Empowering Sustainability: A Comprehensive Analysis of Sarishabari Engreen Solar Power Plant—Bangladesh's Pioneering Grid-Connected Solar Endeavor

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Abstract - *Energy is the cornerstone of contemporary society and a fundamental necessity for achieving sustainable progress. Solar power plants are increasingly important in energy production due to their clean and renewable attributes. Within this context, an advanced solar power plant is defined by its utilization of panels operating on the principles of photovoltaics. We conducted an analysis of the performance ratio, a crucial component of energy efficiency, for the Engreen Sarishabari Solar Plant Ltd. This solar facility, a 3 MW grid-connected solar PV power plant located in Sarishabari, Jamalpur, Bangladesh, was subject to a comprehensive economic evaluation as part of our study. Additionally, we evaluated the impact of the 3 MW grid-connected solar PV power plant on the environment, the power system of Sarishabari upazila, and the local people. The analysis of the solar power plant was conducted employing PVsyst software, integrating data provided by plant officials for a comprehensive and accurate assessment. As a result, the annual power plant performance is around 71%. The installation cost of the power plant was 7,012,823 USD. The average annual energy production is 3845 MWh. The cost per KWh of energy generation is 0.1048 USD, and the payback period is 9.6 years.*

Keywords*: solar power plant, photovoltaic, PVsyst, economic analysis, Impact on environment.*

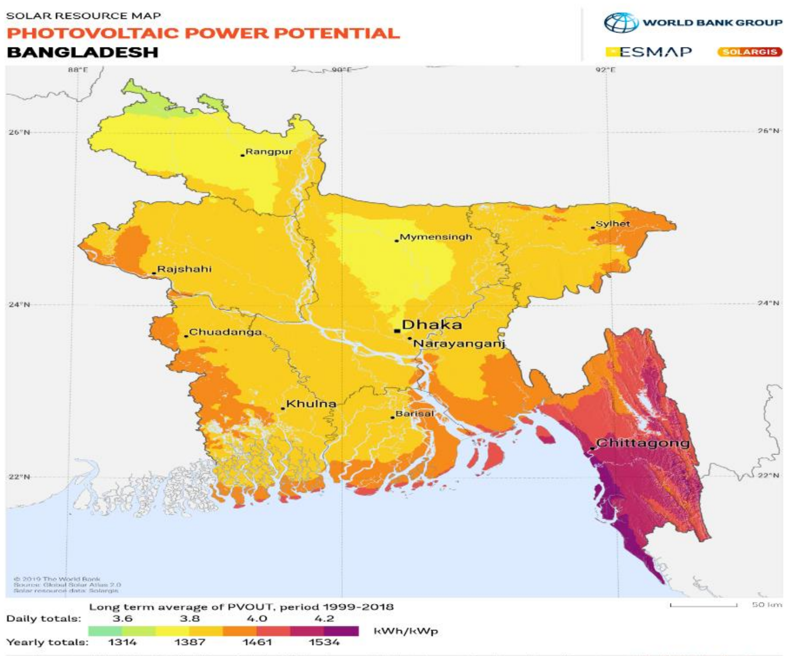
I. INTRODUCTION

The escalating demand for energy, propelled by societal progress and industrial advancements, necessitates the exploration of two primary sources: non-renewable energies and renewable energies. Non-renewable sources, such as fossil fuels, contribute to elevated carbon and greenhouse gas emissions, exerting immediate repercussions on both human life and the ecosystem. With dwindling fossil fuel reserves, the imperative for renewable energy sources has surged as a viable alternative.

Solar energy emerges as a paramount contender in the realm of renewable energy, showcasing superiority in both cost-effectiveness and efficiency. Bangladesh, geographically well-positioned, boasts a substantial potential for harnessing solar irradiation to generate electricity. The country receives an estimated annual solar radiation of 1,900 kWh/m2, translating to a daily range of 4 to 6.5 kWh/m2. Notably, Bangladesh experiences an average of 6.69, 6.16, and 4.81 sunshine hours during winter, summer, and monsoon,

