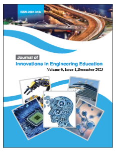

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# Analysis of solar power Return-on-Investment for hospitals in Nepal with Pressure Swing Adsorption (PSA) Oxygen plants - A case study of provincial hospital, Surkhet, Nepal

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Abstract

This paper assesses the effects of implementing a 150 kWp solar power system with Pressure Swing Adsorption (PSA) oxygen production system at Surkhet Hospital in Nepal. In order to address the crucial need for medical oxygen at Provincial Hospital, Surkhet in Karnali province, a PSA oxygen production plant has been installed. However, these plants consume a significant amount of power. Due to the unreliable grid electricity supply, hospitals were compelled to rely on costly diesel fuel for energy. In an effort to alleviate this issue, the World Health Organization (WHO) implemented a 150 kWp solar power plant at Surkhet Provincial Hospital. In this context, this study aims to assess the impact of solar power and determine the return-on-investment (ROI) for hospitals in Nepal equipped with PSA oxygen plants.Analyzing hospital data, it was found that over a three-year period (2018–2021) , the average grid electricity consumption stood at 238,048 kWh. More than half of this energy usage occurred during daylight hours, indicating a potential for substituting grid energy with solar power. The introduction of solar panels led to a decrease in diesel generator consumption, from 5,864.83 liters per month to 652.72 liters per month, resulting in monthly savings of 712,216.55 Nepalese Rupees. Furthermore, this results in an annual reduction of approximately 121 tons of $CO_2$ emissions that would otherwise be released into the environment.The study examined a range of PSA plants (1 to 200 $Nm^3$/hour) to determine power requirements and evaluated solar energy savings under three Global Horizontal Solar Insolation (GHI) scenarios: low (4 kWh/$m^2$/day), medium (4.5 kWh/$m^2$/day), and high (5.0 kWh/$m^2$/day). The findings highlighted substantial financial benefits. This analysis provided insights into the solar capacity needed for PSA plants throughout Nepal.The financial analysis demonstrated promising returns, with an Internal Rate of Return (IRR) approaching 40% and a discounted payback period of less than three years. The Levelized Cost of Electricity (LCoE) from solar plant is ranging from 8.22 to 6.57 Nepalese Rupees per kWh across varying GHI scenarios. Notably, the solar plant contributed to a noteworthy 38% reduction in overall unit energy costs.



## 1. Introduction

### 1.1. Introduction of province hospital Surkhet

Karnali Province stands as one of Nepal's most remote and underdeveloped regions, with limited government infrastructure offering affordable and high-quality healthcare services. Among these scarce facilities, the prominent one is the Province Hospital Surkhet. It is located in Birendranagar, the provincial capital of Karnali province. It was previously the Mid-Western regional hospital before it was converted to today's form. By a decision of MOHP, GoN the hospital in Surkhet was declared a Regional Level Hospital in the year 2062/11/07(2006/02/19)[1]. The Hospital is currently being expanded to secondary level status, with additional floors to existing buildings and new structures being built.

The Hospital is currently being expanded to secondary

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level status, with additional floors to existing buildings and new structures being built. A new building with a 300 bed capacity has been completed and handed over recently to the Government. On an annual basis, the hospital caters to approximately 82,000 patients, addressing a substantial number of emergencies, with about 14,000 emergency cases treated each year[2].

### 1.2. Pressure Swing Adsorption (PSA) oxygen plant

Medical oxygen is a lifesaving and essential input to healthcare provision. It can be used at all levels of the health system and is crucial for the treatment of COVID-19 and other life-threatening conditions such as severe pneumonia, severe malaria, sepsis, trauma, and complications of birth or pregnancy. It is essential to ensure safe surgical, emergency, and critical care services. An uninterrupted supply of medical oxygen is crucial to provision of high quality hospital care.

With the increased demand for oxygen given the increasing number of Covid-19 cases in 2020-21, the Province Hospital was having a hard time managing the treatment of its patients.

In the initiative of Chief Minister Mahendra Bahadur Shahi, to help ensure reliable supply, a Pressure Swing Adsorption (PSA) oxygen production plants have been installed at Karnali Province Hospital like many other hospitals in Nepal[3].

**Salient Features of Duplex PSA Plant Installed at Hospital**

- Type: Duplex PSA Oxygen Generation System
- Major Components: Rotary Screw Type Air Compressor, Air Dryer, Filtering Unit, High Pressure Oxygen Compressor (booster compressor), Filling Station, Control Panel etc.
- Major Power Consuming System: Main Compressor (OSP-37) 37 kW*2 Nos, 8.5 bar output pressure.
  $O_2$ Compressor (RIX-C 2PS-H 50) 1.125 kW*2 Nos (Oxygen Flow Rate 1.7 to 3.2 $Nm^3$/hr at 150 bar pressure).
  Refrigeration Dryer 1.95 kW*2 Nos.
- Cylinder Filling Capacity: 12.8 cylinder per day per compressor, size of each cylinder is 40 L.
- Power Consumption of Each Unit: 40 kW including the power consumption of control and monitoring accessories.

