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The Economic and Environmental Feasibility of Using Renewable Energy in Public Transport: An Extensive Study

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Abstract:
The improvement of a nation's economy may be greatly aided by traditional energy sources based on coal, gas, and oil; but the negative environmental effects of such supplies have forced us to utilize them in moderation and shifted our focus to solar and wind power. By using renewable energy sources, which are thought of as environmentally benign due to their low or nonexistent emissions of emissions and harmful gases like carbon dioxide, carbon monoxide, sulfur dioxide, etc., societal, environmental, and economic issues may be avoided. Given that we can continually create useable energy from renewable resources, they will play a significant role in generating power in the near future. The production of wind energy is thought to consume the least amount of water, emit the fewest greenhouse gases, and have the best social effects. It is regarded as one of the most resilient renewable energy sources, behind geothermal, hydropower, and photovoltaics. These resources can aid in reducing the greenhouse effect and the effects of climate change because they are regarded as clean energy supplies. The appropriate use of renewable energy systems may lead to considerable jobs, improved health, job possibilities, consumer choice, a higher quality of living, social bond formation, income development, demographic impacts, social bond building, and community development. Along with their many outstanding benefits, such supplies also have some drawbacks, including the seasonal changes in outcome that is typical of wind and hydroelectric power plants. To address this, special design and consideration are needed, which are satisfied by the hardware and software due to advancements in information technology. A real example will be investigated in this article for better imagination and computations.

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1 Introduction

The current work aims to suggest a model compatible with solar energy systems and their use in railway operations, which reduces fuel consumption and carbon emissions, which are the main cause of global warming or climate changes. Thus, the practical and economic benefit can be calculated in addition to preserving the living environment for individuals and societies. As a result, using clean energy is the greatest way to take use of the sun's free energy. In India, we looked at the possibility of placing solar photovoltaic modules on train cars. The majority of Indian Railways' long-distance trains use Company limited (specific types) coaches, which lack self-generating equipment, necessitating the use of diesel generator cars to supply the requisite power for the coaches' electrical loads. It was investigated if solar photovoltaic modules mounted on the coach roofs might be used to augment the diesel generator sets. The space available on the coach's roof was determined to be more than adequate for solar modules to supply the electrical lighting load. A typical railway line covering a distance of 1,800 kilometers was examined for the case study. Diesel was saved in the amount of 90,000 liters per year per train set. According to the research, the return on investment is about 4 years. Furthermore, this technique will cut CO2 emissions by 239 tons per train each year. Indian Railways, the world's largest railway network, runs 160 LHB trains per day. As a result, considerable savings in diesel and CO2 emissions can be realized.

It describes the performance of Indian Railways' solar photovoltaic modules. This study aimed to discover how much less fuel next-generation coach end-on generators utilize. By connecting a coach with two flexible solar photovoltaic panels to three popular south Indian trains, speeds of up to 120 km/h were achieved. The expected advantages of operating solar train carriages are based on testing results. One solar rail coach is anticipated to provide at least 18 kWh of power per day, saving 1700 liters of diesel per year. The Indian Railways has a total of 63,511 carriages. The Indian Railways operates 63,511 carriages and potentially save roughly 108.5 million liters of diesel per year under optimum conditions. This would help with pollution management and climate change mitigation by reducing CO2 emissions by 2.9 million tonnes per year. The Indian Railways devised a statistical model to determine the benefits of running solar rail coach on different routes.

Solar photovoltaic (SPV) trains have been successfully built and operated in just a few nations. Three freight waggons and five passenger coaches were equipped in Italy with amorphous silicon modules [1]. The state-owned railway of France, TER-SCNF (Transport Express Regional Soci and e Nationale des Chemins de Fer Français), tested a Diesel Multiple Unit (DMU) equipped with thin-film CIGS (Copper Indium Gallium Selenide) SPV modules in 2010. The rooftop mounted SPV system with a capacity of 990 W p provided some power for the DMU's electrical lighting system [2]. In 2011, Indian Railways installed SPV modules with a 1 kWp capacity on the roofs of trains in Pathankot, Punjab, India. The SPV modules provide 420 W of electrical power. KalkaSimla Mountain Railway in Himachal Pradesh, India, attempted a similar attempt to deliver electricity for six LED lamps rated at 6 W each [3]. These experiments were conducted on railcars with a peak speed of 40 km/h and a narrow gauge. Despite the success of testing SPV systems on trains, little scientific data is available for future study and development of Solar Rail Coaches. According to a 2013 research conducted in Iran, an SPV system can provide 74% of a coach's power demand during hot months and 25% during cold months. The SPV system's maximum production was 63.7 kWh, resulting in a decrease of 37 tons of CO2 emissions per year [4].

