Analysis and Application of Trignometry in Constructing Solar Panel for its Optimal Utility

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Abstract: Solar energy is one of the fastest-growing sources of renewable energy in the world. As the demand for clean and sustainable energy increases, solar power has become an important alternative to fossil fuels. Solar energy is obtained from the sun's radiation and is converted into electricity through photovoltaic (PV) panels. Understanding the mathematical principles behind solar energy systems helps improve their efficiency and performance. This study focuses on how mathematical concepts such as geometry, trigonometry, graphs, data tables, and percentage calculations are used to analyze solar radiation and photovoltaic power generation. Mathematics plays a significant role in determining how solar panels capture sunlight. Geometry is used to calculate the best position and angle for installing solar panels so that they receive maximum sunlight during the day. The tilt and orientation of the panels depend on the geographic location and the movement of the sun. Proper positioning helps increase the amount of solar energy that can be converted into electricity.

Trigonometry is also important in studying solar radiation. The position of the sun changes throughout the day and across different seasons. Trigonometric calculations help determine the solar altitude and azimuth angles, which influence the amount of sunlight reaching the solar panels. By using these calculations, scientists and engineers can predict the most effective placement of solar panels and estimate the potential solar energy available in a particular area.Overall, mathematical modeling helps predict solar energy production and improves solar panel performance. Accurate calculations and data analysis support better energy planning for homes, schools, and industries, making solar energy a reliable and sustainable solution for future power needs.

Keywords: *Solar Radiation, Photovoltaic System, Efficiency, Mathematical Modeling, Solar Intensity, Renewable Energy, Data Interpretation.*

How to Cite: S. A. Prartthana; Bhaviya B.; Madhavi Latha P.; Dr. Sivasakti Balan D. P.; R. J. Thayumanaswamy (2026) Analysis and Application of Trignometry in Constructing Solar Panel for its Optimal Utility. *International Journal of Innovative Science and Research Technology,* 11(3), 2032-2039. https://doi.org/10.38124/ijisrt/26mar1005

I. INTRODUCTION

Solar energy refers to the energy obtained directly from sunlight. With rising global temperatures, increasing energy demands, and depletion of fossil fuels, solar energy has become a crucial alternative. Mathematics plays a vital role in analyzing solar power: it helps calculate sunlight intensity, determine optimum panel angles, predict annual energy output, and measure the performance of photovoltaic systems. This research explores solar energy from a mathematical perspective and presents calculations, data interpretation, and applications.Mathematical calculations help estimate solar potential for a given location using latitude and solar angles.

Geometry and trigonometry reduce energy loss by optimizing tilt angle and direction.Algebraic models allow prediction of daily, monthly, and yearly energy production.Cost–benefit analysis uses arithmetic and unitary methods to evaluate financial feasibility.Mathematical optimization increases system efficiency and sustainability.

The primary objective of this study is to examine how mathematical concepts can be applied to understand and improve the functioning of solar energy systems. One important aim is to apply the principles of geometry and trigonometry to determine the most suitable placement and tilt angle of solar panels so that they receive the maximum possible sunlight throughout the day. Proper positioning plays a significant role in increasing the efficiency and performance of solar panels.

Another objective is to analyze the mathematical relationship between the surface area of solar panels, their

efficiency rate, and the electrical power output they produce. By studying these relationships, it becomes easier to understand how different factors influence energy generation.

The study also aims to calculate the amount of electricity generated using real-life solar radiation data, allowing for a better understanding of energy production patterns. In addition, it evaluates the cost of solar panel installation and the potential savings in electricity bills using basic arithmetic calculations. Overall, the study highlights solar energy as a practical and real-world application of applied mathematics.

II. REVIEW OF LITERATURE

Solar energy research has significantly advanced over the years, and many researchers have emphasized the role of mathematics in understanding and optimizing solar power systems. Mathematical concepts such as geometry, trigonometry, statistics, and optimization techniques are widely used to analyze solar radiation, determine panel positioning, and predict energy generation. The review of previous studies highlights the importance of mathematical modeling in improving the efficiency and planning of solar energy systems.

One of the most influential contributions in the field of solar energy analysis comes from the work of Duffie and Beckman. Their research explains how geometric and trigonometric principles can be applied to calculate solar angles and the intensity of solar radiation reaching the Earth's surface. The position of the sun changes continuously throughout the day due to the rotation of the Earth and varies across seasons due to the tilt of the Earth's axis. By using trigonometric formulas, researchers can calculate important parameters such as solar altitude angle, solar azimuth angle, and the angle of incidence of sunlight on solar panels. These calculations help determine the optimal tilt and orientation of solar panels so that they receive the maximum possible sunlight during the day. Accurate calculations of solar angles are therefore essential for improving solar panel efficiency and maximizing energy production.