Energy consumption of PSA plants is significant, with associated financial burden on hospital budgets. To reduce the operating costs of PSA plants, 150 kWp solar

Figure: PSA plant installed at hospital

power generation plants has been installed by World Health Organization (WHO), Nepal to offset the power demand of PSA plants.

### 1.3. Solar power plant at Surkhet province hospital

A 150 kWp solar power plant was successfully commissioned on 26 March 2023 Hospital, Surkhet, in the presence of local representatives[4]. The system support to power the PSA oxygen plant, and also support a wide variety of essential medical and basic information and communication technology equipment. The use of solar energy system also help reduce operational cost by minimizing usage and dependency on diesel required to run the plant, resulting in affordable medical oxygen for the public.

## 2. Methodology adopted

To conduct an impact assessment study, following methodologies were adopted:

**Step-1: Data Collection and Project Overview:**

- The project commenced by gathering pertinent data related to the solar project from the installer company. This encompassed design specifications, technical drawings, and product details.
- Furthermore, the energy production records of the solar project were obtained from the installer company's remote monitoring system and subjected to data analysis.

**Step-2: On-Site Evaluation:**

- A comprehensive site visit was conducted at Surkhet Hospital, during which critical information regarding the installed solar systems was documented.
- This involved observing the layout, operational conditions, and capturing visual documentation

such as images of key components, including the PSA (Pressure Swing Adsorption) plant, Solar Arrays, and Inverters.

**Step-3: Utility Bill Analysis:**

- Information about the utility bill before the installation of solar from the Surkhet Hospital were also collected during visit. That data consist of NEA bill from BS 2076-7(2019-10) to 2080-03(2023-06) as per NEA bill.

**Step-4: Energy Savings Calculation:**

- A thorough analysis of the collected data was performed to quantify the energy savings achieved by the solar installation, comparing grid energy consumption before and after the implementation of the PSA and solar plant.

**Step-5: PSA Plant Sizing:**

- Engineering calculations were carried out to determine the appropriate sizing of the PSA plant, varying between 2 to 200$Nm^3$/h oxygen generation capacity.

**Step -6: Solar System Sizing and Energy Generation Estimation:**

- Sizing of the solar system was aligned with the PSA sizing range (2 to 200$Nm^3$/h oxygen generation capacity). Estimated energy generation was computed for both medium and high annual solar irradiance scenarios.
- A comparative study was undertaken, evaluating three distinct solar power plant scenarios for each PSA plant size: 100%, 150%, and 200% of the PSA plant's power demand.

**Step-7: Financial Assessment:**

- Financial analysis was conducted based on the derived results and encompassed the following parameters:
  - Net Present Value of Project (NPV)
  - Return on Investment (ROI) and Payback Period (simple and discounted)
  - Internal Rate of Return (IRR)
  - Benefit Cost Ratio (B/C)

**Step-8: Preparation of Final Study Report:** Based on the comments and suggestions provided by the WHO, the draft report underwent a revision process. Feedback was carefully integrated to enhance the accuracy, clarity, and comprehensiveness of the report's content.

- Subsequent to incorporating the WHO's comments and suggestions, a final version of the report was meticulously prepared. This version represented a refined and improved representation of the project's methodology, findings, and recommendations.

This concluded the project's lifecycle, ensuring that the comprehensive and refined report was made available to the intended stakeholders.

## 3. Summary of installed solar power generation plant

### 3.1. Salient features of 150 kWp solar project

Table 1 below shows the Salient features of 150 kWp solar project.

### 3.2. General Overview of Solar Plant

The general layout of the system is presented in Figure 1 below. Following are the major equipment:

#### PV array install capacity

The total installed capacity of PV array is 150.420 kWp DC (276 nos of PV Solar Module of 545Wp each)[5].

#### Inverter

The system consists of 110 KW SMA Sunny Tri-Power (STP) on-grid inverters. This unit converts the solar DC Power into three Phase AC Supply. The output of these On Grid Inverter are connected in parallel with AC Connection box and finally connected with 3 phase NEA Grid Line. This generated power is consumed by Hospital and excess energy can also be export to NEA grid Line[5].

#### Mounting system

Ground Mounting GI Structure. The ground mounting structure were installed with a provision for parking under the structures. The ground mount GI Structures are designed to withstand up-to 180km/hour of wind speed and are resistant to earthquake.

#### Other installation materials

DC and AC Cables and Conduits, DC and AC Combiner Boxes, Earthing and Protection units, Voltage Stabilizer (3 Phase/ 200kVA and accessories for Oxygen Plant), 3 phase energy meters, measuring units.

