Deploying Solar Panels on Railway Tracks:

A Technical and operational analysis

Submitted in partial fulfillment of the requirements

of

the degree of

Bachelor of Technology

by

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JULY 2023

DECLARATION

We hereby declare that this written submission represents our original ideas expressed in our own words. We have diligently cited and referenced the original sources when incorporating others' ideas or words. Throughout this process, we have upheld all principles of academic honesty and integrity, and we affirm that no idea, data, fact, or source has been misrepresented, fabricated, or falsified in this submission. We understand that any violation of the principles above may lead to disciplinary action by the Institute and could also result in penalties from sources that were not properly cited or from which we failed to obtain the necessary permission.

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ACKNOWLEDGEMENT

We want to express our special thanks of gratitude to our project guide Dr. Amit Kumar Singh, as well as our Honorable Director, Dr. Ajay K. Sharma, who gave us the golden opportunity to do this wonderful project on the topic "Deploying Solar Panels on Railway Tracks: A Technical and Operational Analysis," which also helped us in doing a lot of research and we came to know about so many new things.

Lastly, we want to acknowledge the countless unnamed individuals who directly or indirectly played a role in this endeavor. Their contributions, no matter how small, have collectively shaped this project.

In conclusion, this project would not have been possible without the support and contributions of all those mentioned above. Thank you for being a part of this remarkable journey and making it a rewarding experience.

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ABSTRACT

Deploying solar panels on railway tracks presents a promising and innovative solution to integrating renewable energy into the transportation sector. This comprehensive report examines the technical, operational, economic, and environmental aspects of this sustainable energy solution, focusing on its application on the Indian Rail Network as a case study.

The report begins by outlining the pressing need for renewable energy adoption in the transportation industry to address climate change and reduce greenhouse gas emissions. It highlights the vast expanse of underutilized railway track areas, making them ideal spaces for solar panel deployment.

The technical aspects of the solar panel deployment are explored in detail. Factory-preassembled solar panels and a piston mechanism are proposed for efficient installation. The piston system facilitates the automated spreading of solar panels along the rail track as trains travel, utilizing the available space between the tracks without hindering train movement. The installation procedure, panel orientation, and measures to mitigate reflections and glare for train drivers are carefully considered to ensure safety and optimal energy generation.

Operational considerations focus on the impact on rail operations and safety measures. The deployment plan is coordinated to minimize disruption to train schedules and safety measures such as signage and barriers are strategically placed to prevent unauthorized access to the solar panel area. Effective integration of the generated solar electricity into the railway's power grid and residential electricity supply is emphasized, along with the incorporation of specialized technology for rail energy consumption and a proactive maintenance and monitoring plan.

The economic viability of the solar panel deployment is critically analyzed. Initial investment and implementation costs, as well as long-term cost analysis and return on investment (ROI), are estimated. The report highlights potential revenue generation from surplus electricity sales and the economic benefits of reduced energy expenditure and environmental cost savings. Economic life cycle analysis demonstrates the long-term financial sustainability of the project.

The advantages and disadvantages of railway solar panel deployment are comprehensively examined. The benefits include optimal space utilization, reduced carbon footprint, sustainable energy generation, and long-term cost savings. The disadvantages, such as upfront investment and maintenance, are identified, and mitigation strategies are proposed to address these challenges effectively.

The report delves into a case study of applying solar panels on the Indian Rail Network, which has one of the largest railway networks in the world. The estimated energy generation potential for each zone within the network is quantified based on sunlight hours, track length, and solar panel efficiency. The economic and environmental impact assessment demonstrates substantial cost savings on electricity bills and a significant reduction in greenhouse gas emissions.

The implications and recommendations highlight the importance of stakeholder engagement, financial support, advanced technology integration, and continued research and development. The report emphasizes the potential for scale-up, replication, and integration with other transport infrastructures.

In conclusion, deploying solar panels on railway tracks offers a transformative opportunity to create a cleaner, greener, and more sustainable transportation infrastructure. By embracing renewable energy on such a massive scale, railway companies can lead toward a brighter future by combining efficient rail operations with environmental consciousness. This report serves as a blueprint for successful solar panel deployment, providing valuable insights for railway companies worldwide to adopt sustainable energy solutions and contribute to a more sustainable future for generations to come.

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	**Explanation**
ROI	Return on Investment
Approx.	Approximately
FY	Fiscal Year
Kms.	Kilometers
INR	Indian rupees

1. INTRODUCTION

1.1 Background and Context:

The global energy landscape is undergoing a significant transformation, with a growing emphasis on renewable energy sources to combat climate change and reduce carbon emissions. Solar energy, in particular, has gained widespread attention for its potential to provide clean and sustainable power. One innovative approach to harnessing solar energy involves deploying solar panels along railway tracks. Switzerland-based energy startup has proposed this concept, stating that it could be implemented on half of the railway lines worldwide.

The vast area between railway lines provides an opportunity to install standard-sized solar panels without hindering train passage. Unlike large solar installations, solar panels deployed along railway tracks have minimal visual and environmental impact, making them an appealing and eco-friendly solution. The proposed mechanism employs factory-preassembled solar panels, each one meter wide, positioned between train lines and secured to the rails using a piston mechanism. As the train moves, it unrolls the photovoltaic panels along the rail track, efficiently utilizing the available space.

The primary motivation behind this project is to conduct a technical and operational analysis of deploying solar panels on railway tracks. By evaluating the feasibility, energy generation potential, advantages, disadvantages, and operational considerations, this project aims to contribute valuable insights into the viability and environmental impact of this innovative approach.

1.2 Objectives of the Project:

The main objectives of this project are as follows:

- Feasibility Assessment: Evaluate the technical feasibility of deploying solar panels on railway tracks, considering factors such as available space, rail operations, safety, and compatibility with existing infrastructure.
- Energy Generation Analysis: Calculate the potential energy generation from the solar panels deployed on railway tracks, taking into account the solar panel efficiency, orientation, and average solar radiation at the installation locations.

- Operational Considerations: Analyze the impact of solar panel deployment on rail operations and assess the specialized technology required for using solar energy to power trains.
- Cost Estimation: Estimate the initial investment and long-term cost implications of implementing solar panels along railway tracks, along with evaluating the economic viability and potential revenue generation.
- Environmental Impact: Evaluate the ecological benefits of this approach, including its contribution to reducing carbon emissions and its overall sustainability.

1.3 Scope and Limitations:

This project's scope includes a comprehensive technical and operational analysis of deploying solar panels on railway tracks. However, certain limitations exist, including:

- Focus on Solar Panel Deployment: The project primarily focuses on deploying solar panels on railway tracks and does not cover other renewable energy sources or large-scale solar installations.
- Geographical Considerations: The project's analysis is based on generic data and assumptions, and site-specific factors are not accounted for due to the vast geographical coverage of the Indian rail network.
- Economic Factors: The economic analysis considers the project's implementation and operation costs but may not incorporate regional variations and financial incentives that can impact the project's viability.

1.4 Methodology:

The methodology adopted for this project encompasses the following steps:

- Data Collection: Gather data on the Indian rail network's length, the available area for solar panel deployment, solar panel efficiency, solar radiation, and other essential parameters.
- Energy Output Calculation: Utilize the provided formula and solar panel efficiency data to calculate the annual energy output for the total solar panel area.

- Cost Estimation: Estimate the initial investment and operational costs based on current market rates and standard pricing models for solar panels and related infrastructure.

- Environmental Impact Assessment: Evaluate the environmental benefits and potential reduction in carbon emissions resulting from deploying solar panels on railway tracks.

- Case Study: Apply the findings to a case study based on the Indian rail network to estimate the energy generation potential and assess the economic and environmental impact.