Research conducted by the National Renewable Energy Laboratory (NREL) further highlights the importance of mathematical models in predicting photovoltaic (PV) power output. NREL studies use mathematical equations and simulation models to estimate the amount of electricity that can be generated by solar panels under different environmental conditions. These models take into account factors such as solar irradiance, temperature, panel orientation, and system efficiency. By analyzing these variables mathematically, researchers can forecast the performance of photovoltaic systems and estimate their energy production over time. Such predictive models are especially useful for designing solar power systems and ensuring that they meet the energy demands of households, institutions, and industries.

In India, the Ministry of New and Renewable Energy (MNRE) has also conducted several studies to assess the country's solar energy potential. MNRE reports use statistical methods and long-term solar radiation data to estimate the average solar energy available in different regions. By analyzing large datasets collected over many years, researchers calculate statistical averages and trends in solar radiation. These calculations help identify areas that receive high levels of sunlight and are therefore suitable for large-scale solar energy installations. The use of statistical analysis enables policymakers and energy planners to make informed decisions regarding the development of solar infrastructure across the country.

Several research studies also indicate that mathematical optimization techniques can significantly improve the efficiency of solar energy systems. Optimization involves adjusting certain variables, such as the tilt angle, orientation, and spacing of solar panels, in order to achieve the highest possible energy output. According to various studies, proper optimization of solar panel placement and system design can improve overall solar efficiency by approximately 10–25 percent. This improvement can lead to higher electricity generation without increasing the number of solar panels, making solar energy systems more cost-effective and efficient.

Overall, researchers widely agree that mathematical modeling plays a crucial role in solar energy planning and development. By applying mathematical tools such as geometry, trigonometry, statistics, and optimization techniques, scientists and engineers can better understand solar radiation patterns and improve the performance of photovoltaic systems. These models also help in predicting future energy production, planning solar installations, and supporting sustainable energy strategies. As the demand for renewable energy continues to grow, mathematical modeling will remain an essential component in the advancement of solar power technology.

III. METHODOLOGY

The Survey on Solar Energy Was Conducted Using Bothprimary and Secondary Data.

➤ *Primary Data:*
It was collected through a structured questionnaire administered to selected respondents via face-to-face interviews and offline forms, focusing on awareness, usage, benefits and challenges of solar energy. Respondents were chosen using random sampling to ensure unbiased results

➤ *Secondary Data:*
It was gathered from reliable sources such as government reports, research journals, official energy websites and statistical databases to provide context and support for study. The combined approach allowed for a comprehensive understanding of public perception, adoption levels and current status of solar energy.

- *Do you Currently Use Any Solar Energy?*
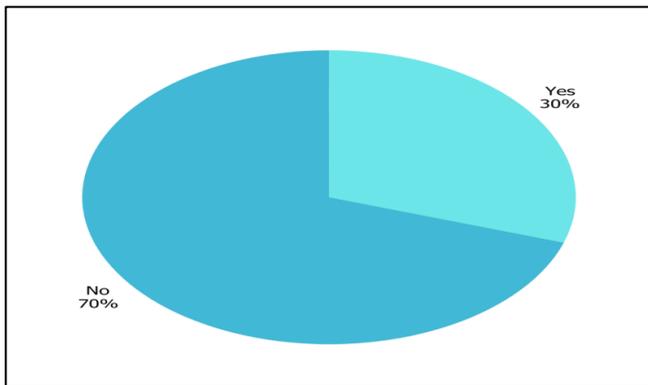
✓ YES

✓ NO

Fig1 Usage of Solar Energy

- *What is your main source of information about solar energy?*

✓ Television
✓ Internet
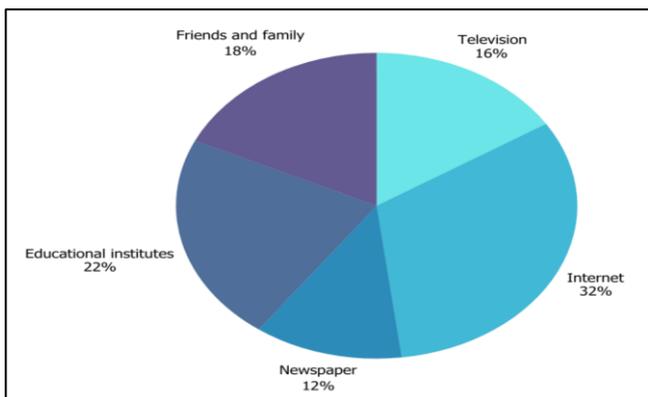✓ Newspaper
✓ Educational institutes
✓ Friends and family