### 3.3. Brief description of the components

#### Solar PV Module

Based on the site visit and information provided by the supplier, the description of solar PV module is as follows:

Table 1: Salient Features of Solar Project at Surkhet Hospital

| Heading | Particulars | Description |
|---|---|---|
| Solar Panel Installation Area | Installation Area | Building premises |
| | Ownership | Government |
| | Topography and Orientation | Plane |
| Solar Resource Potential, Technology, and Project Capacity | Solar Insolation | GHI=4.69 kWh/m$^2$/day |
| | Module Technology | Silicon Mono-crystalline PERC PV module |
| | Installed Capacity | 150 kWp |
| | Plant Capacity | 110.0 kW |
| | DC to AC Ratio | 1.36 |
| | Capacity of Each Module | 545 Wp at STC |
| | Module Efficiency | 21.09% |
| | Total No. of Modules | 276 Nos. |
| | Type of Inverter | Grid-tie inverter |
| | Inverter Technology | String Inverter |
| | Capacity of Each Inverter | 110.0 kW |
| | No. of Inverters | 1 nos |
| | Total Inverter Capacity | 110.0 kW |
| | Inverter Peak Efficiency | 99.0% |
| | Inverter Euro Efficiency | 98.7% |
| Plant Performance | Total De-Rating Factor | 21.8% |
| | Specific Yield | 3.9 kWh/kWp/Day |
| | Performance Ratio | 74.81% |
| | Capacity Utilization Factor | 19.3% |
| Electricity Generation | Estimated Annual Energy Generation | 205,431 kWh/Year ± 5%, First Year |
| Cost | Project Cost | NRs 21,055,000 (without VAT) |
| Financial Overview (Assume: 100% Equity, i=2%pa) | Project IRR 40.3% | Average Return on Equity 39.8% |
| | Payback Period | 2.56 years (discounted) |
| | B/C Ratio | 6.8 |
| | Levelized Cost of Energy | 7.01 NRs/kWh |
| | Nominal Interest Rate | 2% (for government project) |

Figure: Part of PV array mounting structures of 150kWp On-grid solar PV system[5]

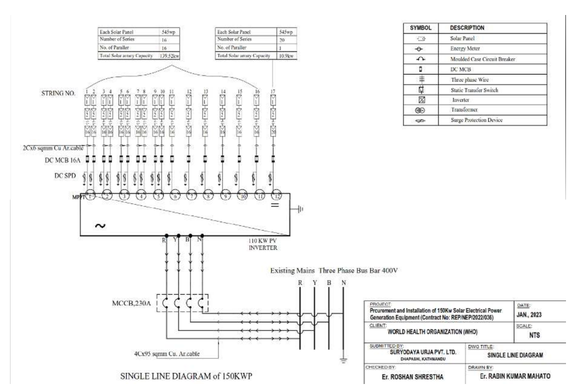



Figure 1: Single line diagram of 150kWp On-grid solar PV system (Source: Suryodaya Urja)[5]

The Solar PV Modules used are high efficiency Mono-crystalline modules made in China by a tier 1 PV module manufacturing company named Jiangsu Seraphim Solar System Co., Ltd. In total 276 nos. of 545 Wp half cut Solar PV modules are used in this system. The manufacturer of the modules provides 25 years power warranty against 20% power loss on all its range of modules. The solar PV modules installed at Province Hospital Surkhet complies with IEC 61215 and IEC61730 international certifications. The installed solar PV modules are certified from renewable energy.

Figure: Images of Solar Array installed at Surkhet hospital[6]

Figure 2: SUNNY TRIPOWER STP CORE 2 installed at site[6]

### On-grid PV inverter

The inverter installed in this project is manufactured by SMA Solar Technology AG, Germany (is a leading global inverter manufacturer) and marketed under brand name 'SUNNY TRIPOWER CORE 2 (MODEL: STP 110-60 Core 2). The Sunny Tripower is a transformer-less PV inverter with 12 MPPT trackers which converts the direct current of the PV array to grid compliant three-phase current and feeds it into the utility grid. The output of the 150.42 kWp solar array is connected to this inverter as shown in Figure 2.

### Voltage stabilizer

PSA oxygen plants require precise control over various components, including compressors, valves, and adsorption beds. Fluctuations in voltage can disrupt these components' functioning, leading to inefficiencies or even shutdowns. Sudden voltage spikes or drops can damage sensitive electronic components within the PSA oxygen plant. Also, the performance of the PSA process depends on maintaining specific pressure and flow rates. Inconsistent voltage levels could lead to variations in these parameters, affecting the quality and purity of the oxygen produced. To overcome these problems, a voltage stabilizer plays a crucial role in ensuring the efficient, reliable, and safe operation of a PSA oxygen plant, particularly in healthcare facilities where consistent oxygen supply is a matter of life and death.

