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Solar-powered farm rickshaw for agricultural transport

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ABSTRACT

The automobile sector is rising rapidly at a global level. In the current scenario, emphasis is given on electric vehicles (EVs) to reduce conventional energy demand and minimize greenhouse gasses. Most work has been done on solar-powered vehicles used for the transportation of people rather than agricultural transport such as labor, tools, and farm production. Therefore solar-powered farm rickshaw were tailored to Indian farm conditions. A three-wheel rear-driven 450-watt capacity solar-powered farm rickshaw was designed, developed, and evaluated in Indian climatic conditions. The developed rickshaw were comprised of three 150-watt polycrystalline solar modules. The produced electricity is stored in a 48-volt 30 Ah lithium-ion battery. A maximum power point tracking (MPPT) system was also incorporated to access the maximum power from solar panels. Statistical analysis was made with ANOVA tool and FCRD-test. The results were tested at the 5% significant level. The developed rickshaw has a cargo capacity of 300 kg and can be used to transport labor and farm produce. It reduces annual fossil fuel demand by approximately 350 liters and annual CO_2 emissions by approximately 837 kg. The developed solar-powered farm rickshaw not only reduces fossil fuel demand but also reduces the emission of greenhouse gasses at large. The main goal behind the design and development of a solar-powered farm rickshaw is to do farm work at low-cost and pollution-free.

1. Introduction

Energy is a current issue that is becoming increasingly relevant in our lives. The demand for energy is growing as the human population increases. In the 2050s, the world's population is expected to reach ten billion people. The world's reliance on fossil fuels is growing by the day, particularly in the automobile industry, and they are predicted to continue to dominate until 2040 [1]. The daily depletion of fossil fuels raises the demand for alternative and renewable energy to meet the world's energy needs [2–4]. According to the U.S. Energy Information Administration (EIA), fuel demand will rise at a high rate in the late 2020s, increasing by 0.1 million barrels per day each year. The demand for fossil fuels is increasing rapidly due to the increasing automobile sector. In Indian metro cities, auto rickshaws are mainly used for transportation. An auto rickshaw is an IC-engine operated vehicle, which requires petrol as a fuel. As the vehicle industry expands, climate change and air pollution are exacerbated as a result of fuel burning [5]. The combustion of diesel and petrol in automobiles generates greenhouse gasses, which enhance pollution. Extensive use of fossil fuels destroys living species territories and harms the environment [6]. The transportation industry is the second largest source of pollution, and due to that, human health issues are created. The air pollution that is warming the earth's surface as a result of pollutants from automobiles, which accounts for around 23% of overall air pollution [7]. There are various sources of pollution, but road transport contributes to that 14% shown in Fig. 1 [8]. India's transportation sector contributes about 10% of total national greenhouse gas (GHG) emissions, and road transportation contributes about 87% of the total emissions in the sector. The transportation sector's CO_2 emissions will continue to grow by 4.1 to 6.1 percent per year, leading to an increase of seven times in 2050 relative to 2010 [9]. Therefore, the Indian government shifted towards electric vehicles, which do not emit harmful gasses, so it can be beneficial to achieve the target of zero emissions by 2050. Fig. 1 shows the different types of sources of pollution.

The demand for electric vehicles (EVs) is increasing every day due to the fact that they are a pollution-free green mode of transportation. In the future, electric vehicles are expected to increase worldwide energy consumption by 30% while reducing harmful carbon emissions by 25–60% [10]. The importance of charging EVs using solar technology is increasing as a result of the continued drop in price of photovoltaic modules, worries about how greenhouse emissions would affect global energy laws, and growth in EV purchase. India, being a country near to the equator, is bestowed with vast solar energy potential. About 5000 trillion kWh per year of energy is incident over India's land area, with most parts receiving 4–7 kWh per sq. m per day [11]. Solar power should be used to power these vehicles in order to produce a sustainable environment for all living beings by reducing pollution generated by the burning of petrol and diesel in autos [12,13]. A solar rickshaw is a transportation system based on auto rickshaws that functions in an ecolog-

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Nomenclature

Ah	ampere hours
kg/m^3	kilogram per meter cube
kWh/m^2	kilowatt-hours per square meter
F	force
min	minute
PV	photovoltaic
W	watt
₹	rupees
$	dollar
DF	degrees of freedom
MSS	mean sum of squares
TAB F	tabulated F value
S	significant
CD	critical difference
ANOVA	analysis of variance
A	ampere
kWh	kilowatt-hours
cm	centimeter
m	meter
N	Newton
V	voltage
L	liter
₹/h	rupees per hour
€	euro
SS	sum of squares
CAL F	calculated F value
NS	non significant
SEM	standard error of mean
CV	coefficient of variation

ically responsible manner [14]. In farm work, tractors are mostly used for transportation, such as labor, farm produce, and tool transportation. This agricultural work necessitates the use of a tractor, which consumes more fuel. Farmers can conduct this agricultural work efficiently without spending any money on fuel and in an environmentally friendly manner with the help of the solar-powered farm rickshaw. Fig. 2 shows the importance of solar powered vehicles.

Keeping in view the above situation, solar powered farm rickshaw was developed as per Indian farm road conditions to improve efficiency, save fossil fuels, reduce greenhouse gasses and lower health risk by reducing environmental emissions. The main purpose of the development of solar-powered farm rickshaws was to reduce the burden of fuel costs on the farmer and help to reduce pollution. This newly developed solar powered farm rickshaw mainly consists of a solar panel, a Maximum Power Point Tracking (MPPT) solar charge controller, a lithium-ion battery, and a Brushless Direct Current (BLDC) motor. The evaluation of the developed model was tested as per Indian conditions on both types of concrete and without concrete roads to measure the charging and discharging characteristics of the battery and the distance covered per charge with and without solar power connection.