respectively. Throughout the country, all corners receive 4-6 watts of solar radiation per square meter, with a noticeable increase in sunshine during summer due to the sun's higher altitude. Bangladesh's geographical location and weather conditions create an optimal environment for solar power generation. According to the National Renewable Energy Laboratory (NREL), Bangladesh demonstrates a remarkable solar potential of 240,000 MW, assuming a mere 1.5% utilization of the country's total land. This underscores the promising prospect of leveraging solar energy as a pivotal component in meeting Bangladesh's burgeoning energy needs. Since 2017, there has been a noteworthy surge in both investment and research and development (R&D) activities in the realm of solar energy in Bangladesh. This substantial increase in investments has catalyzed a concerted focus on research pertaining to efficiency and optimization within the solar energy sector. R&D entities, including both companies and universities, are delving into a comprehensive exploration of numerous variables. These variables encompass critical factors such as sunshine duration, radiation angles, temperature, humidity, wind patterns, precise location coordinates, solar panel types, and inverter efficiency.

This heightened scrutiny reflects a commitment to understanding and enhancing the performance of solar energy systems in the specific context of Bangladesh. The intricate investigation into these diverse factors is instrumental in refining the design, deployment, and operation of solar power installations. This collaborative effort between R&D entities and academic institutions underscores the growing acknowledgment of the importance of tailoring solar energy solutions to the unique environmental conditions and requirements of the region. As a result, these endeavors contribute not only to the advancement of solar technology but also to the overall sustainable development goals of the country. Bangladesh has pledged to generate 40% of its electricity from renewable sources by 2041. This would result in a 16 GW RE capacity (target of 30%) in 2031 and a 40 GW RE capacity (target of 40%) in 2041. Renewable sources currently contribute 3.7% to the total energy mix, with solar energy accounting for approximately 75% (or 2.8% of the total energy mix). The state prioritizes utilizing power generated from renewable sources over non-renewable sources. Government officials have scheduled multiple solar projects with a combined capacity of over 3 GW for the upcoming years. In this study, the efficiency of the Engreen Sarishabari Solar Plant Ltd. was investigated. It stands as the first grid-connected solar PV power plant in Bangladesh, and its engineers and designers encountered numerous challenges due to a lack of experience. The primary objective of this study is to facilitate future energy investments through a thorough assessment of the plant. By undertaking a comprehensive evaluation, the study aims to provide invaluable guidance to potential investors, contributing to more precise planning and project design. The overarching goal is to empower investors with the insights and information necessary to make informed decisions, ultimately fostering the development of sustainable and well-optimized energy projects. Although there is a scarcity of research in this field in our country, we conducted efficiency evaluations under various conditions. This study seeks to fill this gap and make a significant contribution to the missing solar photovoltaic (SPP) efficiency studies. We calculated the performance ratio (PR) as a component of energy efficiency and performed an economic analysis. Plant officials provided the SPP cost after selecting the plant. The PVsyst program was used to determine hourly, daily, and monthly sunshine durations, as well as solar radiation, in accordance with the aims and objectives stated in the study. The solar energy maps of Bangladesh are shown in Figure 1.



II THE BACKGROUND OF ENGREEN SARISHA SOLAR PLANT LTD

The Engreen Sarishabari Solar Plant, located in Sarishabari, Jamalpur, Bangladesh, is a significant venture spearheaded by Engreen Sarishabari Solar Plant Ltd. The project, situated on an 8-acre site leased from the Bangladesh Power Development Board (BPDB), underscores the country's commitment to harnessing renewable energy sources. With GPS coordinates at 24°46'19" NL & 89°50'37" EL, the solar photovoltaic power plant boasts a capacity of 3.3 MW DC and 3 MW AC. The construction, undertaken by the company, comes with a project cost of 54 crores and was initiated after the signing of the contract on February 18, 2015. Commercial operations commenced in August 2017, marking a significant milestone. The plant operates on a grid-tied system, with an evacuation voltage of 33 KV.

The tariff charges, set at 0.1897 US cents/KWh or 14.7491 BDT/KWh, are governed by a Power Purchase Agreement (PPA) between the company and BPDB. The payment methodology outlines obligations upon achieving commercial operation, including the purchase of energy during testing. The Land Lease Agreement with BPDB dictates an annual payment of 10 lacs BDT for utilizing the site. The project, designed for a 20-year lifespan, places responsibility on the company for ownership, operation, and maintenance during this period, with post-term arrangements subject to PPA agreements. The Engreen Sarishabari Solar Plant stands as a testament to Bangladesh's strides in sustainable energy practices, contributing to the nation's energy landscape while adhering to ethical, contractual, and environmental considerations.