Over 12,000 trains a day are operated by Indian Railways, one of the world's largest rail networks [5]. In addition, it is a major consumer of diesel fuel, using 2.7 billion liters a year to move and power its coaching stock [6]. As a result, the Indian Railways are working to cut fossil fuel usage and implement environmentally friendly technology [7].

Solar energy has a lot of potential in the railway industry, particularly in tropical nations. There are a total of 63,511 coaches on the Indian Railways, including both conventional and Linke Hofmann Busch (LHB) carriages [8]. The majority of these trainers work year-round in direct sunlight. That is a great opportunity for Indian Railways to look into the possibility of putting solar rail coaches into service across the country. For the End-on Generation (EOG) system, which provides power to the electrical load of LHB coaches, this will lower the fuel consumption [9]. In this context, Divecha Centre for Climate Change, Indian Institute of Science (IISc), Bangalore, in collaboration with Integral Coach Factory (ICF), Chennai, performed the Solar Rail Coach project. Two flexible SPV modules were installed onto an ICF-manufactured LWSCN Coach, which is an LHB Second Class Sleeper Coach. This "Trial SPV Coach" was pulled by three of the country's most popular trains at speeds of up to 120 km/h. At the start of the south-west monsoon, tests were done to see how well the PV system worked when there was not much light.

In general, transportation industry contributes significantly to global CO2 emissions and warming. Solar energy can help cut CO2 emissions from buses and trains. The Adelaide City Council constructed solar photovoltaic (SPV) roof-mounted charging facilities for its all-electric buses. These buses were shown to be significantly less expensive to operate than diesel counterparts [10]. Two locomotives and three freight trains all had amorphous silicon modules installed in Italy [11]. The state-owned railway of France, TER-SCNF (Transport

Express Regional Société National des Chemins de Fer Français), tested a DMU (Diesel Multiple Unit) equipped with thin-film CIGS (Copper Indium Gallium Selenide) SPV modules in 2010.

The 990Wp SPV system put on the rooftop provided electricity for the DMU's electrical lighting system in part [2]. Installed SPV modules in Pathankot, India, in 2011 to provide the 420W electrical demand on the train's carriage with 1 kWp of power. Similar attempts to supply electricity for six 6W LED lamps were tried on the Kalka-Simla Mountain Railway (toy-train) [12]. Indian Railways conducted tests on small gauge train carriages traveling at a maximum speed of 40 km/h. The viability of delivering solar electricity for broad gauge (1,676 mm) LHB coaches used by Indian Railways' long-distance trains, which travel at a maximum speed of 160 km/h, is discussed in this study.