2. Material and methods

The design and experimental investigation of solar powered farm rickshaw was made at Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology (CAET), Junagadh Agriculture University (JAU), Junagadh, Gujarat, India (21° 31′ N, 70° 28′ E).

2.1. Working principle of solar powered farm rickshaw

The solar-powered farm rickshaw is totally powered by solar energy. In the developed model, solar PV panels are attached to the vehicle's roof and they convert sunlight directly into electricity as per shown in Fig. 3. The maximum power point tracking (MPPT) controller were used to capture the most power from solar panels in order to charge lithium-ion vehicle batteries. A Brushless Direct Current (BLDC) electric motor were used to convert battery power into mechanical drive energy. Differential gears deliver the power from the motor to the rear wheels. The main components of solar-powered vehicles are shown in Fig. 4.

2.2. BLDC motor power

The electric vehicle's most important part is its electric motor, which provides the power to drive the vehicle. A BLDC motor was used for efficient operation, and it provides noiseless operation, gives undervoltage and overvoltage protection, and is waterproof [16]. The required motor power was calculated as follows;

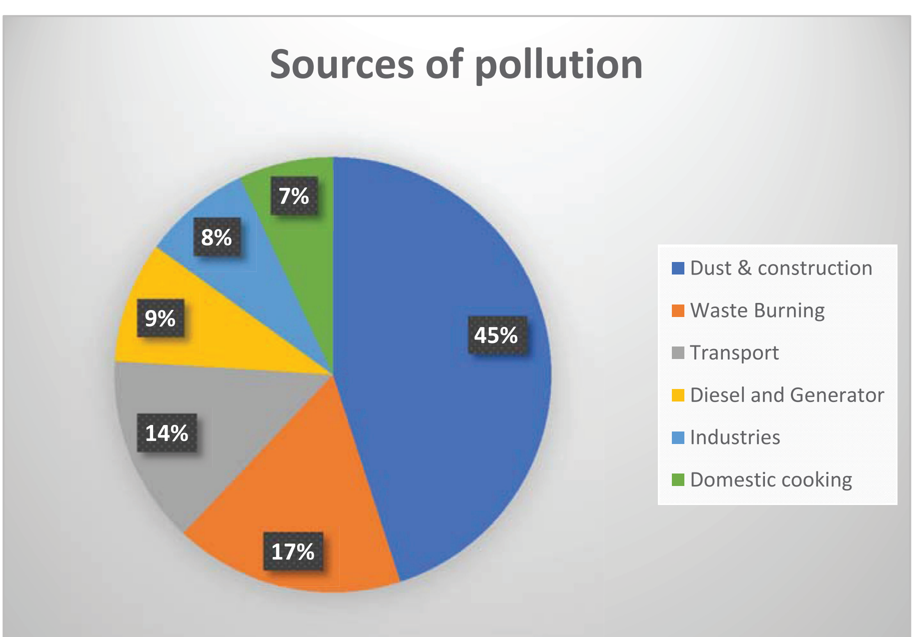

Fig. 1. Sources of pollution in India [8] source: https://en.wikipedia.org/wiki/Air_pollution_in_India.

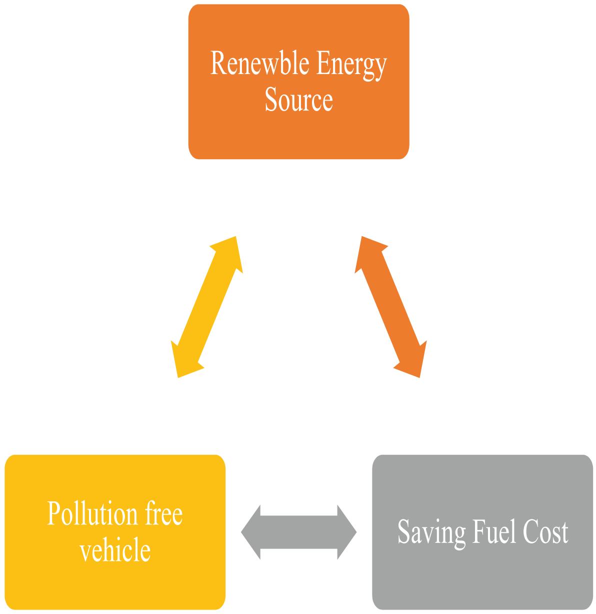

Fig. 2. Importance of solar-powered vehicle.

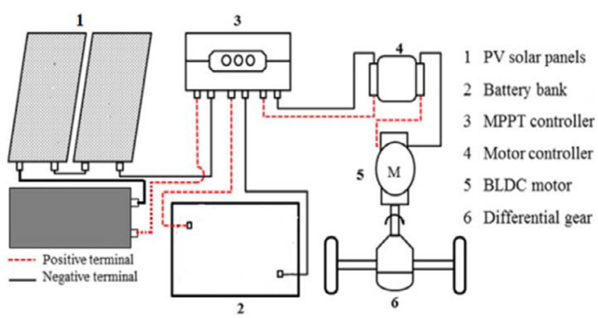

Fig. 3. The operating principle of the developed solar powered farm rickshaw [15].

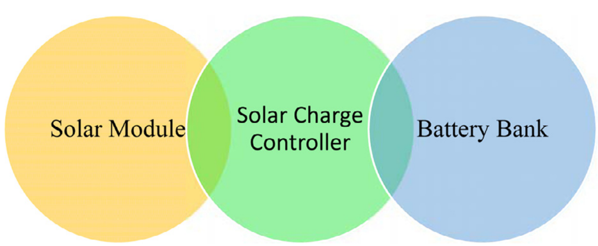

Fig. 4. Main components of solar powered vehicle.