Figure 1 Engreen Sarishabari Solar power plant ltd

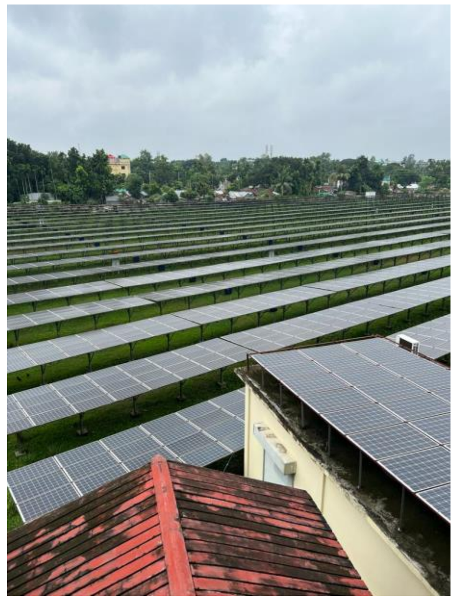


Figure 2 Engreen Sarishabari Solar power plant ltd

III. MATERIAL AND METHODS

The analysis of the solar power plant involved the utilization of PVSyst software. Within the software, precise coordinates of the designated area were input, enabling the determination of essential parameters such as radiation values, average temperature, wind speed, and humidity values. Subsequently, key components of the power plant—specifically, the photovoltaic panels and inverters—were carefully chosen. The quantities and specifications of these components were obtained directly from plant officials, ensuring accurate representation and integration into the analytical framework. This meticulous process within PVSyst forms the foundation for a comprehensive evaluation of the solar power plant's performance and efficiency. Additionally, details regarding other elements and total investments were collected and inputted. Upon completion of the design phase, the monthly energy production data for the power plant, boasting an installed capacity of 3.3 MW was computed. and the

average Performance Ratio (PR) of the facility was calculated. PR is determined by the following formula:

PR=Egrid/Ginc .Pnom

Where:

Egrid is the available energy (or energy output) from the solar power plant.

Pnom is the installed power under standard conditions, typically representing the nominal or rated capacity of the solar power plant.

Ginc is the global incident solar radiation, which is a measure of the total solar energy received per unit area.

In this study, the PVSyst software was utilized to analyze both the total electricity generation and payback period.

The results were then compared with the official data from the power plant. Additionally, the environmental impact of the power plant was assessed using the software. Meanwhile, the impact of the power plant on the power system in Sarishabari, Jamalpur, was gathered from government official websites.\

3.1 Design of solar power plant

In the design of a solar power plant, achieving maximum efficiency throughout the year requires careful selection of panel tilt angles and azimuth values. For the Engreen Sarishabari power plant, the Solar World's SUNMODULE PLUS SW 285 MONO, a product of the German company Solar World, was meticulously chosen as the solar panel. The inverter used for this setup was SMA Solar Technology AG's Sunny Tripower, model: STP 25000TL-30.

Table 1. Orientation of PV array

Tilt angle	30^0
Azimuth	0

Table 2. Technical data of SUNMODULE PLUS SW 285 MONO

***STC: 1000W/m², 25 °C, AM 1.5**

Parameter	Variable	Value
Rated Max. Power	Pmax	285 Wp
Open Circuit Voltage	Voc	39.7 V
Rated Voltage	Vmpp	31.3 V
Short Circuit Current	Isc	9.84 A
Rated Current	Impp	9.20 A
Module Efficiency	Hm	17%

Table 3. Technical data of Sunny Tripower Inverter

Input dc	
Max. generator power	45000 Wp
DC rated power	25550 W
Max. input voltage	1000 V
MPP voltage range / rated input voltage	390 V to 800 V / 600 V
Min. input voltage / start input voltage	150 V / 188 V
Max. input current input A / input B	33 A / 33 A
Max. DC short-circuit current input A/input B	43 A / 43 A
Number of independent MPP inputs / strings per MPP input	2 / A:3; B:3
Output AC	
Rated power	25000 W
Max. AC apparent power	25000 VA
AC nominal voltage	3 / N / PE; 220 V / 380 V 3 / N / PE; 230 V / 400 V 3 / N / PE; 240 V / 415 V
AC voltage range	180 V to 280 V
Max. output current / Rated output current	36.2 A / 36.2 A
AC grid frequency / range	50 Hz / 44 Hz to 55 Hz 60 Hz / 54 Hz to 65 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V

The design details of Engreen Sarishabari Solar Plant Ltd are shown in table 4.

