricity is used only to explore the potential of cost reduction on electric tractors, not to recommend it for wide adoption. However, short-term, discounted agriculture power tariffs can be a robust tool for increasing the competitiveness of electric tractors until the market reaches maturity as new business models are developed. This can potentially accelerate the progress of agricultural mechanization and encourage the development and adoption of other electric agricultural equipment.

Another effective strategy is the deployment of fast-charging infrastructure. The wide availability of fast-charging stations could lower opportunity costs by reducing waiting time. The impacts might be less than that shown in Figure 2, given that the additional costs of building, running, and maintaining charging facilities are not included. But the availability of charging facilities could ensure satisfactory performance of tractors in the field to meet continuous work demand during busy seasons.

Uncertainty

A missing piece in estimating the TCO is the cost associated with charging infrastructure. Additional costs for chargers, manual installation, and maintenance are often borne by electric tractor owners and operators. These costs will be more significant in building public charging stations considering the required spending to lease land, set up new electricity connections, and hire staff. However, information about costs associated with off-road charging infrastructure and facilities is still quite limited. Based on the data for India's electric vehicles, the chargers for home charging with the 15 kW sockets could add another INR 1-2 Lakh (Carandbike Team, 2022, Lendingkart, 2022). Costs for building charging stations will be at least INR 20-40 Lakh for the first year, then INR 10 Lakh in the following years. The price could be cheaper for agriculture equipment with a lower land lease. Meanwhile, incentives are identified for installing the charging facilities for electric vehicles. Cities like Delhi have launched plans to subsidize installing home charging for electric vehicles, with a net cost that could be as low as INR 2,375 after subsidy (Zee Media Bureau, 2022). For public charging stations, it is estimated that installation costs can be recovered within 3-5 years (Lendingkart, 2022).

Given the limited understanding of the real-world performance of the tractors in India, uncertainty could affect the numerical estimation of the TCO. Our analysis relies on average usage estimated year-round, but tractors' performance can differ by season, size, and geographic location. We adopted 900 hours of usage annually based on the average number from Sinha et al. (2017), assuming about two-thirds of the hours are used for agricultural work and the rest for social purposes such as transporting freight and passengers. The study also highlighted that the average annual use of tractors could vary from 600 hours to 1000 hours in the Mahakoshal region. A recent report also confirmed that the agricultural use of tractors in India is about 500-600 hours annually in most states (Gulati, 2020). Beyond the farming operations, tractors often perform as motor vehicles to transport passengers and goods in the rural areas. However, data to

differentiate the power usage pattern between agricultural and social work is lacking. In addition, the performance pattern can also be different by ownership status (purchase or rental), which was not considered in this study.

Similar limitations can also be found in understanding the costs associated with usage. Our analysis evaluated the fueling, maintenance, and opportunity costs, respectively, but many analyses combine these and report them as operational costs. The survey conducted by Sinha et al. (2017) indicated that operational costs might differ by tractor age, usage, and annual usage. The study estimated the operational cost was about INR 252.97 per hour for tractors less than two years old and decreased to Rs 200.69 per hour for tractors 4–6 years old. The operational costs could increase to INR 261 when a tractor reaches 10 years of age. The average operational cost of smaller tractors with a power range between 19 and 26 kW was estimated at INR 268 per hour for agricultural activities and INR 239 per hour for other work. Bhatnagar (2021) reported that the operational cost is Rs 447 per hour for the rotavator and Rs 353 per hour for the moldboard plow. The report also claimed that the operational costs for electric tractors are estimated at Rs 332 per hour with a rotavator and Rs 301 per hour with a moldboard plow.

Figure 3 compared the per-hour operational costs estimated by this analysis (ICCT) with the data from the literature review. The operational costs from this study align well with the numbers reported by other studies. Furthermore, Figure 3 highlights the components of operational expenses from this study, which are the fueling costs (green pattern), opportunity costs (red pattern), and maintenance costs (brown pattern). The observation is consistent with the 10-year TCO shown in Figure 1, as fueling costs contribute the biggest share of the per-hour operational costs. For electric tractors, opportunity costs are high due to the long waiting hours.