Figure: Voltage Stabilizer installed for PSA plant[6]

A 3 Phase, 200kVA Servo Voltage Stabilizer has been installed in the hospital along with its accessories for Oxygen Plant. The aim of this stabilizer is to continuosly monitor the incomming voltage variations and maintain the required output voltage at all times by doing voltage corrections as and when required. It alows the elimination of overvoltage and voltage drop phenomenon in an electrical network this allowing electrical system to be free of faults and provides desired output voltages.

### Earthing

The earthing system in solar installations is critical for safety, protection against electrical faults, compliance with standards, system performance, and overall operational reliability. It contributes to a safer, more efficient, and long-lasting solar energy system.

In an electrical installation, an earthing system or grounding system connects specific parts of that installation with the Earth's conductive surface as a point of reference.

In this project Early Streamer Emission type lightening arrestor has been used along with combination of DC SPD, Neutral Grounding, Body Earthing and earthing electrode in a pit with bonding/backfill chemical to enhance the conductivity of the ground[5][6]. All of the components are found to be connected in earthing system. The ESE Type lighting arrestor protects the Solar PV Components by intercepting lightning strikes and safely passing their extremely high voltage currents to "ground". Lightning protection systems include a network of ESE (Early Streamer Emission) lightning rods, metal conductors, and ground & electrodes Designed to provide a low & resistance path to ground for potential strikes.

Table 2: Actual energy generation from 150 kWp Surkhet solar project for 8 different sampling days[7]

| Sample Date | Daily Generation kWh/Day | Maximum Power (kW) | Specific Yield (kWh/kWp/Day) |
|---|---|---|---|
| 4/22/2023 | 679.9 | 106.02 | 4.53 |
| 4/25/2023 | 675.3 | 107.2 | 4.50 |
| 5/5/2023 | 708.2 | 110.04 | 4.72 |
| 5/28/2023 | 641.4 | 99.92 | 4.28 |
| 6/23/2023 | 537.7 | 102.03 | 3.58 |
| 6/26/2023 | 517.5 | 107.93 | 3.45 |
| 7/6/2023 | 422.1 | 97.31 | 2.81 |
| 8/15/2023 | 504.1 | 96.4 | 3.36 |
| All Average | 585.78 | 103.36 | 3.91 |

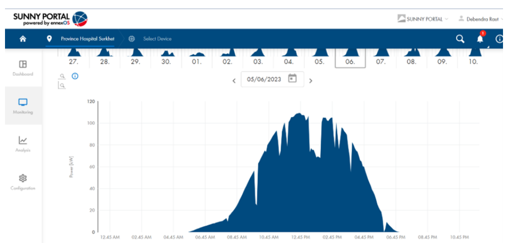


Figure 3: Remote Monitoring System[7]

### Remote monitoring

For the purpose of remote monitoring, the new Sunny Portal powered by ennexOS has been used in this project. Data can be monitor, manage and grid compliant power control in PV systems. The data can be monitor by login the web: ennox.sunnyportal.com with given username and password. The sample of this monitoring system is as shown in Figure 3.

## 3.4. Energy Generation from Solar

Energy generation data been collected from the web portal of 150 kWp Surkhet project, for a random sample of 8 days between April and August 2023. The summary of findings are as follows as shown in Table 2. The snap-shots of the power generation profile of those 8 different days are presented here.[7] The summary of this estimation is provided below:

- Five Month Actual (April to Aug): 89,319 kWh
- Expected Annual Energy: 220,582 kWh/Year
- Projected Energy: 205,432 kWh/Year (around 7% below the expected energy)

The tabulated data(Table 3) reveals that the average energy production over the span of five months fell short of expectations by approximately 9%. Nonetheless, when considering the annual calculation, the deficit in energy generation is projected to be around 7% compared to the expected data.