Fig 2 Awareness on Solar Energy

- *What is the Main Barrier Preventing Adoption of Solar Energy?*

✓ High installation cost
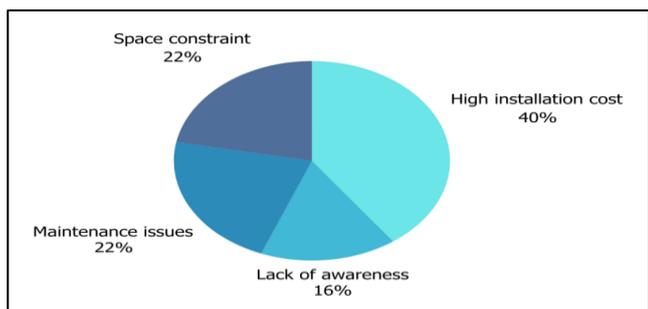✓ Lack of awareness
✓ Maintenance issues
✓ Space constraint

Fig 3 Barrier Preventing Adoption of Solar Energy

- *Government Policies and Subsidies are Sufficient to Promote Solar Energy Adoption?*

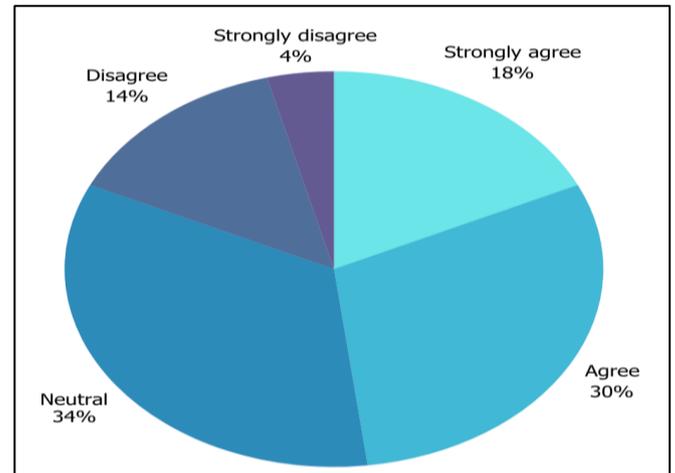✓ Strongly agree
✓ Agree
✓ Neutral
✓ Disagree
✓ Strongly agree

Fig 4 Policies and Subsidies are Sufficient to Promote Solar Energy Adoption

- *How Would you Rate Your Awareness of Solar Energy?*
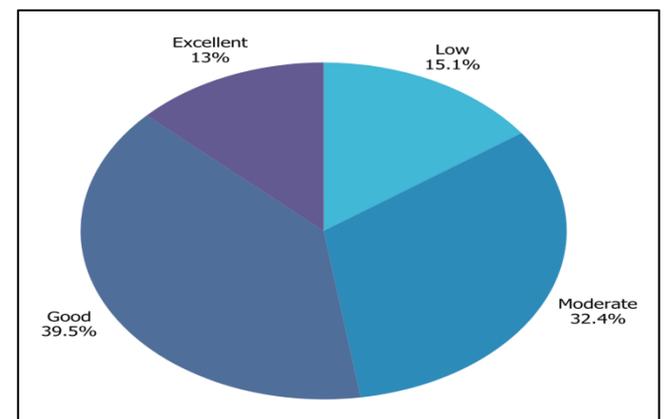
✓ Very low
✓ Low
✓ Moderate
✓ Good
✓ Excellent

Fig 5 Awareness Rate Among General Public

- *Which Factor is Most Important for You When Considering Solar Energy for Your Home?*