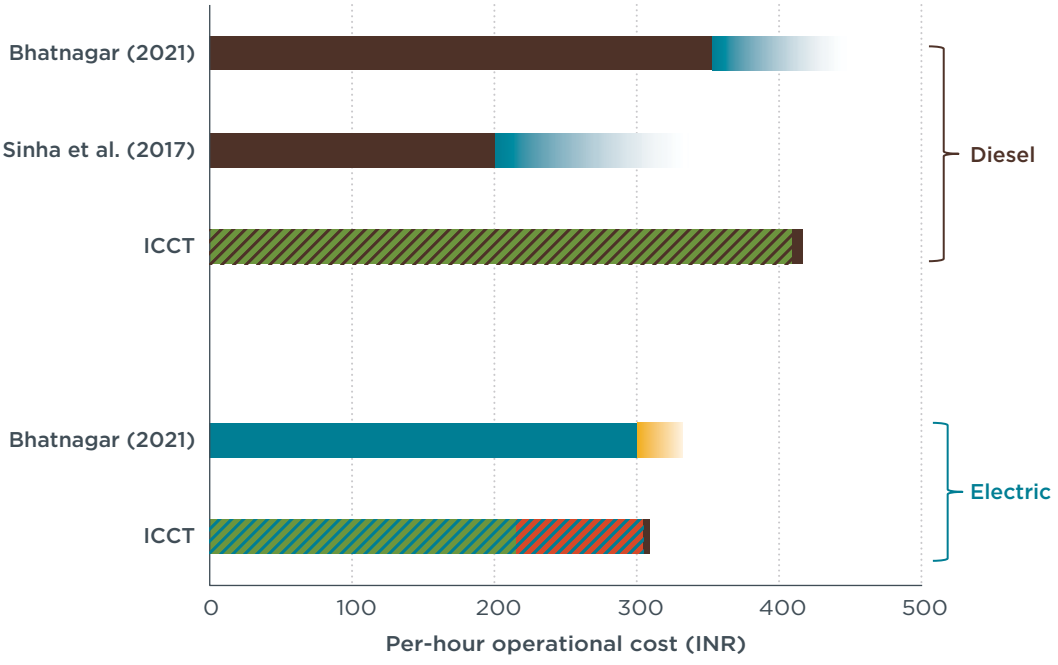

Figure 3. Comparison of per-hour operational costs.
The gradient shade represents the range of operational costs estimated.

The other uncertainty that might affect the estimation of operational costs is charging patterns. We assume that 15% of the charging will rely on a four-hour charging system. The remaining will be residential overnight charging as the baseline, given that almost no designated charging facilities exist for tractors in India. The availability of charging facilities and the charging price can determine consumers' preferences. Figure 4

highlights the range of operational costs with different charging behaviors and energy prices and compares them with our baseline estimation. Relying entirely on the four-hour charging system could double the fueling costs due to the high charging unit price (INR 19.5 per kWh), although it could save about 50% of the opportunity cost because of reduced waiting hours. However, a discounted charging price (INR 5.5 per kWh), led by the availability of charging stations, can reduce fueling costs by about 40% compared with the baseline. Meanwhile, relying solely on home charging would likely save fueling costs due to the availability of cheaper and/or free agricultural power but might increase the opportunity costs accordingly. In general, electric tractors have much lower operational costs than diesel ones. It is worth mentioning that Figure 4 is designed to present the potential operational cost range of different charging behaviors, but does not include the costs associated with the additional infrastructure needed.