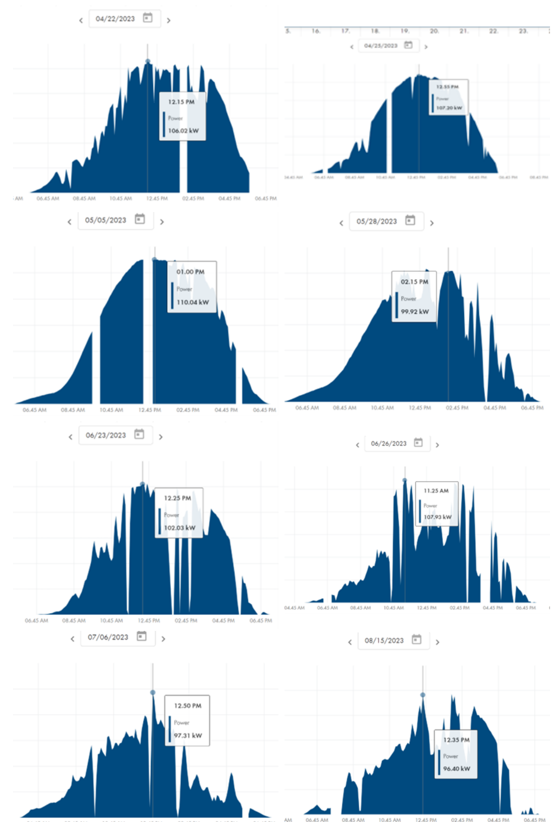
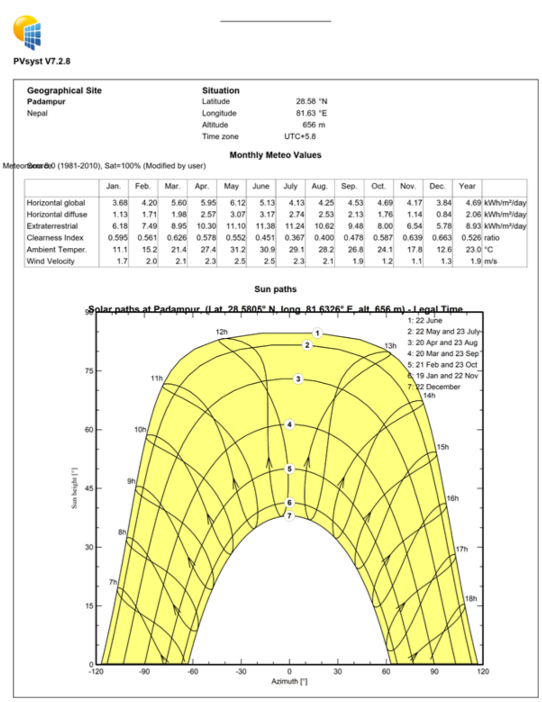


Figure: Power Generation Profile

Between April and August, the real energy generation was extracted from the web portal of the SMA inverter, and the variance was computed. Using this variance and the anticipated energy output, future energy production was forecasted.

Table 3: Energy Generation Table

| Month | Days | Insolation on Horizontal Plane GHI ($kWh/m^2/day$) | Expected Energy kWh | Actual Generation kWh | Deviation from Expected |
|---|---|---|---|---|---|
| Jan | 31 | 3.68 | 15,822 | | |
| Feb | 28 | 4.20 | 14,827 | | |
| Mar | 31 | 5.60 | 21,888 | | |
| Apr | 30 | 5.95 | 22,506 | 20,758 | 7.8% |
| May | 31 | 6.12 | 23,920 | 21,450 | 10.3% |
| Jun | 30 | 5.13 | 19,404 | 17,058 | 12.1% |
| Jul | 31 | 4.13 | 16,142 | 14,199 | 12.0% |
| Aug | 31 | 4.25 | 16,611 | 15,854 | 4.6% |
| Sep | 30 | 4.53 | 18,848 | | |
| Oct | 31 | 4.69 | 18,331 | | |
| Nov | 30 | 4.17 | 15,773 | | |
| Dec | 31 | 3.84 | 16,510 | | |
| Average | | 4.69 | 18,382 | 17,864 | 9.4% |




| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Year | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizontal global | 3.68 | 4.20 | 5.60 | 5.95 | 6.12 | 5.13 | 4.13 | 4.25 | 4.53 | 4.69 | 4.17 | 3.84 | 4.69 | kWh/m²/day |
| Horizontal diffuse | 1.13 | 1.71 | 1.98 | 2.57 | 3.07 | 3.17 | 2.74 | 2.53 | 2.13 | 1.76 | 1.14 | 0.84 | 2.06 | kWh/m²/day |
| Extraterrestrial | 6.18 | 7.49 | 8.95 | 10.30 | 11.10 | 11.38 | 11.24 | 10.62 | 9.48 | 8.00 | 6.54 | 5.78 | 8.93 | kWh/m²/day |
| Clearness Index | 0.595 | 0.561 | 0.626 | 0.578 | 0.552 | 0.451 | 0.367 | 0.400 | 0.478 | 0.587 | 0.639 | 0.663 | 0.526 | ratio |
| Ambient Temper. | 11.1 | 15.2 | 21.4 | 27.4 | 31.2 | 30.9 | 29.1 | 28.2 | 26.8 | 24.1 | 17.8 | 12.6 | 23.0 | °C |
| Wind Velocity | 1.7 | 2.0 | 2.1 | 2.3 | 2.5 | 2.5 | 2.3 | 2.1 | 1.9 | 1.2 | 1.1 | 1.3 | 1.9 | m/s |