✓ Cost and affordability
✓ Long term savings
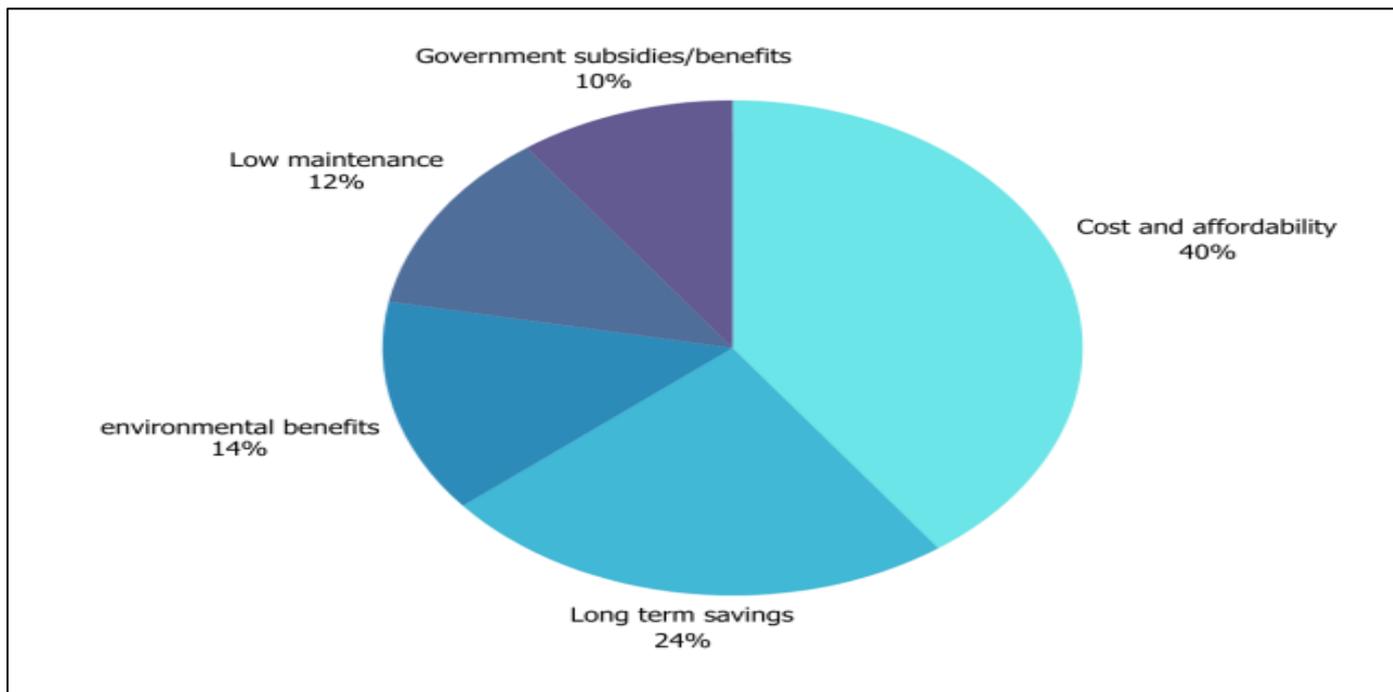✓ Environmental benefits
✓ Low maintenance
✓ Goverment subsidies/benefits

Fig 6 Most Important for You When Considering Solar Energy for Your Home

- *What Do You Think is the Biggest Advantage of Solar Energy?*

✓ Reduces electricity bills

✓ Environment friendly
✓ Low operating cost
✓ Increase property value
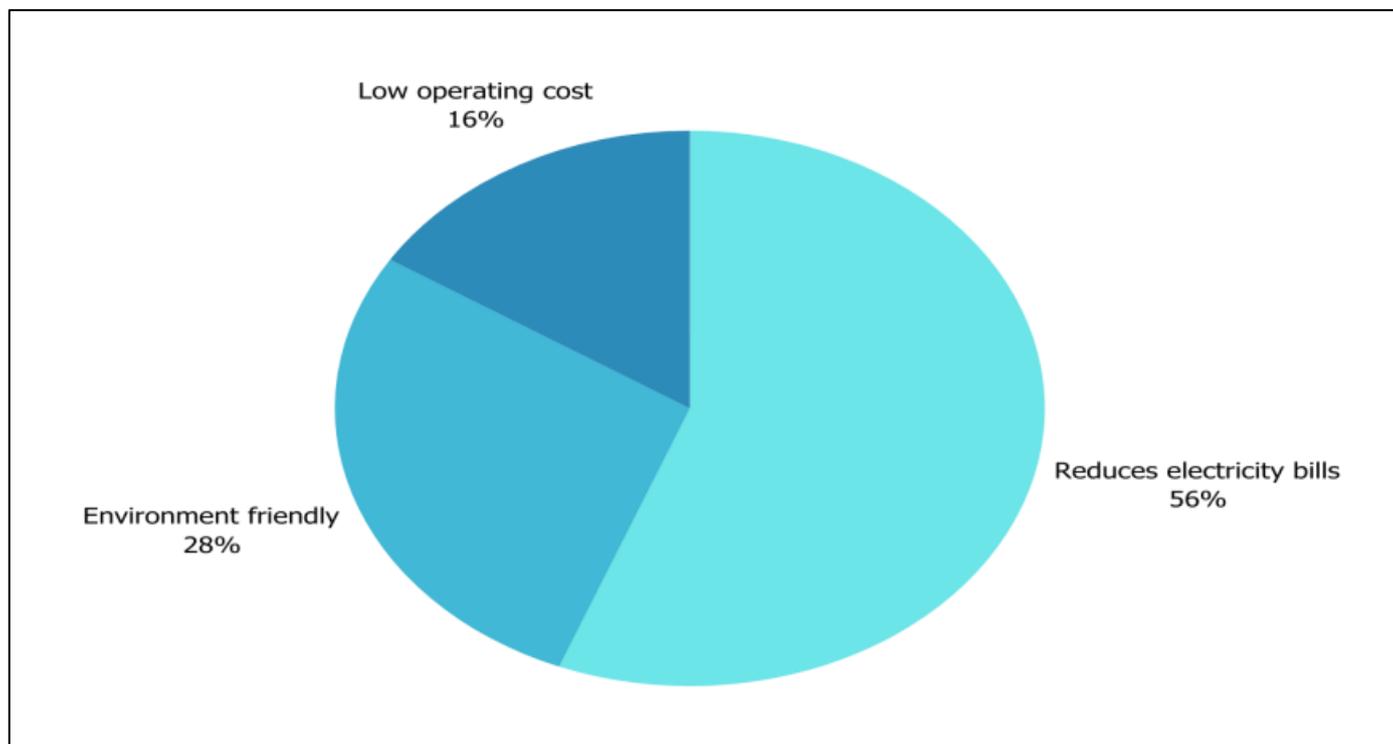