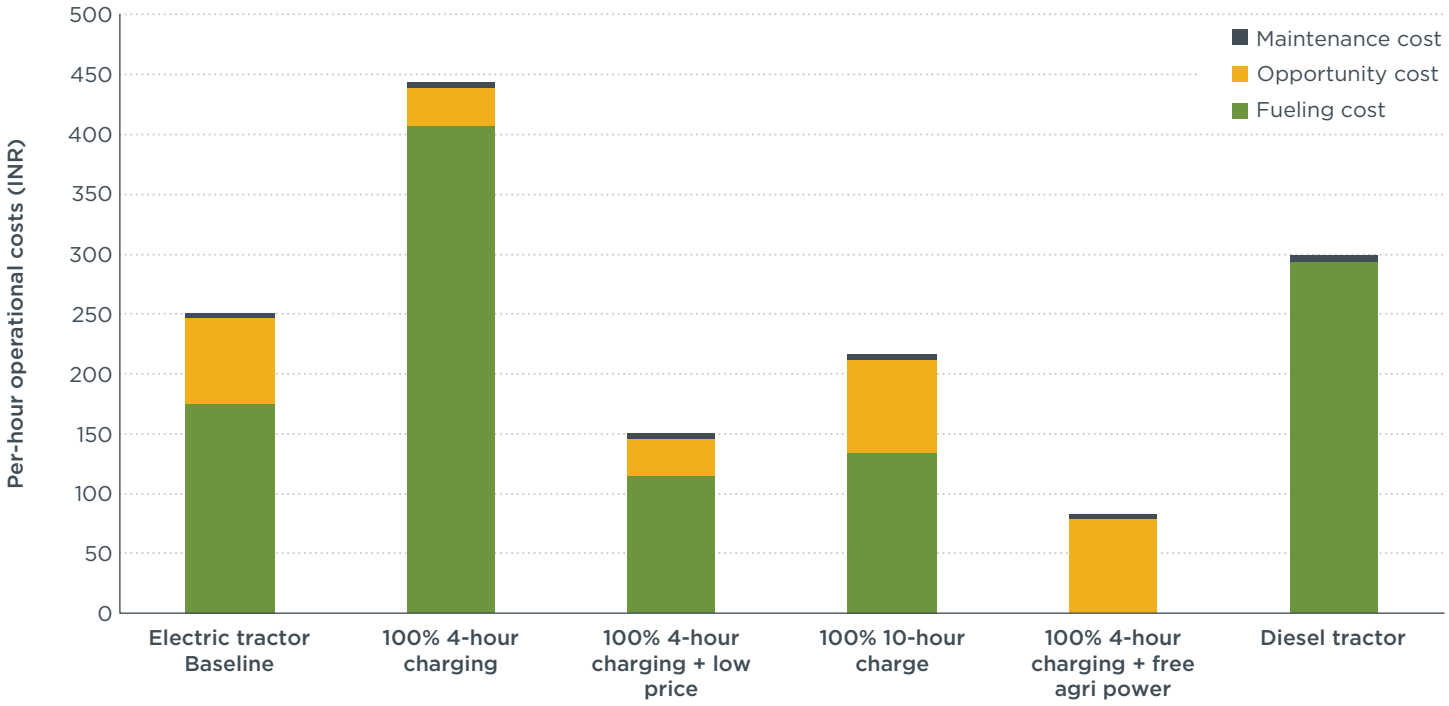

Figure 4. Comparison of per-hour operational costs by different charging patterns and power price

This study might overestimate the opportunity costs associated with the hours of charging. Daily work could total less than 3 hours given the 900 hours of performance annually, which can be easily met on a single overnight charge as claimed by the manufacturer. This implies that using an electric tractor might carry no opportunity cost. Figure 5 highlights the potential impacts on the TCO for using an assumption with lower opportunity costs, as 85% of the tractor usage can be met by a single overnight charge. In this case, the TCO of electric tractors could be much lower than the TCO of the diesel version, yielding cost savings to owners of electric tractors. Still, planting season, which could last several weeks to a month or two, and require that tractors perform continuously for up to 10-14 hours a day, could be challenging to electric tractors, given that refueling could take long hours and might affect cropping and planning progress, particularly with limited availability of charging stations and facilities. But this could be addressed through battery swapping, by renting a second tractor, or through other approaches.

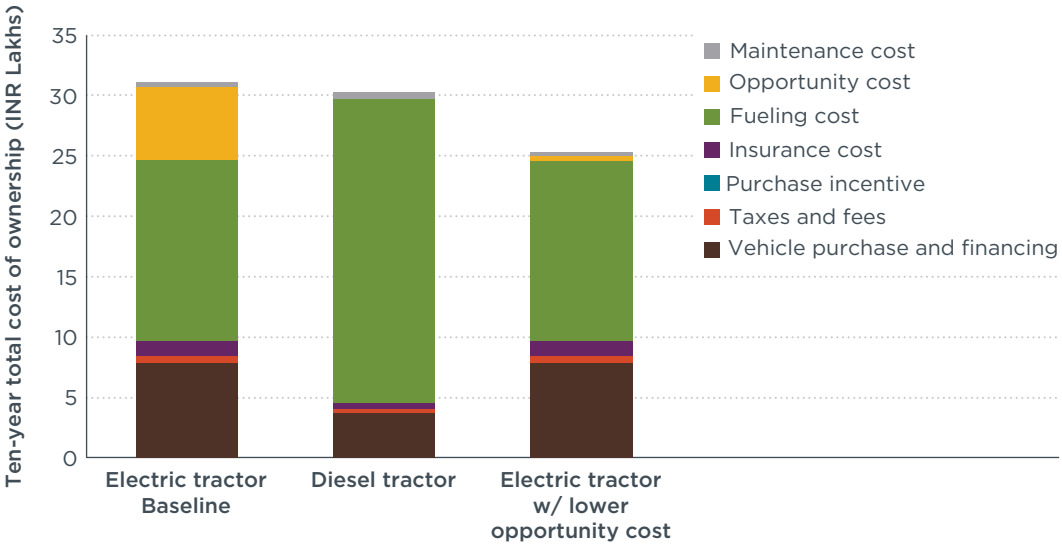

Figure 5. Comparison of ten-year TCO in case of lower opportunity cost associated with electric tractors

Furthermore, the analysis was conducted based on the assumption of sufficient power supply, while power shortages and power cuts are big concerns in many agricultural states. The uncertainty of power supply could drive away potential customers worried about charging availability.