Figure: Solar Insolation data obtained from PVsyst software

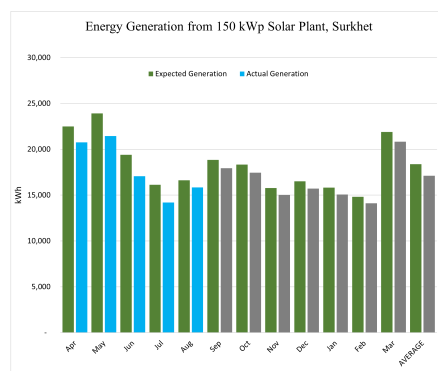



Figure: Comparison of expected energy with actual and projected energy

# 4. Energy supply and consumption in the hospital

## 4.1. Electricity supply system in the hospital and electrical loads

The hospital is connected to three phase, medium voltage (11 kV) NEA's grid line with two transformers each of capacity 200 kVA and has TOD meter installed. The total connected load of the hospital is 734.89 kW[8]. Hospital staffs reported that they frequently face problem of voltage fluctuation from conventional grid connection. There are frequent power cuts during stormy and rainy seasons, so the national grid seems not much reliable.

Hospital has additionally installed a 10 kWp solar system which is used for lighting, computer billing and server system.

The hospital has 2 sets of diesel back-up generators. The capacity of Diesel Gensets are 100 kVA and 160 kVA respectively[5][6]. Fuel consumption of 160 kVA Diesel Genset is 7 liters/hour and that of 100 kVA Diesel Genset is 6 liters/hour. Diesel Gensets are in operation during load shedding or power cuts or voltage fluctuation. During the daytime, hospital energy operators run the 160-kVA generator, but during off hours they run the 100 kVA generator. Till date, they have not faced

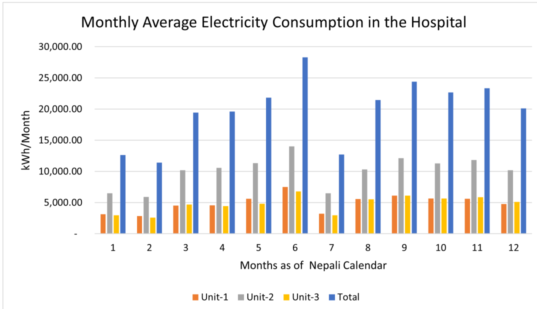



Figure 4: Month wise average electricity consumption in kWh from year 2077(2020)-2079 (2022)

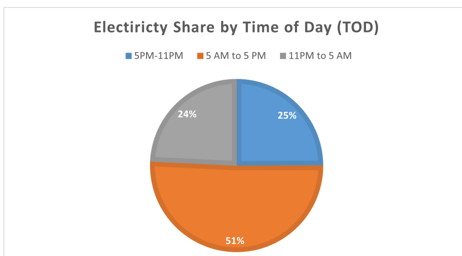



Figure 5: Electricity consumption in three different time slot (TOD meter) in year 2077(2020)-2079 (2022)[9]

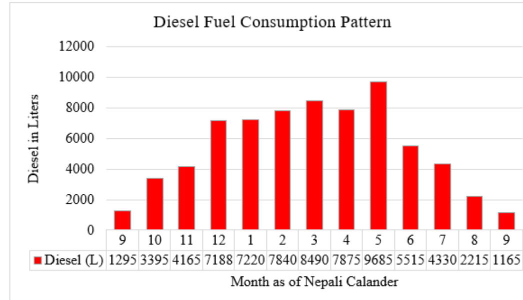



Figure: Diesel fuel consumption in the Hospital (2078-09(2021-10) to 2079-09(2022-10))

any major problem in the Diesel Gensets as they carry out regular maintenance[6].

## 4.2. Utility (NEA) electricity and fuel consumption

The historical data spanning three years, concerning the hospital's utility electricity usage, indicates an average yearly energy consumption of 238,048 kWh[9]. The graphical representation of the average monthly energy consumption can be observed in Figure 4.

As depicted in Figure 5, an observation can be made that 51% of the overall energy was utilized during daylight hours when sunshine is accessible, presenting an opportunity to substitute grid energy with solar PV energy.

A sum of 70,378 liters of diesel was expended during the previous year (from 2078-09(2021-10) to 2079-09(2022-10)). This equates to an average monthly consumption of 5864.833 liters, or 195.5 liters per day. This was the scenario before the implementation of solar panels[9].

Following the installation of solar panels, the diesel consumption dropped to 3590 liters between 2079-10 and 2080-3 BS, spanning a period of 5.5 months.This translates to an average monthly consumption of 652.72 liters, or 21.75 liters per day.[9]

Of greater significance, provided below is a comparative analysis of consumption patterns prior to PSA plant operation, during PSA plant operation without solar, and during PSA plant operation with solar:

## 4.3. Estimation of PSA plant capacity

This PSA Oxygen Generating System is composed of Compressed Air System, Compressed Air Purification System, PSA Oxygen Making System and Oxygen Storage System. Air compressor provides compressed air with certain pressure; Air purification system purifies compressed air by removing the dust, oil and water; Oxygen and nitrogen separation system produce qualified oxygen gas with PSA technology; Oxygen Storage system provides a stable source and store oxygen gas.