Fig 7 Biggest Advantage of Solar Energy

- *Approximately How Much Do You Think Solar Energy Can Reduce a Household's Electricity Bill?*

✓ 0-20%

✓ 20-40%
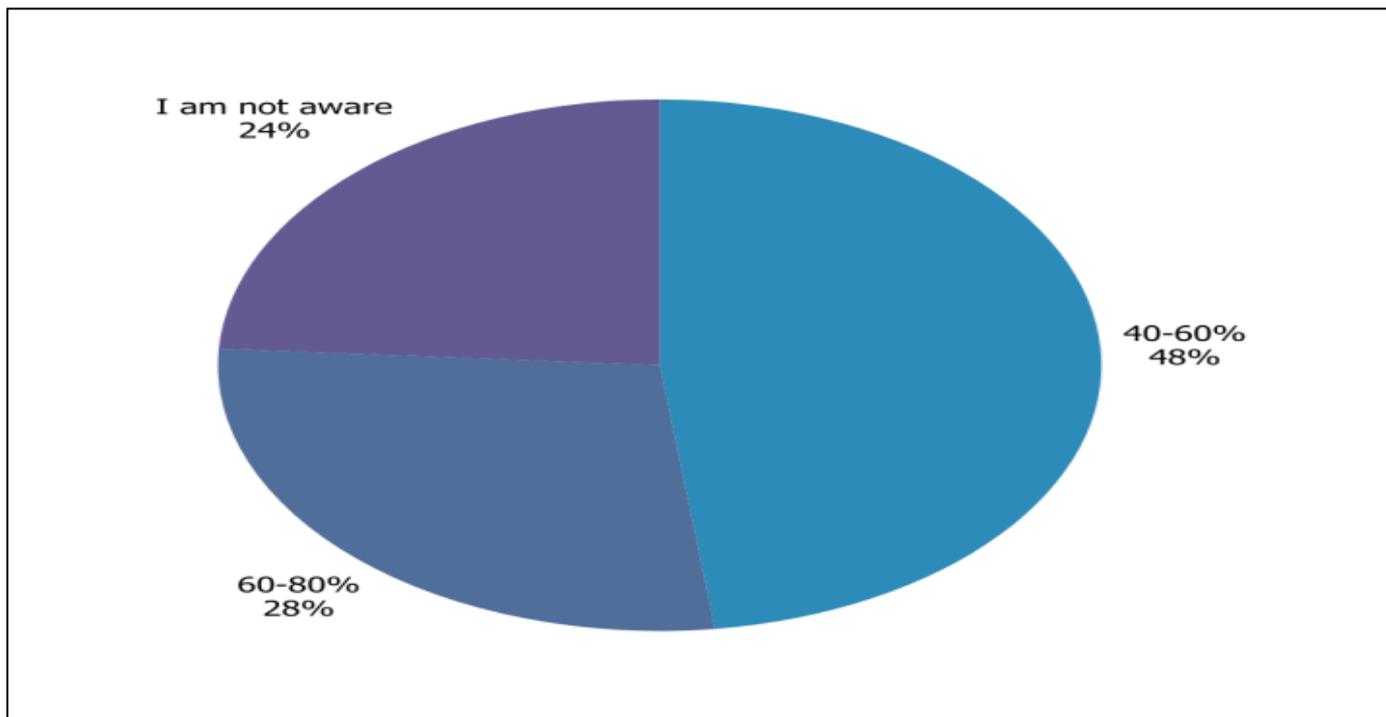✓ 40-60%
✓ 60-80%
✓ I am not aware

Fig 8 Can Solar Energy Reduce a Household's Electricity Bill?