Method: 1

The power necessary to push a vehicle was calculated by combining the forces that must be applied to the vehicle to move it with the vehicle speed at which this propelling force must be sustained.

A. **Rolling resistance**

The rolling resistance force is the force that opposes the tire's rolling motion as it rolls over the road surface. The rolling resistance force is calculated as follows [17,18]:

$$F_{Rolling} = \mu_R \times W \tag{1}$$

where,

μ_R = Coefficient of rolling resistance
W = The weight of the rickshaw in kg

B. **Aerodynamic drag force**

The force applied by the air to keep the vehicle from moving through it is known as aerodynamic drag. The aerodynamic drag force is calculated as follows [18]:

$$F_{Drag} = \frac{1}{2} \times C_d \times A \times \rho \times V^2 \tag{2}$$

where,

C_d = The coefficient of drag of the vehicle
A = frontal area in square feet
ρ = A constant that accounts for the air mass density
V = The vehicle's speed.

C. **The Acceleration Force**

The acceleration force is the force that assists the vehicle in reaching a predetermined speed from a standstill in a given amount of time. The acceleration force is proportional to the vehicle's mass. The force of acceleration, which is determined by Newton's second law of motion, should only be considered when the rickshaw is accelerating [18].

$$F_A = M \times A \tag{3}$$

where,

M = Mass of the rickshaw
A = Acceleration

D. **Total tractive force**

It is the overall force that the power train/power supply mechanism must create in order to accelerate the vehicle to the specified units. The total tractive effort must equal the sum of the three forces mentioned above, and therefore,

$$F_D = F_{Rolling} + F_{Drag} + F_A \tag{4}$$

The power needed to be supplied by the motor in order to provide the current speed and acceleration will therefore be [19],

$$P_T = F_D \times V \tag{5}$$

where,

P_T = Maximum power of BLDC motor
F_D = Drive force
V = Max. allowable speed of the rickshaw

Method:2

Selection of BLDC motor was carried out based on following formula [19],

$$P(watt) = W \times g \times V \times S \tag{6}$$

where,

P = Power of BLDC motor in watt,
W = Total weight of rickshaw including load,
g = acceleration due to gravity (9.81 ms^{-2}),
V = Top speed of rickshaw,
S = Assumed Slope 1.5 to 2%.

Method: 3

From the resulting force and the radius wheel r calculated the torque and then power as per following formula [20],

$$Torque(\tau) = r \times F \tag{7}$$

where,

r = radius of wheel
F = Total tractive forces

$$P(watt) = \frac{Torque(\tau) \times RPM}{9.55} \tag{8}$$

For the motor power calculations using the three different methods, all the methods give three different required powers as follows: Method I: 1034.33 W, Method II: 980.60 W, and Method III: 884.83 W. Method I provides a higher value than the other two methods, so we prefer method one here, but the available motor power in the market is 1200 W, so we use this capacity BLDC motor.

2.3. Electronic motor controller

A motor controller is a device or a set of devices that regulates the performance of an electric motor in some predetermined way. The controller has an automatic switch for turning on and off the motor, selecting forward or reverse rotation, selecting and regulating speed, regulating or limiting torque, and overload protection. The battery pack and the controller feeds are linked to the motor controller [21].

2.4. Battery capacity

The principal source of electrical energy is the battery. The capacity of the battery bank was chosen based on the overall power required for the required length in a day as well as the battery efficiency. The weight of the battery has an impact on the vehicle's ability to travel. As a result, selecting the battery bank's capacity is an important component of constructing a solar-powered system. The capacity of the battery bank was determined using the following formula [22]:

$$\text{Battery Capacity(Ah)} = \frac{Motor\ Power\ (W) \times Operating\ hours(h)}{Battery\ voltage\ (V) \times Max.\ allowable\ disharge} \tag{9}$$

Where, Max. allowable discharge = is the capacity of the battery to provide store energy upto 80% for lithium-ion battery.

The lithium-ion battery offers clear advantages in the automobile industry, such as a long cycle life, large energy capacity, and high efficiency [23]. Therefore, were used lithium-ion battery for energy storage.

2.5. Photovoltaic (PV) panel

The photovoltaic effect transforms light energy into electrical energy. A photovoltaic cell is one of many smaller elements that make up a solar panel. When photons from the sun strike these cells, they release free electrons, resulting in an electron-hole pair. The conversion of light energy into electrical energy is based on the mobility of these electrons and holes [22]. Polycrystalline solar panels were used to convert light to electrical energy, and their power was calculated as follows:

$$Total\ solar\ power\ needed = \frac{Total\text{ power required for motor}}{E_{sc} \times E_b \times E_{mc}} \tag{10}$$

Where,

E_{sc} = Efficiency of solar charge controller
E_b = Efficiency of battery
E_{mc} = Efficiency of BLDC motor controller

$$No.\ PV\ Panels = \frac{Total\ power\ needed}{Capacity\ of\ single\ PV\ panel} \tag{11}$$

2.6. Solar charge controller

The main goal of charge controllers is to operate as battery management system (BMS), regulating the charging and discharging of the battery to ensure trouble-free operation for longer battery life. It also prevents power from flowing backward to the solar panels, therefore avoiding the discharge of the battery [24]. The solar charge controller is typically rated against Ampere and Voltage capacities. Therefore, a solar charge controller were selected as per the following formula: [25],

$$\text{Solar charge controller rating} = \text{Total short circuit current of PV array} \times 1.3 \tag{12}$$

Asrori et al. [26] stated that the MPPT-type solar charger controller is successful in optimizing the battery charging system. Therefore, were used the MPPT solar charge controller. The complete specification details of solar-powered rickshaw are given in Table 1.