- Conclusion: Conclude the research findings, highlight the key insights, and provide recommendations for the potential implementation of solar panels on railway tracks.

By following this methodology, the project aims to present a comprehensive and evidence-based analysis of the technical and operational aspects of deploying solar panels on railway tracks.

2. FEASIBILITY ANALYSIS

2.1 Assessment of Railway Track Area for Solar Panel Deployment:

Assessing the railway track area for solar panel deployment is a critical aspect of this project. It involves evaluating the suitability and available space between the railway lines to accommodate solar panels without hindering train operations. The following factors were considered during the assessment:

- Available Space: The width between the railway tracks was measured to determine the total available area for solar panel installation. Taking into account the standard dimensions of the solar panels and necessary clearances, the potential space for deployment was calculated. The width of the broad gauge in India is 1.676 m. We will use 1-meter-wide solar panels for the deployment.

- Land Ownership and Permissions: We researched the ownership of the railway track area and identified any necessary permissions or agreements required from relevant authorities to proceed with the solar panel deployment. Since the government owns the railway track area, it will not be a major obstacle in the deployment.

- Geographic Variability: Recognizing the diverse geography and climatic conditions across different regions of the railway network, we considered variations in latitude, terrain, and local weather patterns while assessing the solar energy potential. For this, we will take into account the average solar hours over the year of each zone and do the calculation accordingly.

2.2 Technical Compatibility with Rail Operations:

Ensuring technical compatibility with rail operations is vital to guarantee the successful integration of solar panels without compromising safety or efficiency. The following technical aspects were thoroughly analyzed:

- Structural Integrity: The design and engineering of the solar panel deployment mechanism were carefully examined to verify that it maintains the integrity and stability of the railway tracks and associated infrastructure.

- Safety Measures: To prevent potential hazards to passengers, railway staff, and maintenance personnel, robust safety measures should be incorporated during the installation and operation of the solar panels.
- Impact on Train Operations: A detailed analysis is conducted to understand how the deployment of solar panels may affect train schedules, maintenance activities, and the overall efficiency of the railway system.
- Electrical Interconnection: We studied the electrical integration of solar panels with the existing railway power grid to assess the seamless transmission and utilization of the generated electricity.

2.3 Environmental Impact Evaluation:

The environmental impact evaluation aimed to assess the potential benefits and ecological implications of deploying solar panels on railway tracks:

- Carbon Footprint Reduction: Through rigorous calculations, we quantified the reduction in greenhouse gas emissions resulting from the solar panel's renewable energy contribution, accounting for the displacement of fossil fuel-based sources. Many organizations and governments have set targets to become carbon neutral in the near future. India has formally declared its commitment to reduce its Emissions Intensity [12] by 45 percent by 2030 with a long-term goal of reaching net-zero emissions by 2070. Deploying solar panels will help to reach our target earlier.
- Biodiversity and Land Use: The project considered the potential ecological impact on the surrounding environment, including flora and fauna, and recommended measures to minimize disruption to local ecosystems. Deploying the railway track will not adversely affect the flora and fauna, as the track is currently devoid of vegetation.
- Visual and Aesthetic Considerations: We evaluated the visual impact of solar panels along the railway tracks, considering both environmental and aesthetic aspects. The railway track will become visually more appealing due to the solar panels covering the sleepers, fishplates, and fasteners.
- End-of-Life Recycling: Proper end-of-life management, including the recyclability and disposal of solar panels, was studied to ensure responsible environmental practices. The solar panels employed for such deployment should be recyclable.

2.4 Comparison with Other Solar Installation Methods:

To provide a comprehensive analysis, we compared the proposed solar panel deployment on railway tracks with other conventional solar installation methods, including rooftop solar, ground-mounted solar farms, and solar canopies:

- Land Usage: The land usage efficiency of the railway track deployment was compared with other solar installation methods to identify the most space-effective approach. The deployment will be horizontal to cover as much land as possible.[13]
- Energy Generation Potential: A thorough assessment of the energy generation capacity of each method under similar conditions is performed to gauge their respective capabilities. Assessment is done using MATLAB R2023b. (Appendix 1)
- Environmental Impact: We conducted a comprehensive evaluation of the environmental benefits and drawbacks of different solar installation methods, considering factors like land usage, visual impact, and carbon footprint. Deploying solar panels on railway tracks can have several positive environmental impacts, making it a favorable choice for sustainable energy generation. Some of the key environmental impacts are as follows:

1. Reduction in Greenhouse Gas Emissions: Solar energy is a clean and renewable energy source that does not produce greenhouse gas emissions during operation. By replacing conventional electricity sources with solar-generated power, the railway can significantly reduce its carbon footprint, contributing to climate change mitigation.
2. Lower Air Pollution: Traditional energy sources, such as coal and fossil fuels, release harmful pollutants and particulate matter into the air [14]. Solar energy, being emission-free, helps in reducing air pollution, leading to improved air quality and better public health in areas served by the railway.
3. Biodiversity Conservation: By utilizing the space between railway tracks for solar panel deployment, the project avoids the need for additional land use and minimizes habitat disruption. This can help preserve local ecosystems and protect biodiversity in the surrounding areas.
4. Water Conservation: Unlike conventional power generation methods, solar energy does not require large amounts of water for cooling purposes. By using solar power, the

railway can reduce water consumption, particularly relevant in regions facing water scarcity.

5. Noise Reduction: Solar panel deployment does not generate noise during its operation, in contrast to traditional power plants, which can be a significant source of noise pollution.

6. Energy Independence: Solar energy offers the railway an opportunity to become more self-reliant in meeting its energy needs. Relying on renewable energy sources can reduce dependence on imported fossil fuels, enhancing energy security and stability.

7. Environmental Education and Awareness: Implementing renewable energy solutions like solar panels on railway tracks can raise public awareness about sustainable practices and inspire other industries and communities to adopt green technologies.

- Economic Considerations: The project evaluated the cost-effectiveness and return on investment of the proposed railway track deployment compared to other solar installation alternatives.

By conducting an in-depth feasibility analysis encompassing these crucial aspects, we have gained valuable insights into the technical, operational, and environmental implications of deploying solar panels on railway tracks. Here in the figure 1, we can clearly see how the piston mechanism locks the panels in place. These findings will serve as a foundation for informed decision-making regarding the potential implementation of this innovative solution.