- *Which Solar Products Do You Think are Most Useful for Households?*

✓ Rooftop solar panels

✓ Solar water heaters
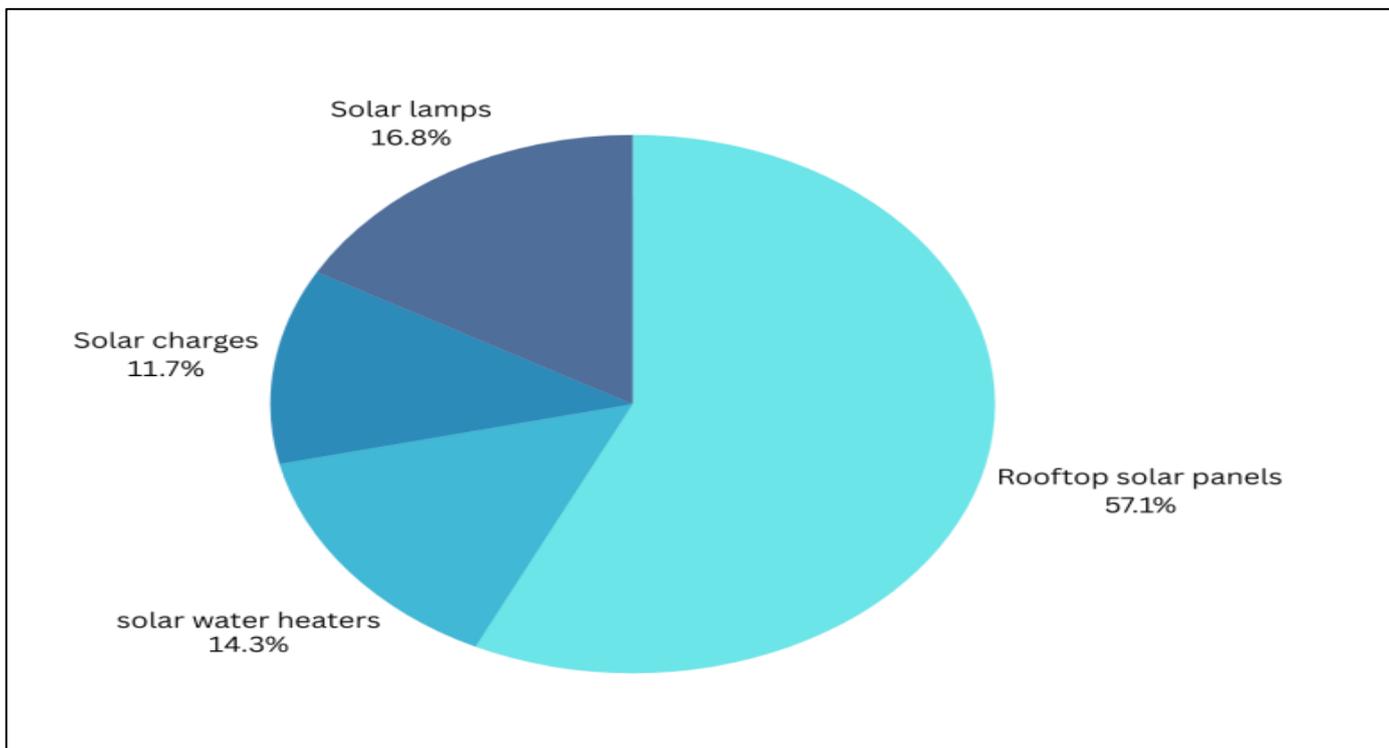✓ Solar charges
✓ Solar lamps

