

## CONFERENCE ARTICLE

# Reducing Diesel Fuel Consumption Through The Electrification Of Agricultural Machinery

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**Abstract:** The potential reduction of direct diesel fuel use through full or partial electrification of agricultural machinery is assessed using a useful-work-based energy balance. Battery-electric and hybrid configurations are compared for a hypothetical low-power operating cycle. With an assumed 4.0 kW mechanical load, a load factor of 0.65 and five operating hours, useful mechanical work is 13.00 kWh/day. The corresponding battery output is 15.20 kWh/day, whereas a conventional diesel reference requires 5.31 L/day under the selected fuel-energy and drivetrain-efficiency assumptions. Electrification shares of 30%, 60% and 100% are evaluated as idealized load substitution cases. Fuel savings depend on the electricity source and the actual duty cycle; all results constitute preliminary calculations rather than experimental validation.

**Keywords:** Agricultural machinery; electrification; diesel displacement; hybrid powertrain; electric tractor; battery sizing; photovoltaic charging; energy efficiency.

## INTRODUCTION

Tractors, seeders, sprayers, irrigation machinery, and transport vehicles constitute important sources of direct fuel consumption in mechanized agriculture. Electrification offers an alternative energy pathway and enables independent speed or torque control of selected implements. Its feasibility nevertheless depends on the required useful work, operating time, battery mass, peak power, and access to charging infrastructure. Comparison on rated engine power alone can be misleading because the field-duty cycle is often intermittent and strongly affected by soil resistance and the implement configuration.

The published literature covers the electrification of tractor-implement combinations, electric drivetrain topologies, and the practical dependence of battery operation on agricultural workload [1–5]. Reviews of solar-powered machinery additionally demonstrate the importance of renewable charging arrangements [6]. Recent tractor tests indicate that load peaks, usable battery time and the distribution of traction and power take-off loads must be considered in component selection [4,5,7].

### Main body

Three electrification routes can be distinguished. A battery-electric configuration replaces the diesel engine with a motor and externally charged energy storage. A parallel or series hybrid retains an internal-combustion engine but transfers part of the duty cycle to an electric drive. Implement-level electrification replaces a selected mechanical or hydraulic function, for example a spraying pump, with a separately controlled electric motor. The actual saving depends on whether external electricity replaces diesel energy or whether the engine generates electricity on board.

Useful mechanical work  $E_m$  and the corresponding battery-output electricity  $E_e$  are calculated using the operating time and mean load factor:

$$E_m = P_n \cdot k_u \cdot t, \quad \text{kWh};$$

$$E_e = \frac{E_m}{\eta_m \cdot \eta_i}, \quad \text{kWh}. \quad (1)$$

Here  $P_n$  is the assumed mechanical load (kW),  $k_u$  is the duty-cycle utilization factor,  $t$  is operating time (h), and  $\eta_m$  and  $\eta_i$  are the motor and inverter efficiencies. Under the same useful-work requirement, diesel consumption for a reference drivetrain is estimated as:

$$V_D = \frac{E_m}{q_D \cdot \eta_D}, \quad L \quad (2)$$

In this equation,  $q_D$  is the lower heating value of diesel per litre (kWh/L) and  $\eta_D$  is the aggregate efficiency of the engine and transmission. If an external electric source supplies an ideal fraction  $\alpha$  of useful work while the remaining diesel duty retains the same efficiency, then:

$$V_{D,\alpha} = (1 - \alpha)V_D;$$

$$\Delta V_{D,\alpha} = \alpha V_D. \quad (3)$$

Equation (3) is an intentionally idealized allocation. A practical hybrid drive can operate the engine at different efficiency points, incur generator and conversion losses, and consume fuel during idle periods. If the battery is recharged using a diesel generator, system-level fuel savings will be smaller than the ideal values and may disappear. Therefore, the source of electricity and the system boundary must be declared in any comparative assessment [1–3].

For the calculation scenario,  $P_n = 4.0$  kW,  $k_u = 0.65$  and  $t = 5$  h provide  $E_m = 13.00$  kWh/day. At  $\eta_m = 0.90$  and  $\eta_i = 0.95$ , the battery delivers  $E_e = 13.00/(0.90 \times 0.95) = 15.20$  kWh/day. With  $q_D = 9.8$  kWh/L and an assumed aggregate diesel efficiency  $\eta_D = 0.25$ , the reference consumption is  $V_D = 13/(9.8 \times 0.25) = 5.31$  L/day. These values describe a hypothetical compact machine and must not be interpreted as measured fuel consumption for a specific commercially available tractor.

Table 1. Idealized diesel displacement at different electrification shares

| Electrification share, $\alpha$ | Diesel use, L/day | Saved diesel, L/day | 150-day savings, L |
|---------------------------------|-------------------|---------------------|--------------------|
| 0%                              | 5.31              | 0                   | 0                  |
| 30%                             | 3.71              | 1.59                | 238.8              |
| 60%                             | 2.12              | 3.18                | 477.6              |
| 100%                            | 0                 | 5.31                | 795.9              |

Increasing the fraction of useful work supplied from an external electrical source reduces direct on-board diesel consumption in proportion to  $\alpha$  under the stated assumptions. However, the accounting boundary matters. Grid electricity may have upstream emissions, whereas solar PV can reduce fossil-electricity demand without guaranteeing zero life-cycle impacts. Realistic comparison must include battery manufacture, charging losses, machine lifetime, and electricity supply. Solar-powered agricultural machinery and its limitations are reviewed in [6].