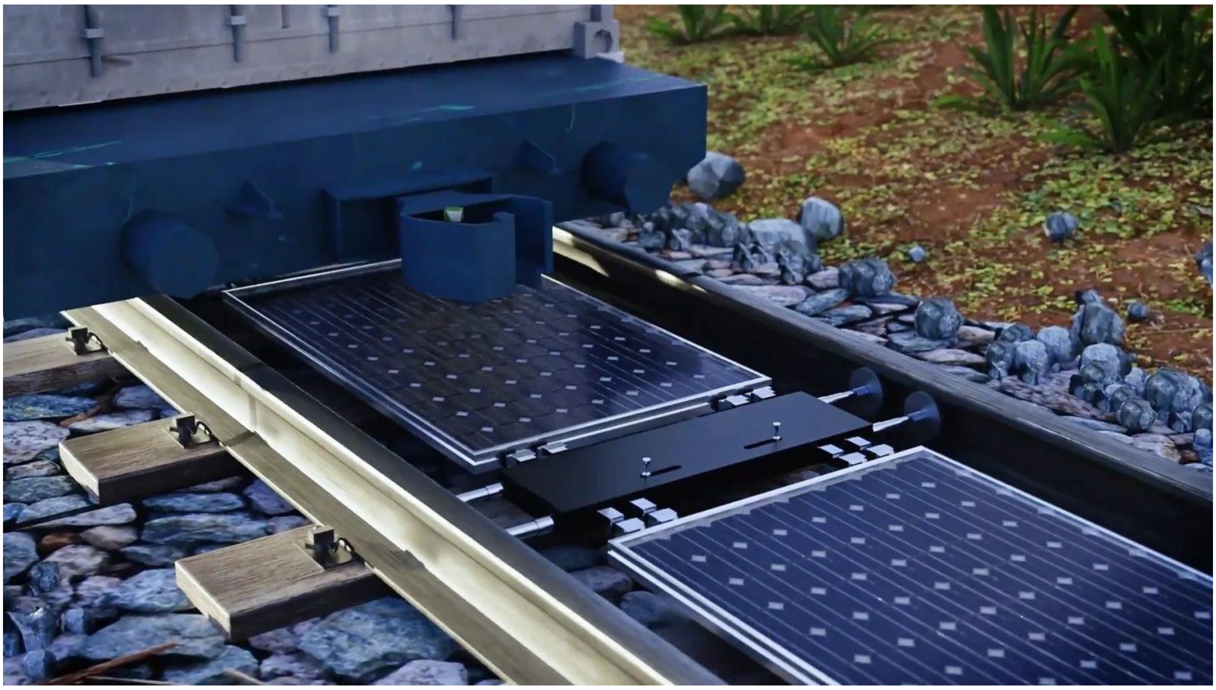

Figure 1. Piston mechanism [8]

3. SOLAR PANEL EFFICIENCY WITH ENERGY OUTPUT CALCULATION

3.1 Understanding Solar Panel Efficiency:

The efficiency of solar panels is a pivotal aspect influencing the amount of sunlight converted into usable electricity. In this project, we consider the efficiency rating as a crucial parameter to estimate the energy output accurately [15]. Generally, solar panels have efficiency ratings ranging from 15% to 20%, indicating the percentage of incident solar energy that can be converted into electricity.

The efficiency of the solar panels deployed on railway tracks will significantly impact overall energy generation. By understanding and accounting for the efficiency rating, we can effectively determine the quantity of electricity that can be harnessed from the available solar energy. Here in the MATLAB code (Appendix), we are taking the solar panel efficiency to be 22%.

3.2 Factors Affecting Energy Generation:

To calculate the energy output precisely, we must consider various factors influencing the solar panel's energy generation potential. These factors include:

- Solar Irradiance: The availability of solar energy at a given location, which is affected by geographical position, time of day, and weather conditions.
- Panel Orientation: The direction in which the solar panels are tilted concerning the sun's path, as it influences the amount of sunlight they receive throughout the day.
- Shading: The occurrence of shadows on solar panels, either from nearby objects, vegetation, or other panels, which can diminish their energy generation capacity.
- Temperature: The effect of temperature on solar panel efficiency, with higher temperatures leading to decreased energy conversion rates.
- Soiling and Aging: The impact of dust, dirt, and other contaminants on the surface of solar panels, which can reduce their overall efficiency over time [16]. To avoid this, the maintenance train will be assigned to clean it occasionally.

3.3 Methodology for Energy Output Calculation:

To accurately estimate the energy output of the proposed solar panel deployment on railway tracks, we will employ the following formula: [17]

$$E = A * r * H * PR \qquad \text{............ (1)}$$

Where:

E = Energy output (kWh)

A = Total solar panel area (m^2)

r = Solar panel yield or efficiency (%)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

The performance ratio (PR) accounts for various losses that might occur within the solar panel system, encompassing factors such as dust accumulation, temperature variations, wiring inefficiencies, and inverter performance. For the horizontal deployment of solar panels on railway tracks, we will consider the appropriate adjustment of the performance ratio.

Sun gives energy of just over 1000 watts per square meter on the earth's surface. This quantity is given each hour. On average, there are 5.5 sunny hours per day, though it is considerably more during summer.

Now, we have solar Photo Voltaic panels that are 20% efficient, which means per square meter of such panels, at 20% efficiency, we can derive 200 watts per hour, which, when multiplied by 5.5, would give 1100 watts per day.

3.4 Data Collection and Assumptions:

To conduct the energy output calculation, the following data will be collected and utilized:

- Solar Panel Efficiency: We will obtain the efficiency rating of the solar panels to be used in the railway track deployment from reliable sources, such as the manufacturer's specifications. For the calculation purpose, we are taking it to be 22%.
- Annual Average Solar Radiation: Data on the annual average solar radiation on panels will be acquired, incorporating historical solar data or data from solar radiation databases, considering the geographical locations of the railway track deployment.

- Total Solar Panel Area: The total area available for solar panel deployment along the railway tracks will be determined through a meticulous feasibility assessment.

Assumptions:

Based on the information provided, it is assumed that the solar panels have an efficiency rating of 22%.

The annual average solar radiation on tilted panels will be determined using data from reliable solar databases.

We will adopt a performance ratio (PR) of 0.75 as a representative value for accounting for various losses in the solar panel system.

By amalgamating collected data and informed assumptions, our energy output calculation will facilitate a comprehensive evaluation of the solar panel deployment's annual electricity generation potential. This quantitative analysis will be instrumental in informing the technical and operational aspects of the project, providing essential insights into its feasibility and sustainability. [18]

4. TECHNICAL ASPECTS OF SOLAR PANEL DEPLOYMENT

4.1 Factory-Preassembled Solar Panels and Piston Mechanism:

The technical implementation of solar panel deployment on railway tracks involves utilizing factory-preassembled solar panels and a piston mechanism. These solar panels will have a width of one meter each and come ready for installation. The factory assembly will ensure consistency and quality in their construction, streamlining the deployment process.

The deployment mechanism employs a piston system, which facilitates the smooth and automated spreading of the solar panels along the rail track as the train travels. The panels are positioned between the train lines and fastened securely to the rails as shown in the figure 2. This unique mechanism, likened to "unrolling a carpet," ensures efficient use of the available space between the tracks without hindering train movement. [19]

Figure 2. Deployment using Trains [8]

4.2 Installation Procedure and Mechanism Operation:

The installation procedure for deploying solar panels on railway tracks involves several steps to ensure proper setup and functionality:

- Track Inspection: Before installation, a thorough railway track inspection will be conducted to assess its structural integrity and identify potential issues.

- Placement of Solar Panels: The factory-preassembled solar panels are carefully positioned between the railway lines and fastened to the rails using the piston mechanism.

- Integration with Power Grid: Electrical connections will be established to integrate the generated electricity from the solar panels into the existing railway power grid.

- Mechanism Testing: The piston mechanism will undergo rigorous testing to ensure its smooth operation and safety during deployment.