Fig 9 Solar Products Do You Think Are Most Useful for Households

- *What Would Encourage More Families to Adopt Solar Energy?*

✓ Lower installation cost

✓ More government subsidies
✓ Easy financing/EMI options
✓ Better awareness programs
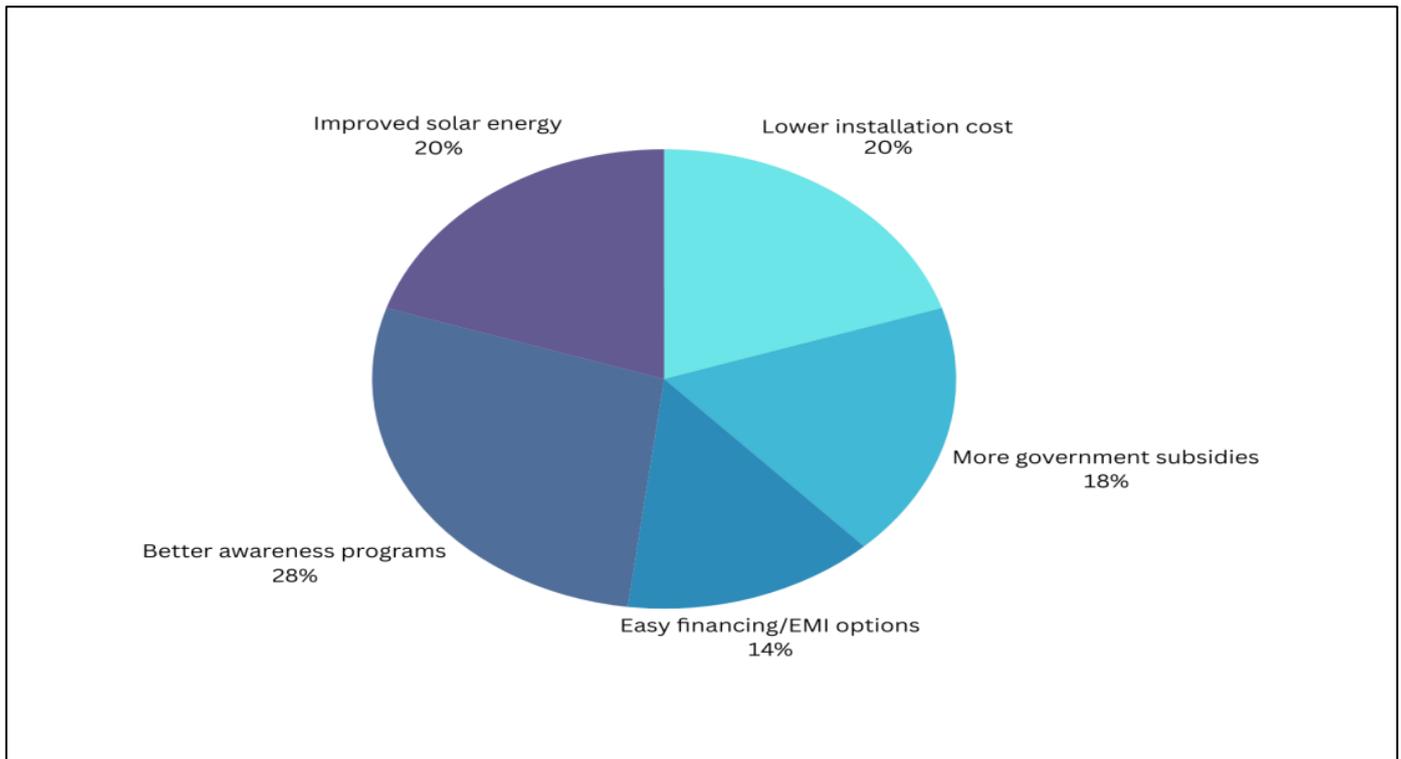✓ Improved solar technology

Fig 10 People Interested on Adopting Solar Energy

IV. MATHEMATICS INVOLVED IN SOLAR PANEL FIXATION

➢ *Solar Radiation and Units*

- Solar radiation is measured in watts per square metre (W/m²).
- Solar Intensity = energy/area*time
- In India, average solar radiation ranges between 800–1000 W/m².
- Daily solar energy received is approximately 4–7 kWh/m²/day, making India highly suitable for solar power generation.

➢ *Angle Tilt (Inclination Angle)*
    To maximize energy, solar panels must face the sun at the correct angle.

- *Mathematical Rule:*

✓ Best tilt angle = latitude

- *Seasonal Adjustment:*

✓ Summer Tilt =Latitude-10
✓ Winter Tilt =Latitude+10
✓ This calculation uses geometrical alignment of Earth–Sun angles.

➢ *Direction Fixation*
    India lies in the Northern Hemisphere, where the sun appears in the southern part of the sky.

- *Mathematically, Received Radiation Depends on the Cosine of the Angle Between Sunlight and Panel Surface:*

✓ $I = I\_0 \backslash Cos\ \theta$
✓ To maximize, the panel must face true south.
✓ Thus, south-facing panels receive maximum sunlight throughout the year.

➢ *Area Required to Fix the Panel*

- *Using Mensuration:*
    Area of one panel=2m * 1m =2m^2

- *For N Panels:*

✓ Total area= n*2
✓ This helps in rooftop space planning using area calculation

➢ *Power and Energy Production*

- *If Each Solar Panel Has a Rating of 330 W:*

✓ Total power= 12*330= 3960W =3.96kW
✓ Average sunlight in India = 5 hours/day
✓ Daily energy= 3.96*5= 19.8kWh/day
✓ This uses a linear time–energy model.

➢ *Efficiency Calculation*

- *Efficiency is Calculated Using Percentage:*

✓ n= Output Power/Input Solar Power*100

- *If:*

✓ Input = 2*900=1800W
✓ Output = 360W
✓ n= 360/1800*100=20%

➢ *Shadow Calculation*

- (Direct application of trigonometry from your notes)
- Shadows reduce panel efficiency and must be mathematically avoided.
- Shadow length= Height of the object/tan(sun elevation angle)

➢ *Conclusion*

Solar panels must be installed more than 7 m away to prevent shading losses.

➢ *Electricity Bill Variation (Before and After Installation)*

- *Monthly Solar Generation:*

✓ 19.8*30=594 units

- *If Original Consumption = 600 Units:*

✓ Remaining Grid Usage = 600 - 594 = 6 units
✓ Thus, solar panels reduce electricity bills by more than 95%, proven mathematically.