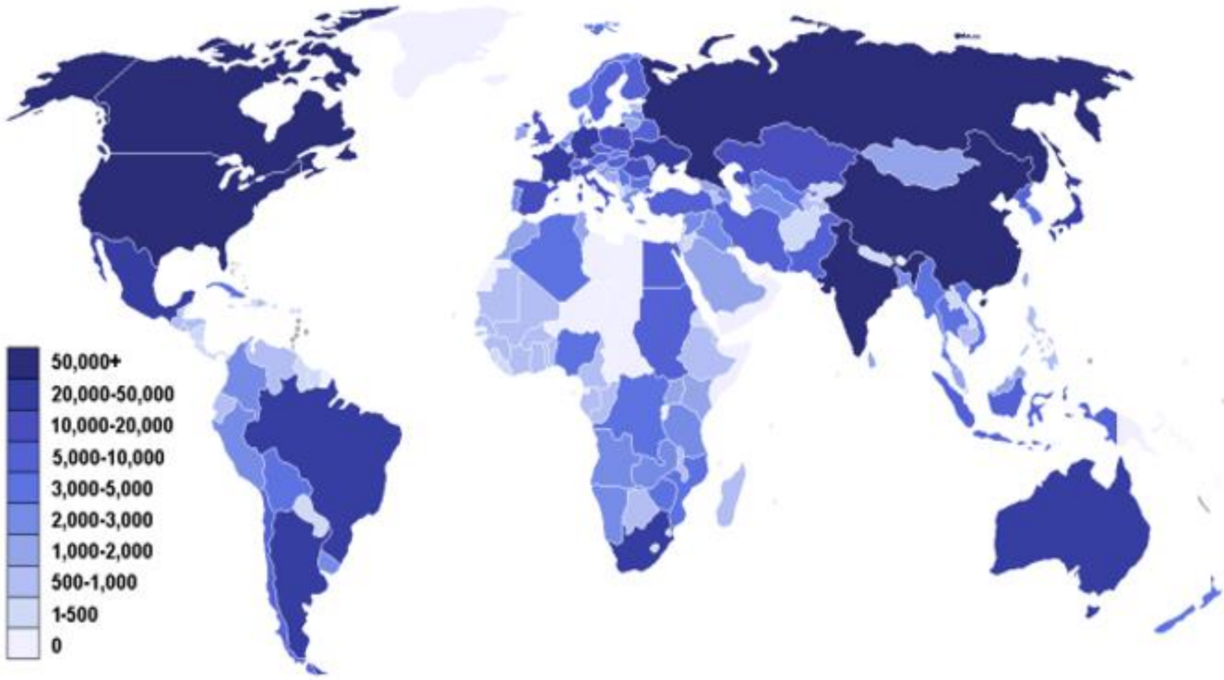

Figure 1 Map describing the length of various railways network in the world.

Figure 1 depicts the lengths of several countries' railway networks. The United States of America, China, Russia, India, and Canada have the longest railway lines, as can be shown. With a total length of 65,436 kilometers and a history of 161 years, India boasts the world's fifth longest railway network. It transports 23 million passengers each day on 12,617 trains and is still the most popular means of transportation [14]. Figure 2 depicts the spotting of several Indian Railways trains, with blue and red arrows indicating trains in transit and trains at stations, respectively.

In India, there are 62,924 passenger coaches in use, with 5,000 of them being LHB types (Wikipedia, 2014). Because LHB coaches have more carrying capacity, are lighter, have less corrosion, require less maintenance, have better aesthetics, and provide greater passenger comfort and safety than conventional coaches, Indian Railways is gradually transitioning from conventional coaches to LHB coaches [16]. Self-Generation (SG) and End-On Generation (EOG) [17] are two key power supply systems for Indian Railways' coaching stock, which are implemented by the utility based on the demand of variations of the coaching stock. For the most part, diesel has been the primary source of energy for Indian railway rolling equipment. As seen in Figure 3, India's transportation industry consumes 70% of diesel, with Indian Railways accounting for 3.24 percent [18].

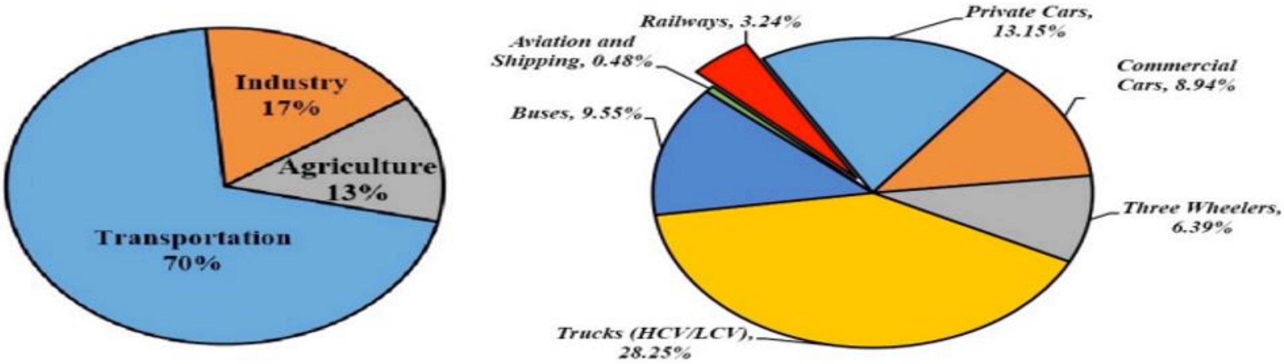

Figure 2 Sectorial consumption of diesel in India.