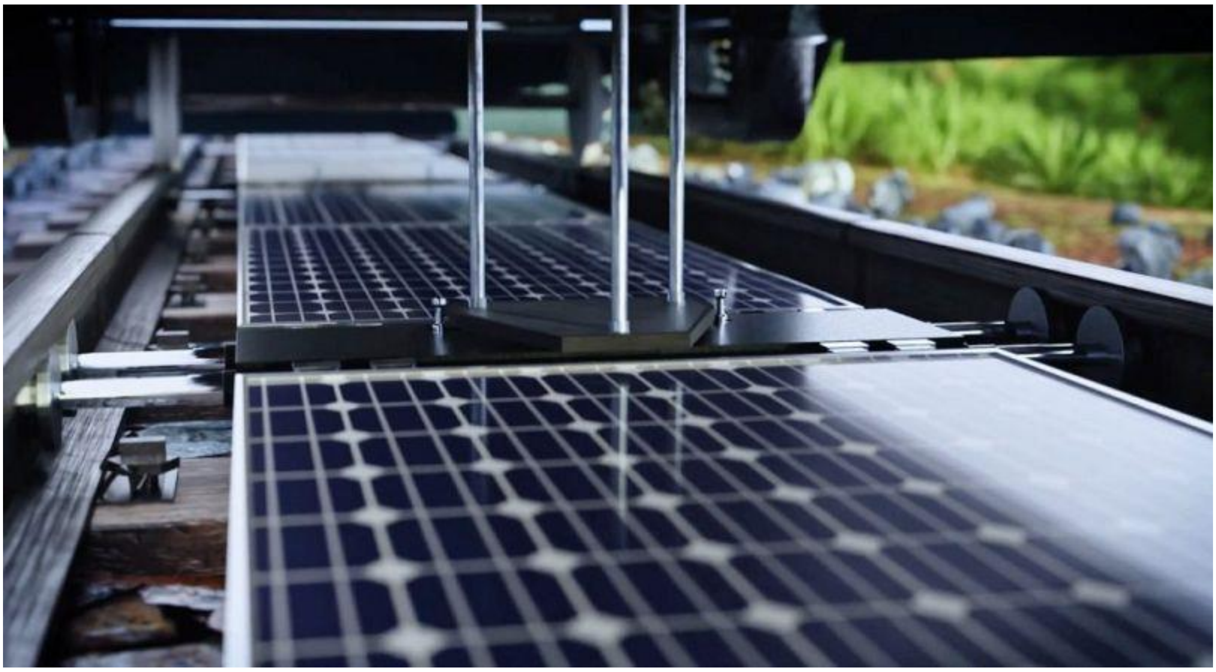

Figure 3. Instrument to lock the piston [8]

4.3 Panel Orientation and Optimal Placement:

The orientation of solar panels significantly impacts their energy generation capacity. For the railway track deployment, the solar panels are laid horizontally to optimize solar exposure throughout the day. The orientation ensures that the panels receive sunlight from sunrise to sunset, maximizing their energy output.

The optimal placement of the solar panels is determined by factors such as available space, shading considerations, and alignment with the direction of train travel. Engineers must carefully plan the arrangement to avoid any potential shading caused by nearby structures or vegetation, which could hinder energy generation. [20]

Also in the figure 3, we can see that the protruding mechanism under the belly of train pushes the piston mechanism in place to lock the solar panel in place.

4.4 Mitigating Reflections and Glare for Train Drivers:

One essential aspect of the technical design is the mitigation of reflections and glare that could affect train drivers. The project aims to ensure the safety and comfort of train operators by implementing the following measures:

- Anti-reflective Coating: The solar panels may be equipped with anti-reflective coatings to reduce the level of reflections that could be directed toward train drivers.
- Panel Tilt Adjustment: The tilt of the solar panels can be optimized to minimize glare and reflections during specific times of the day. We can tilt the solar panel to one side of the track to avoid glare.
- Train Speed Consideration: The train's speed may be considered during the design process to manage any potential glare issues during higher train speeds.

By implementing these measures, the project seeks to mitigate the impact of reflections and glare, ensuring safe and unobstructed visibility for train drivers while optimizing solar energy generation.

The technical aspects of deploying solar panels on railway tracks encompass factory-preassembled panels, the innovative piston mechanism [21], careful installation procedures, optimal panel orientation, and measures to mitigate reflections and glare. These technical details play a critical role in the successful implementation of the project, ensuring efficiency, safety, and seamless integration with rail operations.

5. OPERATIONAL CONSIDERATIONS

5.1 Impact on Rail Operations and Safety Measures:

The operational considerations of deploying solar panels on railway tracks are of paramount importance to ensure smooth rail operations and passenger safety. The project diligently examines the impact of solar panel deployment on rail activities and incorporates necessary safety measures:

- Train Schedule Management: The solar panel deployment should be planned to minimize disruption to train schedules. This involves coordinating installation and maintenance activities during off-peak hours or periods of lower rail traffic.
- Safety Signage and Barriers: To ensure the safety of passengers and railway staff, appropriate safety signage and barriers will be strategically placed to prevent unauthorized access to the solar panel area.
- Emergency Protocols: Comprehensive emergency protocols will be developed to address any potential incidents related to the solar panels, such as panel damage or electrical issues.

5.2 Integration with Power Grid and Residential Electricity Supply:

Effective integration of the generated solar electricity into the railway's power grid and residential electricity supply is a pivotal aspect of the project's operational considerations:

- Grid Connection Infrastructure: Robust electrical infrastructure will be established to connect the solar panels to the railway power grid and enable the seamless transfer of surplus electricity.[22]
- Energy Distribution: An energy distribution strategy will be devised to efficiently channel the solar-generated power to residential areas, contributing to the local power supply.
- Feed-in Tariffs: The project will explore the possibility of feed-in tariffs, encouraging the integration of solar power into the grid and promoting renewable energy use.

5.3 Specialized Technology for Rail Energy Consumption:

Incorporating specialized technology for rail energy consumption is a key consideration to utilizing solar-generated power effectively:

- Energy Storage Solutions: Implementing energy storage systems, such as battery banks, will enable the railway to store excess solar power for use during periods of low sunlight or peak energy demand.

- Power Management Systems: Advanced power management systems will be integrated to optimize the use of solar electricity for various railway operations, including lighting and signaling.

- Energy Efficiency Measures: The project will explore energy-efficient technologies and practices to enhance rail operations and reduce overall energy consumption.

5.4 Maintenance and Monitoring of Solar Panels:

Proactive maintenance and monitoring of the solar panels are essential to ensure optimal performance and longevity of the system:

- Regular Inspections: Routine inspections of the solar panels will be conducted to identify any damage, soiling, or malfunctioning components.

- Cleaning Protocols: Cleaning procedures will be established to remove dust and dirt accumulation on the solar panels, enhancing their efficiency.

- Performance Monitoring: Advanced monitoring systems will be employed to track the performance of individual solar panels and the entire system. Real-time data analysis will aid in identifying and resolving any issues promptly.

By addressing these operational considerations, the project aims to seamlessly integrate solar panel deployment with rail operations [23], promote energy efficiency, and contribute to a sustainable energy supply for both the railway and the surrounding residential areas. Diligent safety measures, grid integration, specialized technologies, and a comprehensive maintenance plan will collectively ensure the success and long-term viability of the solar panel deployment on railway tracks.

6. COST ESTIMATION AND ECONOMIC VIABILITY

6.1 Initial Investment and Implementation Cost:

The project's cost estimation and economic viability analysis of deploying solar panels on railway tracks is a crucial aspect. It involves assessing the initial investment required for the implementation and installation of the solar panel system:

- Solar Panel Procurement: The cost of procuring the factory-preassembled solar panels, including transportation and logistics, will be considered. A 1KW Solar Panel Price in India can be approximately 45,000 - 50,000 INR [1](waree.com)

- Installation Infrastructure: Expenses related to the installation infrastructure, such as mounting structures, electrical connections, and support systems, will be accounted for.

- Engineering and Design: Costs associated with engineering and design services required for the project's planning and execution will be included.[2] (Deployed system figure 4)

- Labor and Construction: The expenses incurred in hiring skilled labor and constructing the solar panel deployment will be factored into the cost estimation. [24]

- Safety Measures: Investment in safety measures, including signage, barriers, and emergency protocols, will be considered to ensure passenger and staff safety.