➢ *Lifespan of Solar Panels*

- *Calculation Formula:*

Remaining efficiency (%) =100- (Degradation rate * Years)

- *Given:*

✓ Initial efficiency = 100%
✓ Average degradation = 0.5% per year

- *Formula:*

✓ Remaining efficiency = $100 - (0.5 \times$ number of years)
✓ APPLICATIONS / REAL-LIFE USES
✓ Rooftop solar planning using area and angle calculations
✓ Avoiding shading using trigonometric shadow analysis
✓ Estimating household energy needs using kWh calculations
✓ Cost optimization using unitary method
✓ Designing solar farms using geometry and statistics

➢ *Result*

- Optimal tilt angles increase energy output significantly.
- Shadow analysis prevents major efficiency loss.
- India's high solar radiation ensures reliable energy generation.
- Mathematical modeling confirms solar energy is cost-effective and sustainable.

Optimal tilt angles play a crucial role in improving the performance of solar panels. When solar panels are placed at the correct tilt angle, they receive maximum sunlight throughout the day. This helps the panels absorb more solar radiation and convert it into electricity more efficiently. In countries like India, adjusting the tilt angle according to the latitude and seasonal sun position can significantly increase the total energy output of a solar power system.

Shadow analysis is another important factor in solar energy systems. Even a small shadow from nearby buildings, trees, or poles can reduce the efficiency of solar panels. By conducting proper shadow analysis before installation, engineers can identify potential obstacles and place the panels in positions where sunlight is not blocked. This prevents major energy loss and ensures continuous power generation.

India receives high levels of solar radiation for most of the year, making solar energy a reliable and sustainable source of electricity. Mathematical modeling helps researchers analyze system performance, predict energy production, and confirm that solar power is both cost-effective and environmentally friendly in the long term.

V. DISCUSSION

This study shows that solar energy systems rely greatly on mathematics for proper design and efficient performance. Mathematical concepts such as trigonometry, algebra, geometry, and averages play an important role in planning and operating solar power systems. Trigonometry helps in calculating the correct tilt angle and orientation of solar panels so that they receive maximum sunlight during the day. Geometry is used to measure panel area, spacing between panels, and the layout of the solar installation. Algebra helps engineers create formulas and models to estimate energy production and system performance. Averages are useful in analyzing solar radiation data collected over different days, months, and seasons.

Through mathematical analysis, engineers can reduce energy loss caused by improper placement or shading. It also helps in predicting the amount of electricity that will be generated over time. This ensures that solar projects are economically feasible and efficient. Without the support of mathematics, solar energy planning would lack accuracy, leading to poor performance and reduced sustainability.

➢ *Limitations of the Study*

- Assumes constant sunlight hours.
- Weather variations are not included.
- Efficiency loss due to dust and aging is ignored.
- Advanced calculus-based models are not used.

VI. CONCLUSION

Mathematics is essential in the planning, design, and improvement of solar energy systems. Different branches of mathematics help engineers and researchers understand how to capture and use sunlight effectively. Geometry is used to

calculate the size, shape, and arrangement of solar panels so that they can cover the required area efficiently. Trigonometry helps determine the best angle and direction for placing panels so they can receive the maximum amount of sunlight throughout the day and across different seasons. Algebra is useful for building formulas and models that estimate how much electricity a solar system can generate under different conditions. Arithmetic calculations are also used to measure daily energy production, system efficiency, and overall costs.

These mathematical methods make it possible to analyze solar radiation accurately and predict system performance. As a result, energy losses can be reduced and efficiency can be improved. Mathematics also supports proper financial planning by helping estimate installation costs and long-term savings. Through these calculations, solar energy becomes a practical, dependable, and sustainable power source.

RECOMMENDATIONS

Calculus plays an important role in improving solar energy systems, especially in real-time energy optimization. Using calculus, engineers can analyze how sunlight intensity changes throughout the day and determine the best operating conditions for solar panels. By studying rates of change and variations in solar radiation, systems can be adjusted continuously to produce the maximum possible energy.

Statistical models are also used to predict yearly energy production. By analyzing past weather data, sunlight hours, and seasonal patterns, statistical methods help estimate how much electricity a solar power system will generate over a year. These predictions are useful for planning energy supply, estimating financial returns, and managing long-term performance.

Artificial intelligence further enhances solar efficiency through mathematical algorithms used in smart solar tracking systems. These algorithms allow panels to automatically adjust their direction to follow the sun's movement, increasing energy capture.

In addition, 3D geometric modelling helps design efficient rooftop solar installations by analyzing roof shape, angle, and available space. Integrating solar data into smart grid systems allows better monitoring, energy distribution, and overall management of renewable power resources.

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