Table 1
Specification of the solar powered farm rickshaw designed.

S. No.	Particulars	Specifications
1	**Name of the equipment**	**Solar powered farm rickshaw**
2	**Type of action and its detail**	
	Action	Self-propelled
	Power source	Solar power
3	**Overall dimensions**	
	Length × Width × Height (mm)	2450 × 1250 × 1800
	Ground clearance (mm)	250
	Weight (kg)	295
	Weight capacity for cargo (kg)	300
4	**Solar panels**	
	Solar panels type	Polycrystalline
	Module dimensions ($L \times W \times$ T)	1480 mm × 675 mm × 35 mm
	Module weight	10.52 kg
	No. of solar panel	3
	Rated maximum power (P_{max})	150 $W \pm$ 3% 8.13 A
5	**Solar panel frame**	
	Material used for frame	G.I. square pipe
	Length × Width (mm)	2155 × 675
	Height of supporting pipe	1000
	No. of supporting pipe	4
6	**Trolley**	
	Material of construction	Mild Steel (MS) plate
	Length × Width × Height (mm)	1160 × 1250 × 1320
	Height from ground (mm)	560
7	**Wheel unit**	
	Wheel type	Pneumatic
	No. of wheel	3
	Material of rim	Steel
	Width of wheel, mm	110
	Rim diameter & Overall diameter mm	254 & 300
8	**BLDC motor**	
	Material of casing	Aluminum
	Power	1200 W
	Voltage	48 V
	Current	25 A
	Dimensions of motor (mm)	250 × 200 × 150
	No. of teeth on shaft	14
9	**Battery**	
	Type	Lithium ion
	Voltage V	48 V
	Current capacity Ah	30 Ah
	Length × Width × Height (mm)	300 × 200 × 200
	Max. voltage at full charged	50.3
	Min. voltage at discharge	47
	Weight (kg)	14.28 kg
10	**Solar charge controller**	
	Type	MPPT
	Voltage	48 V
	Current	15 A

2.7. Brake system

A conventional drum brake was taken into consideration to control the speed of the wheels. The brakes were located on the chassis (Pedal-Brakes), so that when the pedal was pressed, the brakes engaged and stopped the rear wheels. Figs. 5 and 6 shows the design view and developed view of solar-powered rickshaw, respectively.

3. Functional performance of the developed solar farm rickshaw

3.1. Solar charging

The total time required to charge the battery with the solar panel were measured. Solar radiation was measured on the panel surface with the help of a digital solarimeter in watt/m^2. The battery charging status was constantly monitored by the digital battery voltage display unit.

3.2. Battery discharging during transportation

Battery discharging characteristics were measured per kilometer for three different loads (100, 200, and 300 kg) and two road conditions

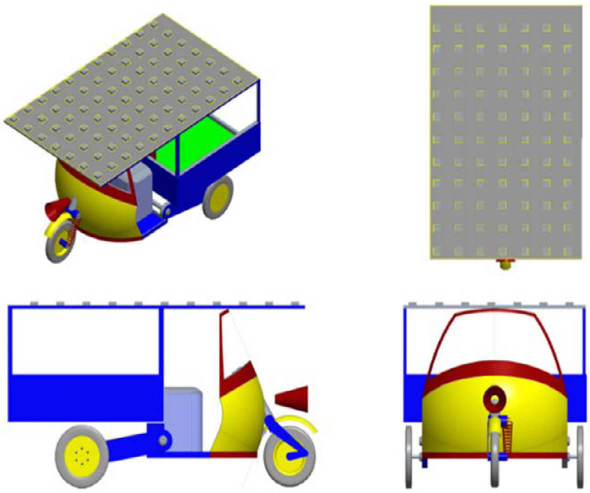

Fig. 5. Different views of designed solar powered farm rickshaw.

Fig. 6. Different views of developed solar powered farm rickshaw.

(on concrete and without concrete road). In this evaluation, the effects of different loads and types of roads on voltage drop and time required to cover a km were studied.

3.3. Distance covered during transportation

Performance evaluation of a fully charged battery were carried out under transport mode for three different loads as follows: 100 kg, 200 kg, and 300 kg on two types of roads (on concrete and without concrete road). After fully discharging the battery, the covered distance was measured. In this evaluation, the effect of different loads and types of roads on total covering distance was studied.

3.4. Comparative analysis of with and without solar power

The comparative analysis between with and without solar power to measure the battery backup time and distance covered was carried out. In the first condition, a fully charged battery was taken, then it was discharged without connection to solar power in transportation, and the total travelled distance and backup time in such condition were measured. In the second condition, a fully charged battery was taken, then it was discharged with the connection of solar power in transportation, and the total travelled distance and backup time in such condition were measured.

3.5. Statistical analysis

In order to discover significant differences, statistical analysis was carried out for voltage drop per km and time required for per km. Data collected during field test were used to quantifying the variation using “ANOVA two- factor with three replications” and Factorial Completely Randomized Design (FCRD)-test at 5% level of significance ($P \le 0.05$).