Table 4.Design details

Installed capacity	3000 KWh
Module Nom. power (Wp)	285
Total number of modules	11580
Nominal (STC)	3300 kWp
Modules	579 string x 20 In series
Inverter Nom. Power	25.0 kWac
Number of inverters	123
Inverter Total power	3075 kWac

IV. RESULTS AND DISCUSSION

4.1 Energy analysis

The Engreen Sarishabari Solar Plant Ltd collected precise data using PVSyst software, which included radiation levels, ambient temperature, loads, energy output from the photovoltaic (PV) system, energy supplied to the grid, and power plant performance ratio.

Tables 5 display the monthly distribution of data obtained from the power plant for the city. To provide more detailed information, Table 7 offers a thorough summary of the yearly energy production and power plant cost and profit analysis for the Sarishabari facility. To provide a clearer visual depiction, Figure 4 and Figure 5 visually demonstrate the data acquired from the region, offering perceptive analyses of energy production and power plant efficiency.
This collection of tables and figures is a valuable resource for understanding the complex dynamics of the plant's energy production and efficiency. It helps to gain a comprehensive understanding of the plant's operational performance throughout the year.

Normalized productions (per installed kWp) and performance ratio

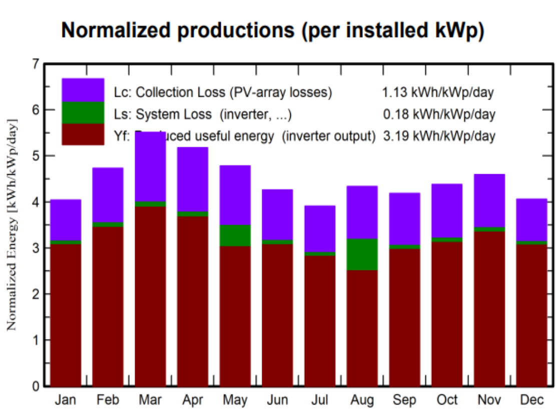


Figure 4

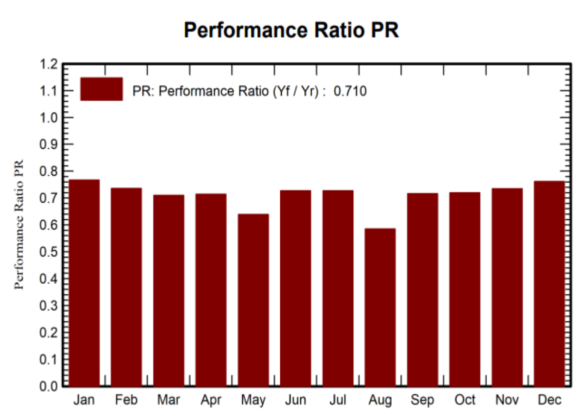


Figure 5

Table 5. Data obtained at the Engreen Sarishabari Solar Plant Ltd

	Global horizontal irradiation	Horizontal diffuse irradiation	Ambient temperature	Global incident in coll. plane	Effective global, corr. for IAM and shadings	Effective energy at the output of the array	Energy injected into grid	Performance ratio
January	101.7	60.92	17.09	125.3	118.5	325643	317319	0.767
February	113.0	61.56	20.89	132.4	125.6	330567	321462	0.735
March	156.5	81.09	25.56	170.7	161.8	411960	400363	0.711
April	154.6	92.26	27.34	155.3	146.7	376816	366355	0.715
May	157.3	96.91	28.20	148.3	139.7	360251	312492	0.639
June	138.3	93.00	28.15	127.8	120.1	316011	306776	0.727
July	130.6	87.80	28.62	121.3	113.8	299900	291116	0.727
August	138.3	90.07	28.78	134.5	126.6	329299	259533	0.585
September	121.8	73.26	28.01	125.5	118.3	305858	296939	0.717
October	121.6	73.14	27.14	135.8	128.6	331825	322352	0.719
November	110.7	57.23	22.90	137.7	130.4	343299	333980	0.735
December	99.2	57.26	18.90	125.8	118.9	324417	316100	0.762
Year	1543.7	924.50	25.15	1640.4	1548.9	40558446	3844789	0.710

4.2 Economic analysis

The requirements for cost analysis, including unit element costs and total costs, are outlined in Table 12. The construction of the plant commenced in 2015, and the total cost of installing the power plant was 540,000,000 BDT. At that time, the exchange rate was 1 USD = 77 Taka. Following this analysis and converting the BDT to Taka, the total plant installation cost amounted to 7,012,823 USD.