The power requirement of a compressor with given oxygen flow and pressure ratio can be calculated using the formula below:

$$\text{Power(in Watts)} = \frac{n}{n-1} P_1 V_1 \frac{(P_2/P_1)^{\frac{n-1}{n}} - 1}{\eta} \quad (1)$$

Where,

$P_1$= Intake or Suction Pressure in Pa

$P_2$= Discharge Pressure in Pa

n= index of compression (n=1.4 for main compressor)

$\eta$= Efficiency ranging from 0.9% to 0.97% (higher capacity with higher efficiency)

Using Eq-(1), it can be determined the power required expected for a representative range of PSA plants installed at Nepal MoHP hospitals. The range is taken 1 to 200 $Nm^3$/hour medical oxygen flow output for individual PSA plants. First, power of main compressor is calculated whose output is compressed air at 7 bar. In the second stage, power requirement of booster compressor is calculated whose output is compressed pure oxygen at 150 bar. The graphs of PSA power required verses oxygen flow is presented below for different loading of PSA plant is presented in Figure 14below.

As depicted in Figure 6, it becomes evident that a

Table 4: Surkhet Hospital Energy Consumption Details (NEA Bill and Diesel Fuel)[9]

| Headings | Without PSA Plant | Event | PSA Plant without Solar | Event | PSA Plant with Solar |
|---|---|---|---|---|---|
| Date Nepali[dd/mm/yy] | Till 8/9/2078 | 8/9/2078 | 8/9/2078 to 12/12/2079 | 12/12/2079 | 12/12/2079 to 18/3/2080 |
| Date English [dd-mm-yy] | 23-Dec-21 | 24-Dec-21 | 24 Dec 2021 to 26 March 2023 | 26-Mar-23 | 26 March 2023 to 3 July 2023 |
| Operating Days | - | | 457 Days | - | 99 Days |
| Fuel Consumption (Liter/Month) | 2,100.00 | | 4,617.70 | | 1,013.64 |
| DG Operation Hours/Month | 23.70 | | 314.52 | | 58.64 |
| Average Electricity Consumption (kWh/Month)* | 12,449.00 | PSA Plant Start to Operate | 33,622.00 | Solar Start to Operate | 35,672.00 |
| PSA Operation (Hours/Day) | - | | 12 hours/day from DG Supply | | 8-12 hours/day from Solar and Grid Supply |
| Energy Generation from 150kWp Solar (kWh/Month)** | - | | - | | 17,595.00 |

*20 Month Average
**Specific Yield 3.91 kWhac/kWp/Day

significantly large PSA plant capacity is necessary to accommodate a 200 $Nm^3$/h oxygen flow rate. Therefore, for the purpose of this report, detailed calculations will focus on oxygen flows up to 100 $Nm^3$/hr, the graphs for this is presented in Figure 7.

In the figure 7, the left y-axis consists of the total power estimated for a PSA oxygen plant, y-axis in the right hand side represents the estimated power of solar required for different flow rate of oxygen for hospital.

Following assumption were considered for sizing solar array for PSA plant:

- The Coefficient of Losses (CoL) applied to the Solar Power Plant is set at 78.17%, encompassing the temperature derating factor corresponding to an annual average temperature of approximately 24°C.
- An initial power degradation of 2% is accounted for in the first year for the PV module.
- The Global Horizontal Insolation (GHI) stands at 4.7 kWh/$m^2$/day, representing the national average value for Nepal.
- The PSA plant's solar-powered operation is anticipated for a duration of 6 hours per day.

## 5. Summary of financial analysis of the project

A comprehensive evaluation of the cost-saving of the 150 kWp solar project, which has been established at Surkhet hospital, is condensed and outlined within the Table 5 provided below. This table encapsulates the comparative costs and benefits associated with the installation and operation of the solar project at the hospi-

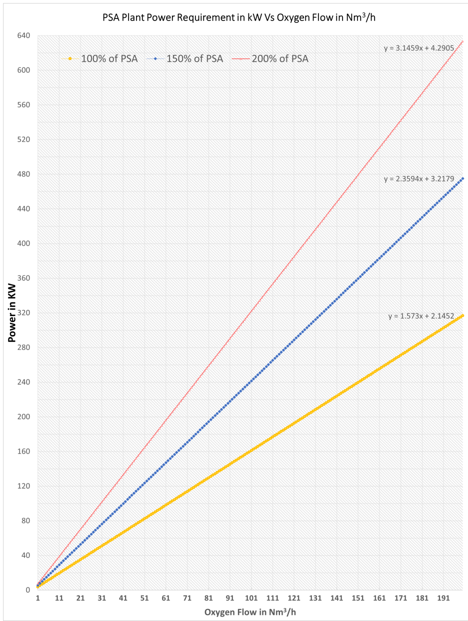



Figure 6: Graphs of PSA plant power required verses oxygen flow in Nm$^3$/hr for different loading of PSA plant