Figure 4. Fully deployed Solar panels [8]

6.2 Long-Term Cost Analysis and Return on Investment:

The economic viability analysis extends beyond the initial investment to evaluate the long-term cost implications and the return on investment (ROI) of the solar panel deployment on railway tracks:

- Operation and Maintenance: An estimation of the operation and maintenance costs for the solar panel system, including regular inspections, cleaning, and repairs, will be projected over the system's operational lifespan.
- Energy Savings: The potential energy savings resulting from solar electricity generation will be calculated, considering the displacement of conventional electricity sources.
- Return on Investment (ROI): The projected ROI will be calculated by comparing the cumulative savings from energy generation with the initial investment and long-term maintenance costs.
- Economic Life Cycle Analysis: An economic life cycle analysis will be conducted to assess the overall cost-effectiveness and financial viability of the solar panel deployment over its expected operational lifespan.

6.3 Economic Benefits and Potential Revenue Generation:

The economic analysis will also consider the broader economic benefits and potential revenue generation from the deployment of solar panels on railway tracks:

Reduced Energy Expenditure: The use of solar-generated electricity can significantly reduce the railway's energy expenditure on conventional power sources, leading to substantial cost savings. [3]

Feed-in Tariffs and Incentives: The project will explore potential feed-in tariffs and government incentives available for renewable energy projects, which could further enhance the economic benefits.

Revenue from Surplus Electricity: The surplus solar electricity generated can be supplied to the power grid, generating additional revenue for the railway company through electricity sales.

Environmental Cost Savings: Reducing greenhouse gas emissions due to solar energy usage can lead to ecological cost savings, such as mitigating carbon offset costs. [25]

The project will determine the economic viability and financial sustainability of deploying solar panels on railway tracks through a comprehensive cost estimation and economic analysis. The assessment of initial investment, long-term cost analysis, ROI calculation, and consideration of potential revenue streams will provide valuable insights into the project's economic feasibility and its positive impact on the railway's financial operations. The economic benefits of this sustainable energy solution will contribute to a greener and more economically sound future for the railway network and the surrounding communities.

7. ADVANTAGES AND DISADVANTAGES

7.1 Advantages of Railway Solar Panel Deployment:

The deployment of solar panels on railway tracks offers numerous advantages that make it a promising and innovative renewable energy solution:

1. Optimal Space Utilization: Utilizing the area between railway tracks for solar panel deployment allows for efficient land use without the need for additional land acquisition.
2. Reduced Carbon Footprint: Solar energy is a clean and renewable energy source, leading to a significant reduction in greenhouse gas emissions, mitigating the railway's carbon footprint, and contributing to climate change mitigation.
3. Sustainable Energy Generation: By harnessing solar energy, the railway can sustainably generate electricity, reducing reliance on fossil fuels and non-renewable resources.
4. Low Visual and Environmental Impact: Deploying solar panels along railway tracks has minimal visual and environmental impact, ensuring compatibility with surrounding landscapes and ecosystems.
5. Diversification of Energy Sources: Incorporating solar power into the railway's energy mix diversifies the energy sources, increasing energy security and resilience.
6. Long-Term Cost Savings: Solar panel deployment offers the potential for long-term cost savings by reducing electricity expenses and protecting the railway from fluctuating energy prices.[4]

7.2 Environmental Benefits and Sustainability Aspect:

The environmental benefits and sustainability aspects of railway solar panel deployment contribute to a greener and more eco-friendly railway network:

Renewable Energy Contribution: The project's utilization of renewable solar energy demonstrates the railway's commitment to sustainable energy practices and reducing its environmental impact.

Ecological Preservation: Minimizing land use for solar panel deployment helps preserve natural habitats and promotes biodiversity conservation.

Green Image and Corporate Social Responsibility: Embracing solar energy aligns the railway company with environmentally responsible practices, enhancing its public image and corporate social responsibility.

Potential for Carbon Neutrality: By integrating solar energy and reducing carbon emissions, the railway can work toward achieving carbon neutrality in its operations.

7.3 <u>Challenges and Disadvantages</u>:

Despite the numerous advantages, the deployment of solar panels on railway tracks also presents certain challenges and disadvantages that need careful consideration:

Upfront Investment: The initial capital investment required for solar panel deployment and infrastructure may present a significant financial challenge. [6]

Land Use Conflicts: Depending on the railway's location, land use conflicts or regulatory hurdles may arise when utilizing railway track areas for solar panels.

Maintenance and Cleaning: The regular maintenance and cleaning of solar panels to ensure optimal efficiency can be labor-intensive and may incur additional costs.

7.4 <u>Overcoming Disadvantages and Mitigation Strategies</u>:

To address the challenges and disadvantages effectively, the project proposes the following mitigation strategies:

Financing and Funding: Exploring financing options, partnerships, and government incentives can help offset the upfront investment and reduce the financial burden.

Collaboration with Stakeholders: Engaging with relevant stakeholders, including railway authorities, local communities, and environmental organizations, can help address land use concerns and garner support for the project.

Performance Monitoring and Maintenance Plan: Implementing an efficient performance monitoring and maintenance plan ensures the solar panels operate at peak efficiency and prolong their lifespan, minimizing operational costs.

8. CASE STUDY: APPLICATION ON INDIAN RAIL NETWORK

8.1 Overview of Indian Rail Network and Its Length:

The Indian Rail Network, operated by Indian Railways, is one of the world's largest and most extensive railway networks.[5] Spanning across the vast landscape of India, it connects remote regions, bustling cities, and diverse terrains. The latest available data shows that the Indian Rail Network has a total length of approximately 99,235 kilometers (see table 8.1).

8.1 Running Track Data for each State of India [II] (ircep.gov.in)

State/Union Territory	Running Track Kms.
Andhra Pradesh	6,075
Arunachal Pradesh	12
Assam	2,702
Bihar	5,418
Chhattisgarh	2,183
Delhi	346
Goa	69
Gujarat	6,357
Haryana	2,652
Himachal Pradesh	317
Jammu & Kashmir	366
Jharkhand	4,383

Karnataka	4,837
Kerala	1,745
Madhya Pradesh	8,216
Maharashtra	8,712
Manipur	13
Meghalaya	9
Mizoram	2
Nagaland	11
Odisha	4,443
Punjab	2,768
Rajasthan	8,174
Tamil Nadu	5,492
Telangana	2,596
Tripura	265
Uttarakhand	451
Uttar Pradesh	12,957
West Bengal	7,624

Chandigarh	18
Puducherry	22
Total	99,235

8.2 Potential Area for Solar Panel Deployment:

The railway track area offers a substantial potential for solar panel deployment, considering the vast expanse between the tracks that is often unutilized. Leveraging this available space, we can estimate the potential area suitable for solar panel installation. Considering the standard gauge width of 1.676 meters, the total available area between the tracks can be calculated (see table 8.2). [9]

8.2 State wise Peak Average Year Daylight Hours [III]

State	Average Year Daylight Hours
Andhra Pradesh	2025.75
Arunachal Pradesh	1354.15
Assam	1733.75
Bihar	1861.5
Chhattisgarh	1930.85
Delhi	1843.25
Goa	1978.3
Gujarat	2033.05
Haryana	1876.1
Himachal Pradesh	1733.75

State	Average Year Daylight Hours
Jammu and Kashmir	1810.4
Jharkhand	1887.05
Karnataka	1963.7
Kerala	1664.4
Madhya Pradesh	1923.55
Maharashtra	2095.1
Manipur	1733.75
Meghalaya	1668.05
Mizoram	1835.95
Nagaland	1686.3
Odisha	1810.4
Punjab	1814.05
Rajasthan	2047.65
Tamil Nadu	1887.05
Telangana	1868.8
Tripura	1784.85
Uttarakhand	1762.95
Uttar Pradesh	1949.1
West Bengal	1868.8

State	Average Year Daylight Hours
Chandigarh	1817.7
Puducherry	2040.35

8.3 <u>Energy Generation Estimation</u>:

To estimate the energy generation potential from solar panel deployment on the Indian Rail Network, we will use the formula provided in the methodology section of the report:

E = A * r * H * PR

Where:

E = Energy output (kWh)

A = Total solar panel area (m^2)

r = Solar panel yield or efficiency (%)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance ratio, coefficient for losses (default value = 0.75, adjusted for horizontal panel deployment)

To calculate the energy generation, we will consider the following assumptions:

Based on the provided information, solar panel efficiency (r) is assumed to be 22%.