Item	Quantity	Unit cost (USD)	Total cost (USD)
PV modules	12,200	324	3,952800
Supports for modules			649,350
Inverters	125	3701	462,625
Transformers	3	6493	19479
Cables, computers, software, and measuring equipment			714,285
Field leveling			649,350
Civil construction including a residential building			259,740
Labor cost			259,740
Fence, cameras, and thunder protection			45,454
Power plant installation			7,012,823

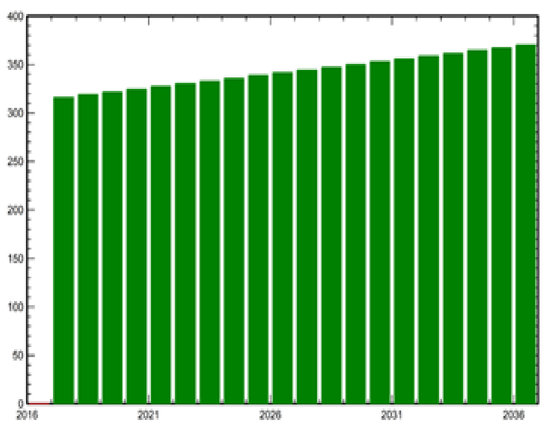
Table 6: installation cost analysis

For the economic analysis, income calculations were based on factors such as annual electricity production, production cost, maintenance expenses, loan interest, and the selling price of the produced electricity. The annual income values shown in the **table 7**

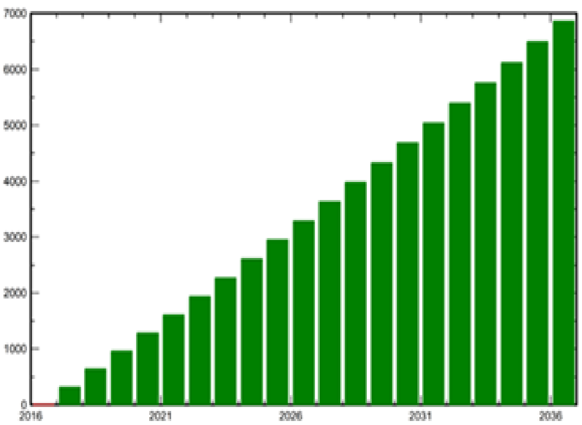
Detailed Financial Analysis

Produced energy	Cost of produced energy	Feed in tariff	Electricity sale	Payback period	Return on investment	Cumulative profit
3845 MWh/year	0.1048 USD/kWh	0.18970 USD/kWh	15,301,258 USD	9.6 years	125.9%	6,172,038

Yearly net profit (KUSD)



Cumulative cashflow (kUSD)



V. IMPACT ANALYSIS

5.1 THE IMPACT OF THE ENGREEN SOLAR POWER PLANT LTD ON THE POWER SYSTEM OF SARISHABARI AND THE LOCAL RESIDENTS

According to Mofazzal Hossain, the executive engineer of the division, there is a demand for 6,000 kilowatts of electricity per hour from a total of 17,514 consumers. These consumers include residents, educational institutions, health and diagnostic centers, business establishments, banks, and various offices within the division. The division has the capacity to allocate a range of 4,000 to 4,500 kilowatts per hour to the consumers.

According to Mofazzal, consumers had to tolerate a daily load-shedding period of seven to eight hours until the solar plant started generating electricity for the division. Nevertheless, the introduction of the solar plant has resulted in a reduction of load-shedding to a duration of two to three hours. This is due to the plant's capacity to provide an average of 1,000 kilowatts per hour to the sub-station. This has allowed consumers to receive electricity with minimal interruption.

In addition, the power plant has improved grid stability. The table derived from the plant demonstrates a strong correlation between grid outage and solar energy production. The data clearly demonstrates that there is a notable decrease in grid instability as solar power generation increases.