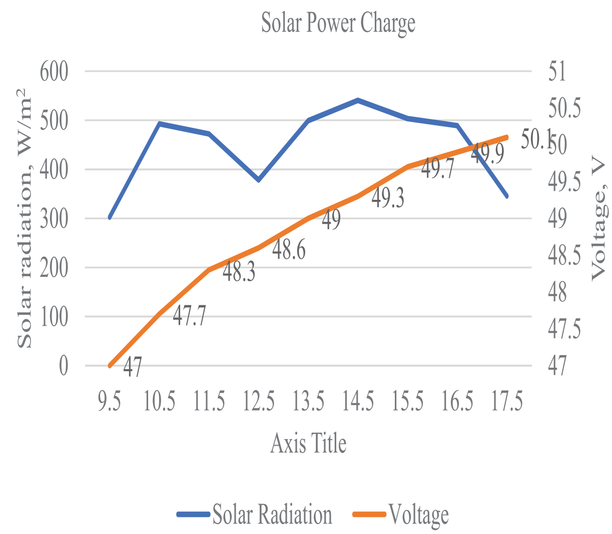

Fig. 7. Solar charging of solar powered farm rickshaw.

3.6. Reduction of CO_2 emission per year

The solar powered farm rickshaw is run on solar power therefore it reduces the carbon dioxide emission. 1 liter of petrol weighs 750 gmes. Petrol consists for 87% of carbon, or 652 gmes of carbon per liter of petrol. In order to combust this carbon to CO_2, 1740 gmes of oxygen is needed. The sum is then 652 + 1740 = 2392 gmes of CO_2/liter of petrol [27,28].

3.7. Techno-Economics of solar powered farm rickshaw

The total cost of a solar powered farm rickshaw is divided into two parts, fixed cost and variable cost, where fixed cost is independent of operational use and variable cost is proportional to usage [29,30]. Depreciation is the loss of value of a machine with the passing of time. Straight line depreciation is the most commonly used and straightforward depreciation method for allocating the cost of a capital asset. It is calculated by simply dividing the cost of an asset, less its salvage value, by the useful life of the asset. Interest is calculated on the average investment of the machine taking into consideration the value of the machine in first and last year [31].

4. Results and discussion

4.1. Solar charging

In the performance evaluation of solar charging, measured the solar radiation and battery voltage for a 1 h. time interval. The Fig. 7 shows the performance of solar power charging:

It shows the solar radiation and voltage with respect to time. The solar radiation data is mostly fluctuating due to the cloudy atmosphere. Therefore, the required time to charge the solar-powered farm rickshaw was around 8 hr. which is more than the theoretically required time. The charging of the batteries is directly proportional to the amount of solar radiation.

4.2. Voltage drop per km

The voltage drop indicates how many volts are dropped per km in the specific treatment. The voltage drop of the battery after driving the

Table 2
ANOVA showing the effect of applied loads, roads and their interaction on voltage drop per km distance.

SOURCE	DF	SS	MSS	CAL F	TAB F	TEST	SEM	CD
Load	2	0.0408	0.0200	5.4440	3.5540	*	0.0210	0.0640
Road	1	0.0004	0.0004	0.1110	4.4130	NS	0.0170	NS
Load X Road	2	0.0008	0.0004	0.1110	3.5540	NS	0.0300	NS
ERROR	18	0.0675	0.0030	CV=				
TOTAL	23	0.1095		29.9937				

* Significant at 5% level.

Table 3
ANOVA shows the effect of applied load and roads and their interaction on the time required to cover per km.

SOURCE	DF	SS	MSS	CAL F	TAB F	TEST	SEM	CD
Load	2	0.4501	0.2250	6.4698	3.5545	*	0.0659	0.1959
Road	1	19.1173	19.1173	549.5240	4.4138	*	0.0538	0.1599
Load X Road	2	0.1836	0.0918	2.6398	3.5545	NS	0.0932	NS
ERROR	18	0.6262	0.0347	CV=				
TOTAL	23	20.3773		3.5828				

* Significant at 5% level.

solar-powered farm rickshaw was calculated and evaluated on the basis of statistical analysis. An ANOVA showing the effects of loads, roads, and their interactions on voltage drops is given in Table 2.

The effect of applied load was found to be significant, while the effect of roads and the interaction of load and road was found to be non-significant. When the applied load was increased, then the required power was also increased, so the voltage drop was found as per change in load condition. In the road and interaction of both conditions, there was no significant change in voltage drop as per condition.

4.3. Time required to travel a kilometer

The time required to cover a km distance shows how much time is required to cover a km distance as per the specified treatment.

It was found that the effect of applied loads and roads on the time required to cover a km distance was significant and their interaction was non-significant, as per shown in Table 3. With the different loads and road conditions, the required time to cover a km distance was significantly changed because when the load was increased, the required time and power were also increased. As in the condition of roads, on the concrete road, required time was low as compared to the without concrete road because on the concrete road, resistance was very low as compared to the without concrete road.

4.4. Effect of applied loads and roads on the distance covered per charge

In this evaluation test, the full charged battery's total distance covered was measured at the different applied loads and road conditions. For this evaluation, three loads were decided: 100, 200, and 300 kg; and two roads, concrete roads and without concrete roads.

A graphical representation of the distance covered at various combinations of applied loads and roads is shown in Fig. 8. The maximum distance was covered with a 100 kg applied load on concrete road, followed by 200 and 300 kg loads. When the applied load was increased, the required power was also increased. Therefore, low load covers more distance per charge. On without concrete road, the minimum distance covered in a 300 kg load was 12.84 km, which was 30% less than the maximum distance covered.