We obtained annual average solar radiation on tilted panels (H) from solar radiation databases for the various regions of the Indian Rail Network.[7]

We adjusted the PR (Performance Ratio) for horizontal panel deployment to account for all relevant losses.

Using the MATLAB R2023b software, we created a program (Appendix) to find the energy generated for each region over the year. Taking data from table 8.1 and table 8.2. The results are as follows:

8.3 Energy generated for each region over the year [Appendix I]

STATE	ENERGY GENERATED (in GW)	GENERATED ENERGY COST (in Crores)	SOLAR PANEL COST (in Crores)
Andhra Pradesh	2030.56	749.27707	4120.63909
Arunachal Pradesh	2.68	0.98937	8.13953
Assam	772.96	285.22141	1832.75174
Bihar	1664.13	614.06218	3674.9996
Chhattisgarh	695.48	256.63305	1480.71689
Delhi	105.23	38.83029	234.6899
Goa	22.52	8.31097	46.80232
Gujarat	2132.48	786.88376	4311.91814
Haryana	820.94	302.92828	1798.83701
Himachal Pradesh	90.68	33.46232	215.01936
Jammu and Kashmir	109.33	40.34279	248.25579
Jharkhand	1364.71	503.57619	2972.96479
Karnataka	1567.24	578.31111	3280.9105
Kerala	479.22	176.83305	1183.6239
Madhya Pradesh	2607.64	962.21965	5572.86761
Maharashtra	3011.66	1111.30414	5909.30168
Manipur	3.72	1.37227	8.81783
Meghalaya	2.48	0.91403	6.10465
Mizoram	0.61	0.22356	1.35659
Nagaland	3.06	1.12937	7.46124
Odisha	1327.2	489.73502	3013.66246
Punjab	828.51	305.72127	1877.51918
Rajasthan	2761.69	1019.06215	5544.37924
Tamil Nadu	1710.01	630.99257	3725.19339
Telangana	800.48	295.37778	1760.85252
Tripura	78.04	28.79771	179.74804
Uttarakhand	131.19	48.40908	305.91082
Uttar Pradesh	4166.99	1537.61954	8788.66184
West Bengal	2350.88	867.47311	5171.31727
Chandigarh	5.4	1.99207	12.2093
Puducherry	7.41	2.73299	14.92248

Total Energy Generated: 31,655.12 GW

The present energy cost for Indian Railways: 3.69 INR per kWh (IV) (financialexpress.com) (Assuming we are using this electricity for household purposes) [11]

Total Solar Panel Cost for India: 67,310.55 Crores

The total cost of energy generated= 11,680.74 Crore INR savings in electricity bills (Yearly) (approx.)

The energy consumption of Indian Railways in FY 2020 was around 18,410 million Units for traction and 2,338 million Units for non-traction load. The total energy used equals

20,748 GW, which is less than what will be the produced by the deployed solar panels for the purpose. The extra units can be supplied for other industrial applications.

Initial investment calculation:

Solar panel price for 1 kWh = 35,000 INR (approx.) According to [1]

We are considering the price of solar panel produced by Loom Solar Panel – SHARK 550 Watt – Mono Perc Half Cut. [10]

⇨ 1 sq. meter solar panel cost = 6,782.945 INR

Total cost for solar panel = 6,782.945 x 1 x 99,235 x 10^3

= 67,310.5 crores INR (approx.) (excluding labor cost)

8.4 Economic and Environmental Impact Assessment:

The application of solar panels on the Indian Rail Network has the potential for substantial economic and environmental impact:

- Economic Impact: By generating renewable solar electricity, the railway can significantly reduce its dependency on conventional energy sources, leading to cost savings on energy expenditures over the long term. Additionally, the project can explore government incentives and feed-in tariffs, further enhancing its economic viability.
- Environmental Impact: Harnessing solar energy along the extensive rail network will considerably reduce greenhouse gas emissions, fostering a greener and more sustainable transportation infrastructure. The environmental benefits include mitigating the railway's carbon footprint, supporting climate change mitigation efforts, and preserving the surrounding ecosystems.
- Social and Public Perception: The project's commitment to renewable energy and sustainability aligns with the broader societal push towards environmental consciousness. Embracing solar energy on a massive scale sets a positive example and fosters a public appreciation for responsible and eco-friendly transportation practices.

Through this case study, the project will demonstrate the potential of solar panel deployment on the Indian Rail Network. By estimating the energy generation capacity, assessing the economic and environmental impact, and considering the social implications, the report will provide valuable insights into the viability and advantages of implementing renewable solar energy solutions in the Indian rail transportation sector.

9. CONCLUSION

9.1 Summary of Findings:

Deploying solar panels on railway tracks offers a promising and innovative solution for integrating renewable energy into the transportation sector. Throughout this project, we have comprehensively analyzed the technical, operational, economic, and environmental aspects of the proposed solar panel deployment. The key findings are summarized as follows:

1. Feasibility Analysis: Assessing the railway track area for solar panel deployment indicates a significant potential for optimal space utilization. The use of factory-preassembled solar panels and the innovative piston mechanism streamlines installation and operation without impeding rail activities.

2. Solar Panel Efficiency and Energy Output: Based on the provided data and calculations, the solar panel system's estimated energy output demonstrates its substantial contribution to the power grid and residential electricity supply. Solar panel efficiency and orientation are vital factors in determining energy generation.

3. Advantages and Environmental Benefits: The advantages of railway solar panel deployment include optimal land use, reduced carbon footprint, sustainability, and long-term cost savings. Embracing solar energy promotes a greener image for the railway company and fosters environmental conservation.

4. Challenges and Mitigation Strategies: While the project presents numerous advantages, challenges such as upfront investment and maintenance have been identified. The implementation of appropriate mitigation strategies can address these challenges effectively.

9.2 Implications and Recommendations:

The findings of this project have significant implications for the railway industry and the broader renewable energy sector. The successful deployment of solar panels on railway tracks can serve as a model for sustainable energy solutions in transportation infrastructure. We propose the following recommendations:

1. Stakeholder Engagement: Engaging with railway authorities, government agencies, local communities, and environmental organizations is crucial for obtaining support, addressing concerns, and facilitating smooth project implementation.

2. Financial Support: Exploring various financing options, government grants, and incentives can alleviate the initial investment burden and enhance the project's economic viability.

3. Advanced Technology Integration: Investing in advanced power management systems, energy storage solutions, and performance monitoring tools will optimize solar energy utilization and operational efficiency.

4. Continued Research and Development: Continuous research and development in solar panel technology, maintenance practices, and cost-effectiveness will further enhance the project's long-term sustainability.

9.3 Future Prospects and Expansion Possibilities:

The successful implementation of solar panel deployment on the Indian Rail Network opens up numerous expansion possibilities and future prospects:

Scale-up and Replication: Upon successful deployment in specific railway sections, the project can be expanded to cover a more extensive network of tracks, increasing solar energy generation and contributing to a more significant reduction in carbon emissions.