2 Power Supply Networks and Training Stocks for Indian Railways

The Indian Railways' coaching stock is divided into three categories depending on the production units: ICF (Integral Coach Factory), RCF (Rail Coach Factory), and LHB (manufacturing license by Linke)

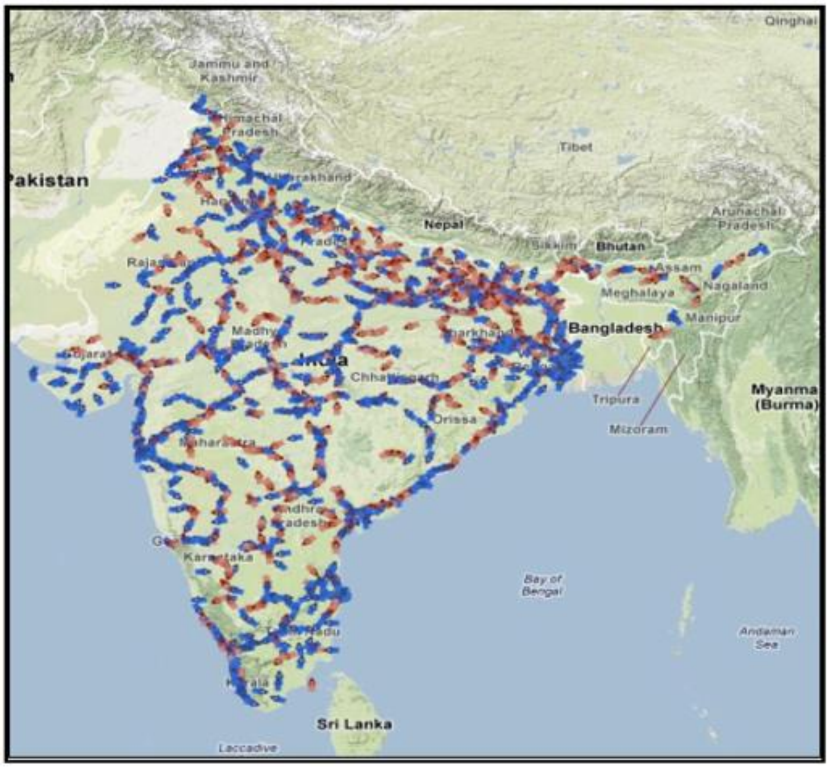

Figure 3 Train spotting of Indian Railways [15]

Hofmann Busch, Germany) [17]. In India, there are 62,924 passenger coaches in use, with 5,000 of them being LHB types [18]. Because LHB coaches have more carrying capacity, are lighter, have less corrosion, require less maintenance, have better aesthetics, and provide greater passenger comfort and safety than conventional coaches, Indian Railways is gradually transitioning from conventional coaches to LHB coaches [19].