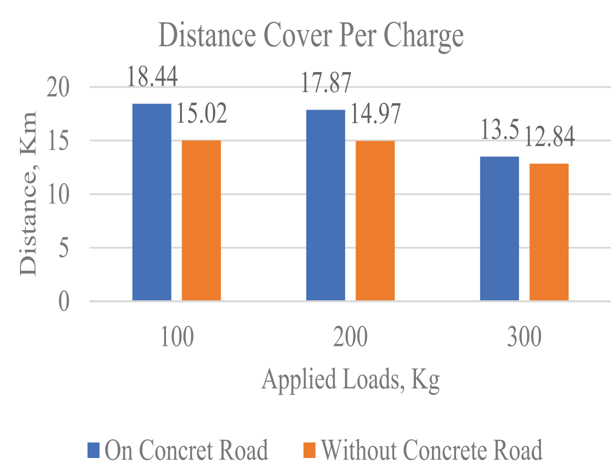

Fig. 8. Effect of different applied loads and roads on distance covered per charge.

4.5. Comparative analysis of with and without solar power

The comparative analysis shows that distance covered and backup time with and without solar power connection during transport shown in Fig. 9.

A solar power connection was provided during transportation, giving the maximum distance covered and the backup time that was found in solar connected transportation of 22.453 km and 128 min, respectively. It added or generated the power, which helped to increase the distance covered. The total distance covered and the backup time in the disconnected mode were 18.44 km and 96 min, respectively, less than the solar connected condition because it was run on only stored battery power.

In the solar connected condition, solar powered farm rickshaws covered around 18% more distance as compared to the not solar connected condition.

4.6. Reduction of CO_2 emission per year

The solar powered farm rickshaw is powered by solar energy therefore it reduces the CO_2 emission. The total CO_2 emission per liter of

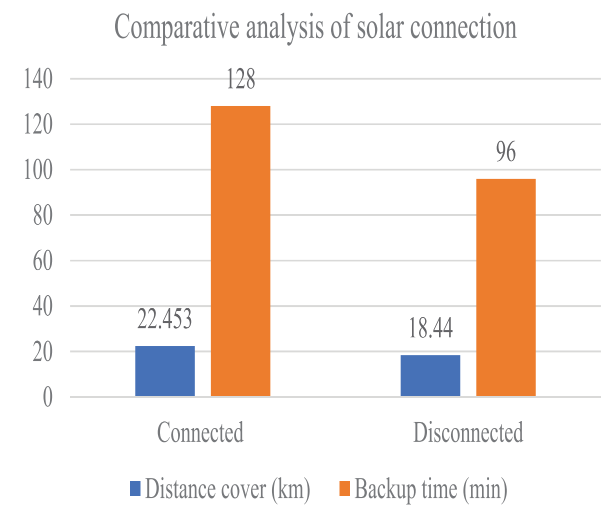

Fig. 9. Comparative analysis of solar power connected and disconnected with battery during transport.

petrol is 2392 gmes. CO_2 emission for the solar powered farm rickshaw was calculated based on some assumptions as per follows:

The total operating hours (H) = 700 hr./year (considering 2 hr. per day)

The average distance covered per liter = 25 km/ liter.

The average speed of solar powered farm rickshaw is 15 km/hr. Therefore, total distance covered by solar powered farm rickshaw per year,

$$\begin{aligned} \text{Total distance covered} &= \text{H} \times \text{Speed} \\ &= 700 \times 15 \\ &= 10500\ \text{Km/year} \end{aligned} \tag{13}$$

The total fuel required for petrol engine rickshaw is calculated as per the following formula,

$$\begin{aligned} \text{Total petrol required per year} &= \frac{\text{Total distance covered}}{\text{Average distance covered per liter}} \\ &= \frac{10500}{30} \\ &= 350\ \text{liter/Year} \end{aligned} \tag{14}$$

Assume the rate of petrol per liter is ₹ 100.

Therefore, total fuel cost saving per year

$$\begin{aligned} &= \text{Total petrol required per year} \times \text{Rateofpetrolperliter} \\ &= 350 \times 100 \\ &= 35000 \end{aligned}$$

Therefore, solar farm rickshaw saves around ₹ 35,000 of fuel cost per year.

Total CO_2 emission reduction per year is

$$\begin{aligned} &= \text{Total petrol required per year} \times \text{Total CO2 emission per liter} \\ &= 350 \times \frac{2392}{1000} \\ &= 837.2\ \text{kg/year} \end{aligned} \tag{15}$$

The total CO_2 emission reduction by solar powered farm rickshaws per year is 837.2 kg. As a result, it reduces massive amounts of greenhouse gasses while also providing a pollution-free environment.

4.7. Life cycle assessment (LCA)

LCA is a generic methodology for evaluating the environmental effects of renewable technology. LCA takes into account the effects of both upstream and downstream activities across a plant's full life cycle. Fig. 10 shows the LCA system boundaries for SPV and IC engine vehicles.

Energy consumption

The required energy for the development of solar-powered vehicles is calculated from the extraction of raw materials to the disposal of materials after use, as shown in the following steps:

According to the Swiss scientific publication MDPI, the energy consumption for manufacturing a vehicle is 55,000 MJ/vehicle. However, because solar modules and batteries are the two main components in solar-powered vehicles, the energy required to manufacture each is calculated separately and then added to 55,000 MJ so we get the total energy requirement.