Similarly, the variation in diesel prices can play an essential role in consumers' decision-making. Unlike the power rate, diesel prices in India change significantly based on the global oil price. The diesel unit price was only around INR 60-70 per liter in 2019 and reached more than INR 100 per liter in early 2022, an increase of more than 30%. If diesel prices continue to climb, the costs of using diesel tractors will climb still higher.

Policy implications

The following section summarizes our policy recommendations for promoting electric tractors based on the 10-year TCO analysis. These encompass critical actions from the government and key stakeholders that can improve the economics of using electric tractors. Many policy recommendations can be applied to other off-road equipment, including agricultural and construction equipment, where support for promoting zero-emission technology is still minimal. Extending the policies to the off-road sector can move India closer to its climate commitments and decarbonization goals.

India needs to extend consistent upfront purchase incentives beyond electric motor vehicles. India has offered central and state-level incentives to spur adoption of electric two-wheelers, three-wheelers, and motor vehicles. But no subsidies are provided for electric tractors or any other off-road equipment. Such upfront incentives can reduce the high initial costs of electric equipment and thus lower the threshold of purchasing clean equipment. The coverage of upfront incentives should be broad enough to cover all zero-emission off-road equipment in addition to motor vehicles, including agricultural equipment and construction equipment. This is particularly urgent for tractors, given that electric models have been available for more than a year already. A lack of sufficient upfront incentives will drive consumers away from clean equipment and, more importantly, could eliminate India's leading role in tractor export. Considering that electric tractors are more than twice as expensive as diesel versions, incentives consistent with those offered for motor vehicles can effectively reduce the cost gap between electric and diesel tractors.

Leveraging the current subsidization of agricultural electricity is effective in lowering costs. An appropriate and feasible way to finance the transition to electric tractors is to provide incentives for using the equipment. The existing mechanism that offers discounted agricultural electricity can be adopted to promote electric tractors and other electric agriculture equipment. This incentive can be expanded to more states for using electric tractors, with lower electricity tariffs on charging electric tractors and other agricultural equipment. This could impose a minor burden on government finances yet help to close the cost gap between diesel and electric tractors. The incentives associated with usage can further encourage the use of electric equipment. The more electric tractors are in the field, the more savings on fuel costs will be realized compared with diesel tractors, given the recent increase in diesel prices. As diesel equipment is replaced, India's reliance on fossil fuel and spending on fuel imports will fall, and societal costs from the use of polluting diesel equipment will decrease.

Support for deployment of charging facilities will facilitate the preference for electric tractors. The limited charging infrastructure in India not only increases the unit charging price but also forces electric tractors to rely on residential charging, which requires 10 hours for a full charge. It can potentially dampen interest in purchasing electric tractors, considering that long charging times can force a pause in usage. Our analysis confirmed that making more fast-charging stations available and reducing unit prices could significantly lower the fueling and opportunity costs of electric tractors. The reduced hours spent on charging can further improve the performance of electric tractors and facilitate the transition away from diesel tractors.

Offering agricultural finance can lower the initial costs. Given the high price of agricultural equipment, financing is a widely adopted purchasing strategy. Offering discounted interest rates and a waiver on processing fees can lower the high threshold of owning electric equipment, particularly at the early stage of the transition. Special finance terms for electric tractors and potentially for other zero-emission agricultural equipment can reduce the high procurement costs associated with advanced technology and reduce monthly payments over the financing period.

Conclusion

India needs to take advantage of the electrification trend in the off-road sector with tractor manufacturers moving ahead and releasing electric tractors in the field. As a global leader in agricultural production and as a major exporter, India has an opportunity to address emissions and greenhouse gas impacts and position domestic manufacturers to better compete in the global market as electrification of agricultural production picks up momentum.

In this paper, we have evaluated the economic impacts of fiscal and non-fiscal incentives for promoting electric and diesel tractors. We compared the 10-year TCO between electric and diesel tractors with similar specifications, and we discussed the underlying elements that could affect the analysis.