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3 A real-life example

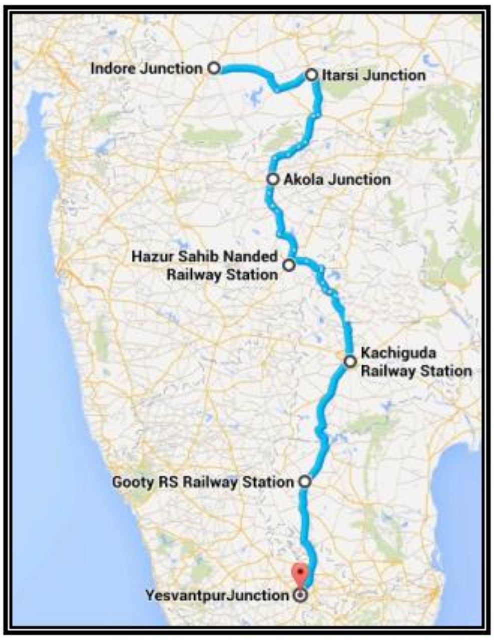
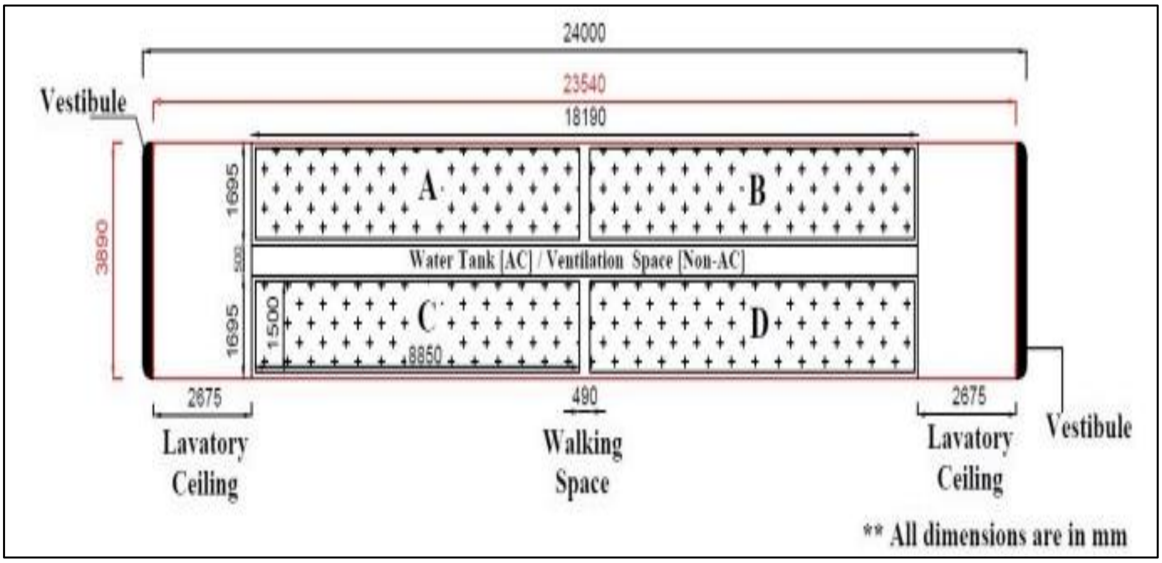


Figure 4 Train's route map evaluated for case study.

To determine if solar power support for LHB coaches is feasible, it is necessary to understand, analyze, and assess the performance of a train consisting of LHB coaches. For this, one of the country's first few mixed rake LHB trains (a train with a rake composition of both air-conditioned and non-air-conditioned coaches) was chosen, and information on various types of electrical loads (both heating and lighting circuits), diesel consumption of generator cars, generator car fueling schedules, and roof-top space available for SPV module installation was gathered. One trip is the word used to describe the shift from source to destination. The train's route and other data are provided in figure 4 and table 1, respectively. The lighting load in the entire rake was determined to be 43 percent of the net electrical load. This project's primary objective was to boost the rake's electrical lighting circuit's power source.

Table 1 Details of the LHB train considered [20]

Name of the train	Indore – Yeswantpur LHB Express
Rake composition (19 coaches) i. No. of air-conditioned coaches ii. No. of non-air-conditioned coaches iii. No. of pantry cars iv. No. of generator cars	 5 13 1 2
Distance between source and target	1,800 km
Duration of 1 Trip (source to destination)	40 hours
Total amount of sunlight during trip	15 hours
Electrical load (lighting circuit only) i. Total lighting load per coach ii. Net lighting load of the rake	 4.6 kW 90 kW
Information about the fuel that generator cars use i. Sort of fuel utilized ii. Cost per litre of fuel	 Hi-Speed Diesel (HSD) US$ 1.07 (Rs. 66)
Fuel used by generator vehicles for 1 trip i. by the net electrical load of the rake ii. by the lighting load of the rake (43% of the net electrical load of the rake) iii. Fuel expenses for supporting the trip's electrical lighting load	 793 gallons (3,000 litre) 341 gallons (1,290 litre) US$ 1,385 (Rs. 85,140)



.**Figure 5** Proposed layout of the roof-top of an LHB coach [20]

Table 2 Roof-top area available for the installation of SPV system on one LHB coach

Roof-top area of the LHB coach i. Roof-top area available on an LHB coach ii. Area occupied by air-conditioning units, lavatory ceilings, water tanks. walkways and ventilation vents iii. Total available area for mounting SPV modules	 93.36 m^2 31.567 m^2 61.793 m^2
Solar power potential in an area of 1 m2	154 W_p
Thus, solar power potential in the area available on the roof-top of an coach	61.793 m^2 154 Wp = 9.5 kW_p
Net solar power potential assuming system efficiency to be 80% and shaded region as 15%	6.5 kW_p

Tables 1 and 2 show that the solar power potential on one LHB coach's rooftop is much more than the coach's electrical lighting load. In order to estimate the practicality of constructing an SPV system to fulfil the lighting load, the average daily Global Horizontal Irradiance (GHI) must be taken into consideration. Figure 6 depicts the trend of the daily GHI averaged over the course of the year [21]. GHI is at its highest and lowest during the months of March and December, respectively. The table displays an estimate of the amount of energy that can be generated by the SPV system and a comparison to the amount of energy consumed by the electrical lighting load on the rake.