Table 8. Source: ENGREEN SARISHA SOLAR PLANT LTD (Yearly Comparetion Report)

MONTH	2022			
	IRR	GRID FAIL HOUR	MINIMUM Power KWH	NET OUTPUT
JAN	105.48	5.050	239,228.64	**294,938.40**
FEB	116.53	2.500	264,290.04	**329,160.00**
MAR	149.45	1.330	338,952.60	**422,108.80**
APR	122.77	22.130	278,442.36	**325,845.60**
MAY	122.87	24.530	278,669.16	**334,471.20**
JUN	97.70	11.620	221,583.60	**273,214.80**
JUL	131.90	4.064	299,149.20	**375,052.80**
AUG	131.38	7.366	297,969.84	**368,151.60**
SEP	108.05	4.133	245,057.40	**306,745.20**
OCT	129.60	11.783	293,932.80	**346,390.80**
NOV	135.080	1.071	306,361.44	**384,182.40**
DEC	103.43	3.400	234,579.24	**293,235.60**
TOTAL	**1454.24**	**98.977**	**3,298,216.32**	**4,053,497.20**

5.2 THE IMPACT ON THE ENVIRONMENT

The solar plant contributes to maintaining a pollution-free environment by mitigating both air and sound pollution. It harnesses power from sunlight, converting light energy into electrical energy through monocrystalline cells in the solar panels. In this conversion process, the panels actively absorb carbon dioxide gas, a primary contributor to the greenhouse effect. Each unit of power generation enables the solar panels to absorb a notable 78 grams of carbon dioxide. With an average production of 12,000 units from sunrise to sunset (over a span of 12 hours), the panels effectively absorb 936 kilograms of carbon dioxide on a daily basis, accumulating 28.08 tonnes monthly and an impressive 336.96 tonnes annually. Furthermore, the power generation process utilizing solar panels eliminates sound pollution, thus earning the designation of "green energy." In stark contrast, conventional fossil-fueled power plants release substantial amounts of carbon dioxide, contributing to air pollution that poses a threat to living organisms.

VI. FUTURE SCOPE

This research has a great deal of potential for the future, including continued advancements in solar technology and efficiency, stronger energy storage solutions, grid integration innovations to support higher solar energy integration, and research into hybrid renewable systems. Furthermore, there are research opportunities to assess the long-term environmental effects of solar power plants and improve sustainability practices. Understanding how changing energy laws and regulations impact the growth of the solar industry is equally important. This study represents a first step toward addressing these issues and advancing solar power's sustainable development, which will help create a more resilient and cleaner energy future.

VII. CONCLUSION

Engreen Solar Power Plant Ltd holds immense significance in the green energy initiative in Bangladesh. Following the establishment of the power plant, many companies have come forward and invested in solar energy. The engineers and planners associated with Engreen are actively disseminating the knowledge gained through their work at the power plant. The main components of a solar power plant are solar modules and inverters. At the Engreen power plant, SUNMODULE PLUS SW 285 MONO panels and Sunny Tripower Inverters were utilized. In this study, the same elements were employed for simulation, along with other data identical to that of the power plant, to ensure the most accurate results. The project's expected lifetime is 20 years, during which it is anticipated to produce 3,844,789 kWh per year. Over this period, the project is projected to yield a profit of 6,172,038 USD through the sale of electricity. Beyond economic gains, the power plant significantly enhances grid stability and reduces power outages. Moreover, it plays a crucial role in fostering the prosperity of the local community across various business sectors. Bangladesh, being one of the countries affected by global warming, benefits from this green project as it does not emit any greenhouse gases, thereby contributing to environmental preservation.

DECLARATION

I hereby certify that the research article titled "Empowering Sustainability: A Comprehensive Analysis of Sarishabari Engreen Solar Power Plant—Bangladesh's Pioneering Grid-Connected Solar Endeavor" is my original work and has not been previously published. All sources of information utilized in this research have been duly acknowledged and credited in the reference list. This study was conducted ethically, adhering to all relevant laws and regulations. I obtained informed consent from all study participants, and all collected data was treated with the utmost confidentiality, exclusively for research purposes. I diligently mitigated constraints through meticulous data collection, analysis, and interpretation. Any errors or omissions in this work are my own, and I accept full responsibility for its content.

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