As per Rathore et al. [30], the energy required is 14.61 MJ/MW for solar module capacity; therefore, for this solar module capacity, the required energy is 2.04 × 10^{-5} MJ. The required energy for the manufacturing of lithium-ion batteries is 55 kW, i.e., 198 MJ [32]. Therefore, the total energy required for material production is 55,198 MJ, i.e., 55.198 GJ. Assumes the value for assembly, disposal, and distribution is the same as the EV, which is 23.21, 0.85, and 0.43, respectively

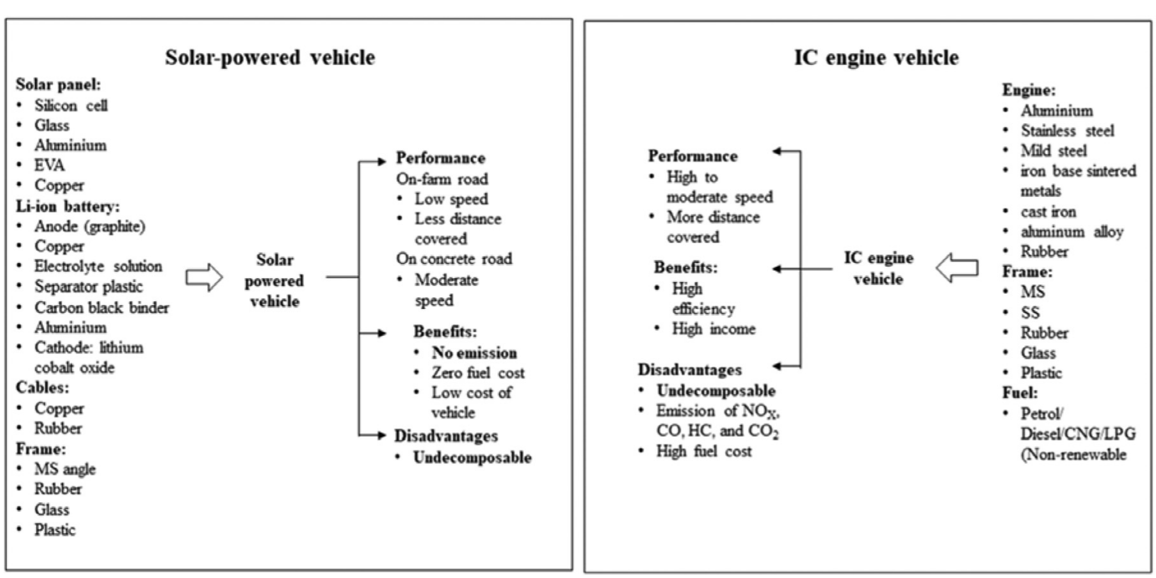

Fig. 10. Life cycle assessment system boundaries for SPV and IC engine vehicles.

Table 4
Energy consumption for development of solar powered rickshaw.

Steps	Energy consumption (GJ)
Material Production	55.198
Assemble	23.21
Disposal	0.85
Distribution	0.43
Total	79.688

Table 5
CO_2 emission from manufacturing of solar-powered vehicles.

Materials	Kg of CO_2 emission/ kg of material [34]	Total emission
Aluminum	9.7	1038.094
Steel	2.14	329.56
Rubber	4.22	42.2
Li-ion Battery	54.74	781.68
Solar cells	311	622
Circuit board	101.24	70.86
Electric components	3.86	27.02
Total		2911.414 kg = 2.91 ton

Table 6
Energy consumption and carbon emission from IC engine and EV [33].

2009	Energy consumption (GJ)		Carbon emission (ton)	
	IC Engine	EV	IC engine	EV
Material Production	81.51	87.06	2.04	1.91
Assemble	23.03	22.55	0.89	0.87
Disposal	0.84	0.83	0	0
Distribution	0.43	0.42	0	0
Total	105.81	110.86	2.93	2.78
2020				
Material Production	90.81	107.13	2.64	2.48
Assemble	19.81	23.21	0.77	0.9
Disposal	0.73	0.85	0	0
Distribution	0.37	0.43	0	0
Total	111.82	131.62	3.41	3.38

[33]. Therefore, the total energy consumption for manufacturing solar-powered vehicles is 79.688 GJ. Table 4, shows the energy consumption for each step.

CO_2 emission

Carbon dioxide emissions are calculated from raw material extraction to the production of solar-powered vehicles. The value of CO_2 emission is different for each material shown in Table 5. The total CO_2 emission from manufacturing of solar powered rickshaw is 2.91 ton.

The comparative analysis of LCA between solar-powered vehicles, internal combustion (IC) engines, and electric vehicles (EV) shows the energy consumption and CO_2 emissions for each vehicle. Table 6 shows energy consumption and carbon emission from IC engine and EV.

The solar powered vehicle shows that the required energy and CO_2 emission during manufacturing is less as compare to the EV and IC engine. Therefore, as per this parameter solar powered vehicles are beneficial as compared to the EV and IC engine vehicles.

4.7. Techno-economics of solar powered farm rickshaw

The operation cost was analysed for the developed solar powered farm rickshaw. Depreciation cost was calculated on the basis of straight-line method. Operational cost for the machine was calculated based on some assumptions. The total cost of solar powered farm rickshaw is ₹ 128,107 ($ 1571.57). The cost parameter is shown in Table 7. Following assumptions were made for cost estimation of solar powered farm rickshaw.

Table 7
Cost economics of developed solar powered farm rickshaw.