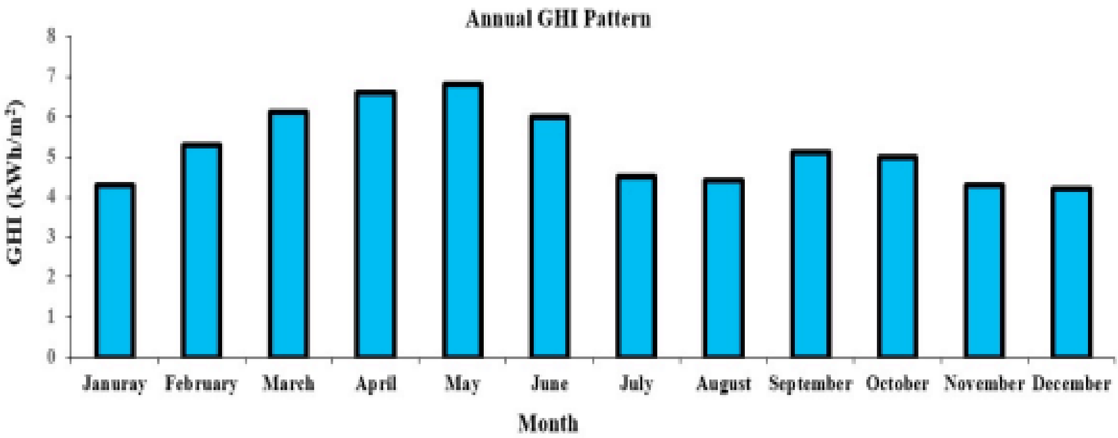


Figure 6 Monthly average daily GHI pattern.

Table 3 Solar power electrical generation by SPV system

From table 2, total area available on the roof-top of all the coaches in the rake	1,174 m^2
Net capacity of SPV system that can be installed on the roof of the rake	6.5 kW_p X 19 = 123.5 kW_p
From figure 6, yield of the SPV system when the monthly average daily GHI is i. maximum (March) ii. minimum (December)	6.8 kWh/m^2 X 1,174 m^2 = 7,983 kWh 4.2 kWh/m^2 X 1,174 m^2 = 4,930 kWh
Lowest daily GHI measured in India [22] Estimated yield of the SPV system for the lowest daily GHI measured	2.5 kWh/m^2 2.5 kWh/m^2 X 1,174 m^2 = 2,935 kWh
From table 1, energy consumed by the net electrical lighting load of the rake during the sunshine period (15 hours) of 1 trip	90 kW X 15 hours = 1,350 kWh
From table 1, volume of diesel consumed by the electrical lighting load of the rake during the sunshine hours of 1 trip	128 gallons (483 litre)

Table 3 shows that the energy necessary to meet the electrical lighting load in the rake can be supplied with ease using the SPV system, even on days with GHI as low as 2.5 kWh/m^2. Table 3 further shows that even if 50% of the rooftops are shaded, the SPV system can sustain the electrical lighting load in the rake, resulting in adequate yield even with diffuse radiation. As a result, seasonal variance would not be a significant impediment.

4 The Scheme's Influence

The train under consideration is anticipated to undergo a periodic over-haul (POH) that lasts up to 30 days and makes up to 188 journeys each year. The utility will gain the benefits listed in Table 4 as well as a significant decrease in CO2 emissions.