The 10-year TCO conducted in this paper confirmed that the cost gap between electric and diesel tractors can be bridged by one or more incentives consistent with those offered for electric vehicles. The bulk of the cost difference is due to the higher upfront price of electric tractors and high opportunity costs. However, great potential exists in driving the electric tractors to be cost-competitive, with existing incentives and policies of electric vehicles being stretched to cover the electric tractors to reduce the upfront costs as shown in Figure 6. With consistent incentives provided for electric vehicles, including the FAME II scheme, state-level incentives, 5% GST, and discounted insurance, electric tractors can reach cost parity with diesel models, or even be less expensive on a TCO basis. In addition, incentives provided at the operational level, such as a discounted

price for power and improved fast-charging capacity, can effectively encourage the operation of electric equipment in the field, given that energy prices might be the most critical element in determining total costs. Additional support, such as agricultural loans with lower interest rates and processing fees, can further support the transition to electric tractors. Those measures should be broadly designed to cover all electric equipment in the off-road sector to enable a faster transition toward zero-emission equipment in India.

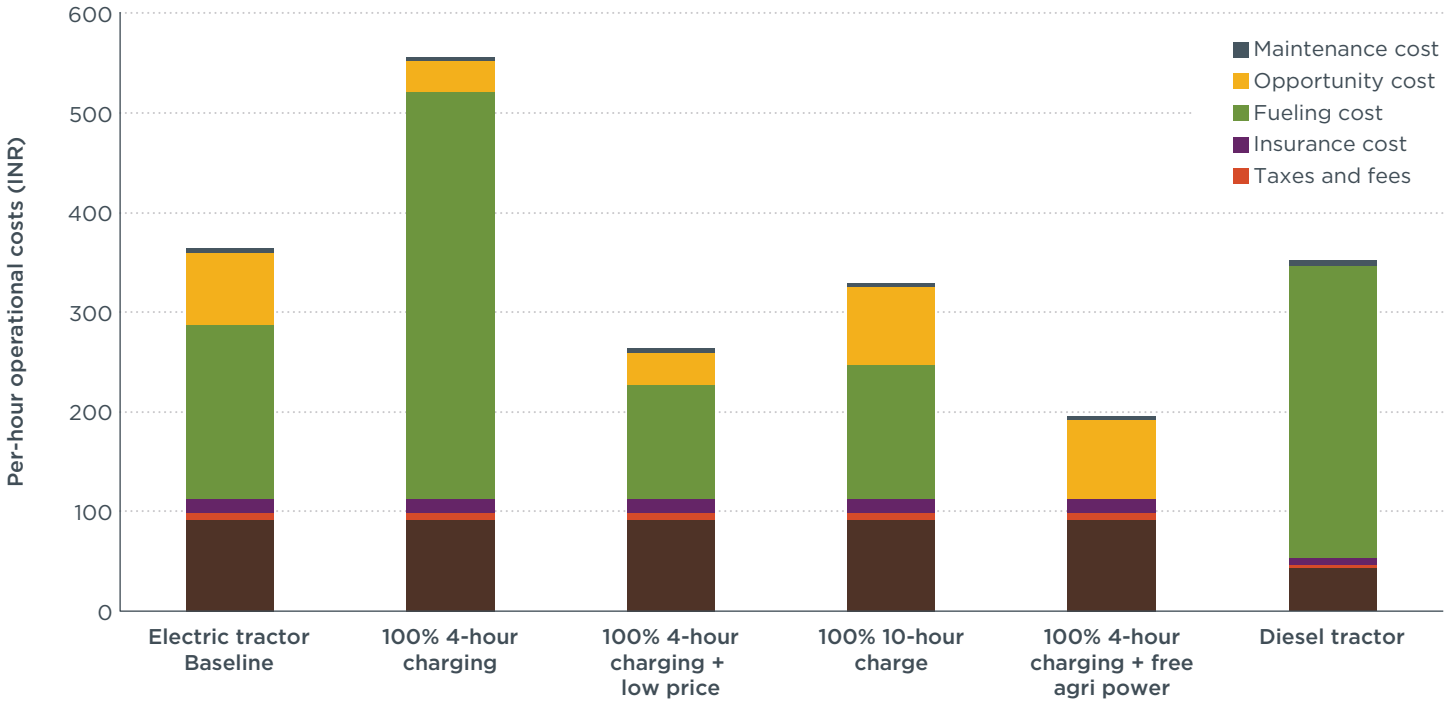

Figure 6. Comparison of per-hour TCO costs by different charging patterns and power price

Our TCO estimate for electric tractors is conservative given limited data availability and understanding of real-world tractor performance, and given that we used a high estimate of opportunity cost and fueling (electricity) cost. As a result, the 10-year TCO of electric tractors may well be lower than that of diesel models, even after accounting for the higher showroom prices of electric versions. Further investment will be needed to better understand electric tractors' performance and charging patterns.

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