Integration with Other Transport Infrastructure: The knowledge gained from this project can be applied to other transport infrastructure, such as metro systems and highways, promoting widespread renewable energy adoption.

Research Collaborations: Collaborating with research institutions and solar energy experts can facilitate ongoing innovation, enabling the project to stay at the forefront of advancements in renewable energy technologies.

Policy Advocacy: The project's success can catalyze advocating supportive policies and regulations promoting renewable energy deployment in the transportation sector.

In conclusion, deploying solar panels on railway tracks holds tremendous promise for transforming the railway industry into a cleaner, greener, and more sustainable mode of transportation. By addressing this project's technical, economic, and environmental aspects, we have laid the foundation for a pioneering initiative that can set a precedent for sustainable transportation infrastructure worldwide. Through careful planning, collaboration, and innovative strategies, the railway company can embrace solar energy and lead the way toward a brighter and more sustainable future for future generations.

10. APPENDIX

MATLAB CODE:

```
ExcelFilePath = "C:\Users\palla\Desktop\PROGRAMS\MATLAB\PROJECT
REPORT\Solar_Panel.xlsx";


% Reading data from the Excel file
dataTable = readtable(ExcelFilePath);


% Initialising variables
sum_energy=0;
sum_energy_cost=0;
sum_panel_cost=0;


% Extracting data from the Excel file
states = dataTable.State;
railwayTrackLength = dataTable.RailwayTrackLength;
averageSunlightHours = dataTable.AverageSunlightHours;




% Defining Constants
solarPanelEfficiency = 0.22;
electricEnergyCost = 3.69;  % (in Rupees per kWh)
PerformanceRatio = 0.75;
per_sq_meter_cost = 6782.945; % (in Rupees)


% Calculating net energy for each state
EnergyGeneratedcost = zeros(size(states));
energyGeneratedPerYear =  zeros(size(states));
SolarPanelCost = zeros(size(states));


for i = 1:length(states)
    % Calculating Energy generated in a year in kilowatt-hours (kWh) for
each state
    energyGeneratedPerYear(i) =  PerformanceRatio * averageSunlightHours(i)
* railwayTrackLength(i) * solarPanelEfficiency /1000; % (in Giga Watts)


    % Calculating Energy generated cost in Rupees per kWh for each state
    EnergyGeneratedcost(i) = 1000 * 1000 * energyGeneratedPerYear(i) *
electricEnergyCost / 10^7;


    % Calculating Total Solar Panel cost for each State
    SolarPanelCost(i) = railwayTrackLength(i) * 1000 * per_sq_meter_cost /
10^7;
```

```
end

% Displaying the results
fprintf('STATE\t\t ENERGY GENERATED\t\t GENERATED ENERGY COST\t\t SOLAR
PANEL COST')
for i = 1:length(states)
    fprintf('%s:\t\t %.2f GW\t\t %.5f Cr\t\t %.5f Cr \n',
states{i},energyGeneratedPerYear(i),
EnergyGeneratedcost(i),SolarPanelCost(i));
    sum_energy=sum_energy+energyGeneratedPerYear(i);
    sum_energy_cost=sum_energy_cost+EnergyGeneratedcost(i);
    sum_panel_cost=sum_panel_cost+SolarPanelCost(i);
end
fprintf('Total Energy Generated: %.2f GW',sum_energy);
fprintf('Total Energy Generated Price: %.2f Crores',sum_energy_cost);
fprintf('Total Solar Panel Cost for India: %.2f Crores',sum_panel_cost);
```

OUTPUT:

```
STATE                    ENERGY GENERATED        GENERATED ENERGY   SOLAR PANEL
                                                       COST            COST
Andhra Pradesh:              2030.56 GW              749.27707 Cr    4120.63909 Cr
Arunachal Pradesh:           2.68 GW                  0.98937Cr      8.13953 Cr
Assam:                       772.96 GW               285.22141 Cr    1832.75174 Cr
Bihar:                       1664.13 GW              614.06218 Cr    3674.99960 Cr
Chhattisgarh:                695.48 GW               256.63305 Cr    1480.71689 Cr
Delhi:                       105.23 GW               38.83029 Cr     234.68990 Cr
Goa:                         22.52 GW                8.31097 Cr      46.80232 Cr
Gujarat:                     2132.48 GW              786.88376 Cr    4311.91814 Cr
Haryana:                     820.94 GW               302.92828 Cr    1798.83701 Cr
Himachal Pradesh:            90.68 GW                33.46232 Cr     215.01936 Cr
Jammu and Kashmir:           109.33 GW               40.34279 Cr     248.25579 Cr
Jharkhand:                   1364.71 GW              503.57619 Cr    2972.96479 Cr
Karnataka:                   1567.24 GW              578.31111 Cr    3280.91050 Cr
Kerala:                       479.22 GW              176.83305 Cr    1183.62390 Cr
Madhya Pradesh:              2607.64 GW              962.21965 Cr    5572.86761 Cr
Maharashtra:                 3011.66 GW              1111.30414 Cr   5909.30168 Cr
Manipur:                     3.72 GW                 1.37227 Cr      8.81783 Cr
Meghalaya:                   2.48 GW                 0.91403 Cr      6.10465 Cr
Mizoram:                     0.61 GW                 0.22356 Cr      1.35659 Cr
Nagaland:                    3.06 GW                 1.12937 Cr      7.46124 Cr
Odisha:                       1327.20 GW             489.73502 Cr    3013.66246 Cr
Punjab:                       828.51 GW              305.72127 Cr    1877.51918 Cr
Rajasthan:                   2761.69 GW              1019.06215 Cr   5544.37924 Cr
Tamil Nadu:                  1710.01 GW              630.99257 Cr    3725.19339 Cr
Telangana:                   800.48 GW               295.37778 Cr    1760.85252 Cr
Tripura:                     78.04 GW                28.79771 Cr     179.74804 Cr
Uttarakhand:                 131.19 GW               48.40908 Cr     305.91082 Cr
Uttar Pradesh:               4166.99 GW              1537.61954 Cr   8788.66184 Cr
West Bengal:                 2350.88 GW              867.47311 Cr    5171.31727 Cr
Chandigarh:                  5.40 GW                 1.99207 Cr      12.20930 Cr
Puducherry:                  7.41 GW                 2.73299 Cr      14.92248 Cr
Total Energy Generated: 31655.12 GW
Total Energy Generated Price: 11680.74 Crores
Total Solar Panel Cost for India: 67310.55 Crores
```