Table 4 Benefits of implementation of this scheme [20]

From table 1, the maximum number of trips the train can make in an year	188
Volume of diesel that can be annually conserved due to this scheme	23,988 gallons (90,804 litre)
Return on Investment (ROI)	3.38 years
Annual reduction in the CO2 emitted by one train, considering the amount of CO2 emitted per litre of diesel burnt as 2.66 kg and factor of combustion as 0.99	239 tonnes

5 Other study results conclusion

High speed Indian Railways trains towed the experimental SPV Carriage, an LHB coach with two 190 Wp flexible solar photovoltaic panels. High speed Indian Railways trains towed the experimental SPV Carriage, an LHB coach with two 190 Wp flexible solar photovoltaic panels. Using data gathering and online monitoring, the functioning of the SPV system was tested. Location, module orientation, variable weather conditions, the global heating index (GHI), module temperature, and module efficiency influence the operation of an SPV system. In addition to the dynamic testing, the coach was kept immobile in the coach yard for a static test.

The SPV system produced roughly 1,3 kWh per day, with a GHI of approximately 4,8 kWh/m2. During the testing, a total of 11,4 kWh was generated. Based on the findings of an experiment, the expected yearly output of one Solar Rail Coach has been calculated. One Solar Rail Coach is expected to provide an annual production of between 6,820-7,452 kWh, resulting in a 1,708-1,863 liter decrease in diesel use and a 4.5-4.9 tons reduction in CO2 emissions. The minimum ROI time is projected to be 7.5 years, although this will reduce as the number of installations increases. The Indian Railways employs around 63,511 coaches, and each train has approximately 20 coaches. Adopting Solar Rail Coaches for all trains would produce at least 433,145,020 kWh of electricity annually, saving at least 108,476,788 liters of fuel annually and lowering CO_2 emissions by 288,339 tonnes. This would also be a reasonable solution for minimising oil imports and climate impact.

Indian Railways might use the statistical model created to predict power output per unit rooftop area of the coach to evaluate the technical and economical feasibility of running solar rail coaches on various routes around the nation. This is accomplished without the coach actually having SPV modules installed. This is done by attaching a small device that checks the amount of light and the temperature of the module. Due to the model's simplicity, modifying the model and strategy based on the GHI and module temperature data acquired during trials along a particular path is straightforward. The predictive model's accuracy and the practical benefits of running solar-powered railway coaches may be evaluated if the experiment is carried out over a longer period of time and on more routes.

Criteria for placing these strategies into operational

If the following conditions are met, solar-assisted power supply for rail coaches can be established.

1. SPV modules that must be attached must be flexible or semi-flexible and must fit the dimensions of the coach. These SPV modules may be chosen from a variety of types on the market and arranged to get the desired voltage. Manufacturing the SPV modules depending on the size of the rail coach might be a preferable choice. In any scenario, the required system voltage of 110 V must be maintained.
2. The design of a smart central processing unit (CPU) with a power conditioning unit (PCU) is necessary. As indicated in Figure 9, this equipment must be able to connect to all power sources and electrical loads.
    a. switch the power source for the lighting circuit between the EOG and SPV systems based on the availability of sunlight
    b. regulate the charging required for the battery bank based on the availability of sunlight and previous data recorded by the system
    c. provide uninterrupted power supply for the net electrical load in the rake by coordinating with all available power sources and efficiently shifting to the default (conventional) power supply during faults
    d. provide real-time data transmission
3. The SPV modules must be installed on structures that can survive unpredictable vibrations and strong wind speeds, which would otherwise compromise the system's functionality.

6 Conclusion

Indian Railways investigation gave a clear picture of the use of renewable energy for a good life. As a result, Oil, gas, and coal are common sources of energy, and their availability is crucial for a nation's economy to grow. While conventional energy sources have a severe influence on human health and the environment, such as the greenhouse effect and the effects of global warming, Pakistan relies solely on these sources of power. Pakistan has hydro, wind, and geothermal energy sources, making it excellent for solar energy generation. Nevertheless, money and politics are the two greatest impediments to producing power from renewable sources. When categorising renewable energy sources, environmental impacts, land requirements and water usage are only some of the considerations that must be taken into account. When it comes to water consumption, greenhouse gas emissions, and social effect, wind power wins hands out. Along with geothermal, hydropower, and photovoltaics, it's a reliable source of renewable energy. Biomass is seen as a good choice for small-scale companies because it saves a lot of fuel. The right use of renewable energy systems could lead to local jobs, better health, more job opportunities, more consumer choice, a higher quality of life, stronger social bonds, more money, changes in the population, stronger social bonds, and community growth. Renewable energy sources have their benefits, but they are hard to set up and can hurt the environment where they are used. When compared to others, their forecasting, planning, and execution require more thought and skill.

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