Minimum nominal battery energy is related to the allowable depth of discharge and discharge efficiency:

$$C_{b, \min} = \frac{E_e}{\text{DoD} \cdot \eta_d}, \text{ kWh.} \quad (4)$$

For DoD = 0.80 and  $\eta_d = 0.95$ , the selected duty cycle gives  $C_{b, \min} = 20.01$  kWh. A preliminary 24 kWh battery therefore provides a sizing margin, but it does not independently verify mass, thermal performance, current limits, or long-term degradation. Full-day heavy tillage would demand substantially greater installed energy, as demonstrated by recent workload-based electric-tractor research [4,5,7].

Partial electrification can reduce initial investment by replacing individual auxiliary drives first. Electrifying the sprayer pump or precision actuator may permit independent speed control and remove selected mechanical power take-off loads. Yet the aggregate diesel saving cannot be calculated by simply dividing the electric motor rating by tractor engine power: actual fuel use must be measured under comparable field conditions and work quality.

Solar charging may be integrated through a stationary PV canopy and a detachable or stationary buffer battery. Since peak sunshine and agricultural operation are not perfectly synchronized, energy storage or access to the electrical grid may be needed for evening, cloudy-day, or consecutive-shift operations. A first-order PV energy estimate is expressed as:

$$E_{PV} = P_{PV} \cdot H_s \cdot PR, \text{ kWh/day.} \quad (5)$$

The quantities  $P_{PV}$ ,  $H_s$ , and  $PR$  denote installed peak PV capacity, equivalent peak-sun hours, and performance ratio, respectively. Seasonal PV yields should be compared with measured monthly work schedules and battery charging requirements. A single sunny-day balance does not prove year-round fuel substitution, because agricultural operations often coincide with weather and seasonal constraints.

Environmental interpretation also requires a consistent boundary. Displaced litres of diesel represent direct on-machine fuel savings; net greenhouse-gas savings can only be reported after identifying charging electricity, upstream fuel and electricity impacts, battery manufacture and machinery lifetime. Published life-cycle assessment of a solar-assisted plug-in hybrid tractor illustrates the need for such comprehensive comparison [10]. No numerical life-cycle emission reduction is claimed by this calculation exercise.

Experimental assessment should compare three practical configurations: an electrically driven sprayer, a hybrid light cultivator, and a compact battery-electric transport platform. Required measurements include fuel use (L/h and L/ha), completed work (ha/h), shaft torque, motor speed, electric demand (kWh/ha), battery state of charge, and charging duration. Each electric and diesel comparison must apply equivalent operating conditions and comparable agronomic work quality.

The temporal structure of field work is particularly important. A machine may alternate between high-resistance cultivation, low-load manoeuvring, relocation, and idle periods. Consequently, nominal engine rating does not represent average power or total energy consumption. Load-duration distributions are more suitable for determining motor continuous rating, short-time overload, and battery capacity [5,7].

Charging should be coordinated with the farm schedule rather than merely with the available grid connection capacity. Overnight charging without dedicated storage may not consume the PV electricity generated the previous afternoon; appropriate accounting requires a grid-interconnected arrangement or a stationary buffer battery. Battery exchange can increase utilization when multiple machines share a charging station, but adds inventory, handling, and safety requirements [8,9].

Electrical safety considerations differ for diesel, hybrid and battery-electric machines. High-energy battery packs need overcurrent protection, isolation, secure cable routing, clear identification, and an emergency disconnect. Inverter control should consider traction slip, sudden implement blocking, battery temperature, and the safe management of regenerative power when supported by the selected drive topology.

Criteria for evaluating overall efficiency. Fuel use per operating hour is insufficient as a stand-alone performance indicator. Comparisons should normalize fuel and electricity to the same agricultural output, for example litres per hectare and kilowatt-hours per hectare, while recording field capacity, travel speed, cultivation depth, application rate, and crop requirements. Only matched functional performance allows fuel displacement to be meaningfully assessed.

Electrification may also improve implement controllability. Dedicated motor drives can adjust pump speed, metering rate, and actuator response without relying entirely on engine speed. These improvements remain conditional on drive losses, sensor accuracy, reliability of power electronics, and suitable field calibration. Potential operational benefits should therefore be evaluated separately from fuel savings.

Steps toward an experimental prototype. The first development stage requires recording the existing machine duty cycle, including engine speed, load torque, fuel flow, implement power and completed field work. The next stage selects a target subsystem and derives a speed-torque envelope for the electric motor. A suitable drivetrain, inverter and battery are then selected according to the measured load distribution. Finally, an energy-management controller is calibrated and tested under representative field conditions.

For reliable measurement, fuel comparisons should be repeated under equivalent soil and implement settings. Flow-meter calibration, electrical power logging, uncertainty evaluation, and separate validation datasets are required. Environmental conditions such as ambient temperature, soil moisture, field slope and operator behaviour should be documented to avoid attributing all observed differences to the powertrain alone.

Economic feasibility depends on diesel and electricity prices, annual utilization, charging infrastructure, PV yield, maintenance requirements, battery replacement and the cost of machine downtime. Annual total cost is a more defensible criterion than multiplying one sunny-day fuel estimate by a nominal number of working days. Published cost analyses show that utilization patterns and battery-management arrangements can materially influence electric-tractor competitiveness [8,9].

## Conclusions

Electrification can reduce direct diesel fuel consumption in agricultural machinery when useful mechanical work is transferred from diesel operation to an externally supplied electrical drive. The assumed 13.00 kWh/day mechanical duty requires 15.20 kWh/day of battery output, while the diesel reference consumes 5.31 L/day. Ideal work-substitution shares of 30%, 60% and 100% correspond to direct savings of approximately 1.59, 3.18 and 5.31 L/day, respectively. These estimates exclude changes in hybrid engine efficiency and upstream electricity impacts. Field trials, powertrain-specific losses, charging-source analysis and full life-cycle costing are required before actual savings can be stated.

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