C++ CODE:

```
#include <iostream>
#include <iomanip>
#include <string>

// Function to manually set data (replace this with your actual data)
void setManualData(std::string states[], double railwayTrackLength[], double 
averageSunlightHours[], int size) {
    // Replace the following lines with your actual data
    states[0] = "Andhra Pradesh";
    railwayTrackLength[0] = 6075;
    averageSunlightHours[0] = 2025.75;

    states[1] = "Arunachal Pradesh";
    railwayTrackLength[1] = 12;
    averageSunlightHours[1] = 1354.15;

    states[2] = "Assam";
    railwayTrackLength[2] = 2702;
    averageSunlightHours[2] = 1733.75;

    states[3] = "Bihar";
    railwayTrackLength[3] = 5418;
    averageSunlightHours[3] = 1861.5;

    states[4] = "Chhattisgarh";
    railwayTrackLength[4] = 2183;
    averageSunlightHours[4] = 1930.85;

    states[5] = "Delhi";
    railwayTrackLength[5] = 346;
    averageSunlightHours[5] = 1843.25;

    states[6] = "Goa";
    railwayTrackLength[6] = 69;
    averageSunlightHours[6] = 1978.3;

    states[7] = "Gujarat";
    railwayTrackLength[7] = 6357;
    averageSunlightHours[7] = 2033.05;

    states[8] = "Haryana";
    railwayTrackLength[8] = 2652;
    averageSunlightHours[8] = 1876.1;

    states[9] = "Himachal Pradesh";
    railwayTrackLength[9] = 317;
    averageSunlightHours[9] = 1733.75;
```

```
states[10] = "Jammu and Kashmir";
railwayTrackLength[10] = 366;
averageSunlightHours[10] = 1810.4;

states[11] = "Jharkhand";
railwayTrackLength[11] = 4383;
averageSunlightHours[11] = 1887.05;

states[12] = "Karnataka";
railwayTrackLength[12] = 4837;
averageSunlightHours[12] = 1963.7;

states[13] = "Kerala";
railwayTrackLength[13] = 1745;
averageSunlightHours[13] = 1664.4;

states[14] = "Madhya Pradesh";
railwayTrackLength[14] = 8216;
averageSunlightHours[14] = 1923.55;

states[15] = "Maharashtra";
railwayTrackLength[15] = 8712;
averageSunlightHours[15] = 2095.1;

states[16] = "Manipur";
railwayTrackLength[16] = 13;
averageSunlightHours[16] = 1733.75;

states[17] = "Meghalaya";
railwayTrackLength[17] = 9;
averageSunlightHours[17] = 1668.05;

states[18] = "Mizoram";
railwayTrackLength[18] = 2;
averageSunlightHours[18] = 1835.95;

states[19] = "Nagaland";
railwayTrackLength[19] = 11;
averageSunlightHours[19] = 1686.3;

states[20] = "Odisha";
railwayTrackLength[20] = 4443;
averageSunlightHours[20] = 1810.4;

states[21] = "Punjab";
railwayTrackLength[21] = 2768;
averageSunlightHours[21] = 1814.05;

states[22] = "Rajasthan";
railwayTrackLength[22] = 8174;
averageSunlightHours[22] = 2047.65;
```

```
    states[23] = "Tamil Nadu";
    railwayTrackLength[23] = 5492;
    averageSunlightHours[23] = 1887.05;

    states[24] = "Telangana";
    railwayTrackLength[24] = 2596;
    averageSunlightHours[24] = 1868.8;

    states[25] = "Tripura";
    railwayTrackLength[25] = 265;
    averageSunlightHours[25] = 1784.85;

    states[26] = "Uttarakhand";
    railwayTrackLength[26] = 451;
    averageSunlightHours[26] = 1762.95;

    states[27] = "Uttar Pradesh";
    railwayTrackLength[27] = 12957;
    averageSunlightHours[27] = 1949.1;

    states[28] = "West Bengal";
    railwayTrackLength[28] = 7624;
    averageSunlightHours[28] = 1868.8;

    states[29] = "Chandigarh";
    railwayTrackLength[29] = 18;
    averageSunlightHours[29] = 1817.7;

    states[30] = "Puducherry";
    railwayTrackLength[30] = 22;
    averageSunlightHours[30] = 2040.35;
}

int main() {
    const int size = 31;

    // Manually set data
    std::string states[size];
    double railwayTrackLength[size];
    double averageSunlightHours[size];

    setManualData(states, railwayTrackLength, averageSunlightHours, size);

    // Initialising variables
    double sum_energy = 0;
    double sum_energy_cost = 0;
    double sum_panel_cost = 0;

    // Defining Constants
    const double solarPanelEfficiency = 0.22;
```

```
    const double electricEnergyCost = 3.69;  // (in Rupees per kWh)
    const double performanceRatio = 0.75;
    const double per_sq_meter_cost = 6782.945; // (in Rupees)

    // Calculating net energy for each state
    double energyGeneratedCost[size] = {0.0};
    double energyGeneratedPerYear[size] = {0.0};
    double solarPanelCost[size] = {0.0};

    for (int i = 0; i < size; ++i) {
        // Calculating Energy generated in a year in kilowatt-hours (kWh) for each
state
        energyGeneratedPerYear[i] = performanceRatio * averageSunlightHours[i] *
railwayTrackLength[i] * solarPanelEfficiency / 1000; // (in Giga Watts)

        // Calculating Energy generated cost in Rupees per kWh for each state
        energyGeneratedCost[i] = 1000 * 1000 * energyGeneratedPerYear[i] *
electricEnergyCost / 1e7;

        // Calculating Total Solar Panel cost for each State
        solarPanelCost[i] = railwayTrackLength[i] * 1000 * per_sq_meter_cost / 1e7;
    }

    // Displaying the results
    std::cout << std::setw(15) << "STATE" << std::setw(25) << "ENERGY GENERATED" <<
std::setw(30) << "GENERATED ENERGY COST" << std::setw(30) << "SOLAR PANEL COST" <<
std::endl;
    for (int i = 0; i < size; ++i) {
        std::cout << std::setw(15) << states[i] << std::setw(25) << std::fixed <<
std::setprecision(2) << energyGeneratedPerYear[i]
                  << std::setw(30) << std::fixed << std::setprecision(5) <<
energyGeneratedCost[i]
                  << std::setw(30) << std::fixed << std::setprecision(5) <<
solarPanelCost[i] << std::endl;

        sum_energy += energyGeneratedPerYear[i];
        sum_energy_cost += energyGeneratedCost[i];
        sum_panel_cost += solarPanelCost[i];
    }

    // Displaying the total results
    std::cout << "Total Energy Generated: " << std::fixed << std::setprecision(2)
<< sum_energy << " GW" << std::endl;
    std::cout << "Total Energy Generated Price: " << std::fixed <<
std::setprecision(2) << sum_energy_cost << " Crores" << std::endl;
    std::cout << "Total Solar Panel Cost for India: " << std::fixed <<
std::setprecision(2) << sum_panel_cost << " Crores" << std::endl;

    return 0;
}
```

OUTPUT:

STATE	ENERGY GENERATED	GENERATED ENERGY COST	SOLAR PANEL COST
Andhra Pradesh	2030.56	749.27707	4120.63909
Arunachal Pradesh	2.68	0.98937	8.13953
Assam	772.96	285.22141	1832.75174
Bihar	1664.13	614.06218	3674.99960
Chhattisgarh	695.48	256.63305	1480.71689
Delhi	105.23	38.83029	234.68990
Goa	22.52	8.31097	46.80232
Gujarat	2132.48	786.88376	4311.91814
Haryana	820.94	302.92828	1798.83701
Himachal Pradesh	90.68	33.46232	215.01936
Jammu and Kashmir	109.33	40.34279	248.25579
Jharkhand	1364.71	503.57619	2972.96479
Karnataka	1567.24	578.31111	3280.91050
Kerala	479.22	176.83305	1183.62390
Madhya Pradesh	2607.64	962.21965	5572.86761
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Mizoram	0.61	0.22356	1.35659
Nagaland	3.06	1.12937	7.46124
Odisha	1327.20	489.73502	3013.66246
Punjab	828.51	305.72127	1877.51918
Rajasthan	2761.69	1019.06215	5544.37924
Tamil Nadu	1710.01	630.99257	3725.19339
Telangana	800.48	295.37778	1760.85252
Tripura	78.04	28.79771	179.74804
Uttarakhand	131.19	48.40908	305.91082
Uttar Pradesh	4166.99	1537.61954	8788.66184
West Bengal	2350.88	867.47311	5171.31727
Chandigarh	5.40	1.99207	12.20930
Puducherry	7.41	2.73299	14.92248

Total Energy Generated: 31655.12 GW
Total Energy Generated Price: 11680.74 Crores
Total Solar Panel Cost for India: 67310.55 Crores

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