Parameter	Formula	Cost
Cost economics of rickshaw		
The fabrication cost with solar panels and BLDC motor is **(C) ₹ 87,607** ($ 1074.73).		
Depreciation (D)	$D = \frac{C-S}{L \times H}$	₹ 7.50 / h
Interest	$I = \frac{C+S}{2} \times \frac{i}{H}$	₹ 6.88 / h
Repair and maintenance	$RM = \frac{initial\ cost}{H} \times P$	₹ 3.75 /h
Cost economics of lithium-ion battery		
The cost of battery with MPPT is **₹ 40,500** ($ 496.84).		
Depreciation (D)	$D = \frac{C-S}{L \times H}$	₹ 6.50 / h
Interest	$I = \frac{C+S}{2} \times \frac{i}{H}$	₹ 3.18 / h
Repair and maintenance	$RM = \frac{initial\ cost}{H} \times P$	₹ 1.15 /h
Total operating cost of solar powered farm rickshaw = ₹ 28.96 /hr.		
Payback period	$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benifit}}$	2.01 years
Benefit: Cost ratio	$\text{B : C ratio} = \frac{\text{Total benefit}}{\text{Total cost of investment}}$	7.46

- Expected life of farm rickshaw = 15 years
- Expected life of lithium-ion battery = 8 years
- Working hour(H) = 700 hr./year, when working hour is 2 hr./day
- Salvage value (S) = 10% of initial cost
- Rate of interest = 10% per annum
- Repair and maintenance = 3% of initial cost

The developed solar powered farm rickshaw was found to be at the cost ₹ 28.96 ($ 0.36) per hour. The developed solar-powered farm rickshaw saves approximately ₹ 35,000 ($ 429.37) in fuel costs per year. The total investment in the solar powered farm rickshaw will be covered in 2.01 years. Therefore, this developed solar powered farm rickshaw is techno-economically feasible.

4.8. Comparative analysis with gasoline driven vehicle and electric vehicle

The developed model is compared with the gasoline driven vehicle and electric vehicle with different socio-economical points. socioeconomic analysis of gasoline driven, battery driven and solar powered electric vehicles was performed in order to differentiate and showcase their respective impacts on society. Table 8 explains the features of vehicles in detail.

The above Table 8, shows comparative analysis of three different types of vehicles, such as gasoline-driven vehicles, electric vehicles, and solar-powered vehicles, shows detailed analysis with different parameters. As per this analysis of the social parameters, which mean effects on human society, solar-powered vehicles are more beneficial than the others because they do not emit any harmful gasses, they use a renewable energy source, the cost of the vehicle is low, and the fuel cost is also zero. Therefore, the solar-powered vehicle is beneficial from a social perspective. The solar-powered vehicle is less beneficial from a yearly income point of view because the developed model travels less distance per hour as compared to the other two models.

5. Discussion

The solar-powered farm rickshaw was designed to totally run-on solar energy. The required time to charge the battery by solar power was more than theoretical time because of the cloudy climatic conditions in the month of July. The voltage drop for lithium-ion batteries varies significantly as per the load changes. It means when load is increasing, the required voltage also increases, but in road conditions it doesn't show the change. The time required to cover a km distance varied significantly depending on load and road conditions. The required time was more on

Table 8
Comparative analysis of different vehicles.

S. No.	Parameters	Gasoline Driven Vehicle (GDV) [35]	Electric Vehicle (EV) [36]	Solar Powered Vehicle (SPV)
1.	Energy source	Gasoline/LPG	Grid/Batteries	Solar panels
2.	Energy storage	Fuel tank	Batteries	Batteries
3.	Type of energy	Non renewable	Hybrid	Renewable
4.	Prime mover	Internal combustion engine (ICE)	AC/DC motor	BLDC motor
5.	Speed control	Variable speed gear box	Motor controller	Motor controller
6.	Emissions	NO_X, CO, HC and CO_2	No emissions	No emissions
7.	Cost of vehicle	₹ 200,000	₹ 150,000	₹ 128,107
8.	Fuel cost per year	₹ 35,000	₹ 5600	₹ 0

the without concrete road as compared to the concrete road due to resistance. Applied load shows the effect on distance covered as per road conditions. When the applied load was 100 kg, it covered more distance as compared to 200 and 300 kg applied loads. When the load increased, the travel distance was reduced per charge. Comparative analysis shows that when solar power was connected during transport, it covered 18% more distance, and backup time was also increased by around 33%. The solar-powered farm rickshaw reduces fuel consumption by around 350 liters per year and carbon dioxide emissions by around 837 kg per year. The technoeconomic analysis also shows that it is economically feasible. A solar-powered farm rickshaw is beneficial for low-cost, pollution-free rides.

6. Conclusions

The primary goal of solar-powered farm rickshaws is to reduce greenhouse gas emissions while also saving farmers money those helpful to enhances farmers' livelihoods. However, it should be noted that in the current energy crisis situation, such alternative renewable energy sources are being used to save energy. Hence, this solar powered farm rickshaw was designed to save petrol for the future. The developed model doesn't require any fossil fuel. This solar rickshaw has a lithium-ion battery to store power. It can travel around 20 km per charge at 15 km/hr. with noise-less operation. The developed solar-powered farm rickshaw is sufficient to carry a load up to 300 kg. The Statistical FCRD test also shows significant results. It is useful for small farm work such as transportation and carrying goods up to 300 kg. The solar-powered farm rickshaw helps to reduce the demand for petrol oil while also lowering CO_2 emissions significantly year after year. Its high-strength material makes it durable and gives it a life span of 15 years. Overall, this solar-powered farm rickshaw reduces pollution, saves fuel, reduces health risks by lowering environmental emissions, and improves the driving experience.

Authors' contributions

Pranay Lanjekar contributed significantly to the preparation of draft manuscript preparation. Mahendra Singh Dulawat contributed to the study's conception and helped perform the analysis with constructive discussions. Jagubhai Makavana and P. M. Chauhan contributed to writing the manuscript and interpreting data. All authors read and approved the final paper.

Declarations

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Ethical statement

This manuscript has not been published before nor submitted to another journal for consideration of publication. All authors have been personally and actively involved in substantive work leading to the manuscript, and will hold themselves jointly and individually responsible for its content.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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