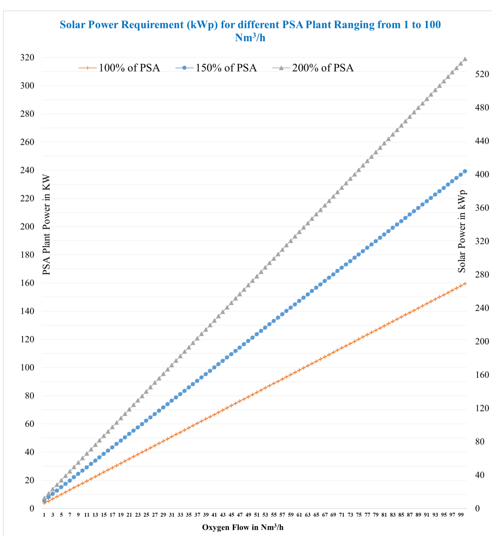



Figure 7: Power capacity of PSA plant (kW) and size of Solar Array required (kWp) Vs Oxygen flow rate

tal premises.

Derived from the cost-saving figures outlined in Table 5, a concise summary of the financial analysis is presented below.

**Assumptions for Financial Calculations:**

- Energy generation from the solar plant is projected over a 25-year span, with an annual degradation of 0.5% in output.

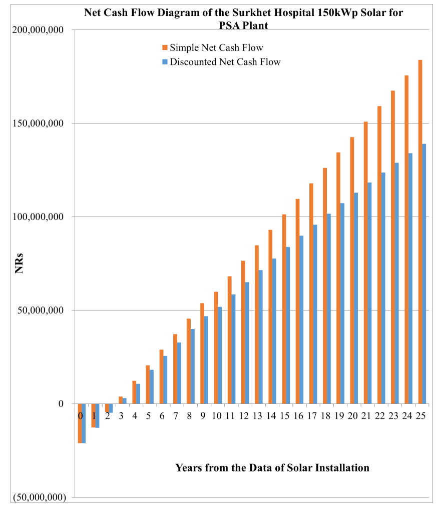



Figure 8: Cash Flow Diagram for an Actual Solar Insolation in Surkhet Project

- Operation and maintenance expenses for the solar plant are estimated at 1% of the initial investment.
- The anticipated future value of the solar project is approximated at 5% of the initial investment.
- TAX and VAT have been excluded from consideration due to the government nature of the project.
- A nominal interest rate of 2% is employed for the Discounted Cash Flow analysis, conforming to the recommended range of 1% to 2% for LIC/LMIC governments.

The presented Table 6 shows that the solar project exhibits highly attractive financial returns. In Surkhet, the actual global solar insolation is expected to 4.69 kWh/m$^2$/day on a horizontal plane. Consequently, the specific yield from solar energy output is 3.95 kWhac, meaning that each installed 1 kWp solar array generates 3.95 units of AC electricity. The Levelized Cost of Electricity in this context is NRs 7.01 per kWh, representing the actual cost incurred to produce each unit of energy. Remarkably, the Internal Rate of Return (IRR) in this scenario nears 40%, indicating a significantly attractive return on investment. Additionally, the discounted payback period is less than 3 years, underlining the rapid recovery of initial investment. The cash flow statement in this scenario is presented in Figure 8 below.

However, the information presented in Table 6 can be succinctly summarized as the cost-benefit analysis of a solar project (150 kWp for instance) implemented across all regions of similar hospitals in Nepal. The various financial parameters have been computed for three distinct ranges of GHI: Low (4.0 kWh/m$^2$/day), Medium (4.5 kWh/m$^2$/day), and High

Table 5: Saving from 150 kWp Surkhet Hospital Solar Project

| Parameters | Data | Unit/Remarks |
|---|---|---|
| Diesel Fuel Saving After the Installation of 150 kWp Solar | 3,604.07 | Liter/Month |
| Electrical Energy Saving from Diesel Generator (DG) | 11,893.42 | kWh/Month(1L diesel:3.3kWhe) |
| Cost Saving from DG —(A) | 644,082.64 | NRs/Month |
| Estimated Energy Generation from Solar Plant | 17,120.00 | kWh/Month |
| Remaining Energy From Solar Generation After Compensating Energy from DG | 5,226.0 | kWh/Month |
| Saving Cost of Grid Electricity by Solar —– (B) | 62,458.0 | NRs/Month (Average Tariff : NRs 11.95/kWh ) |
| Total Saving from Solar Plant (A+B) | 8,478,488.0 | NRs/Year |

Table 6: Summary of Financial Analysis of a Reference 150kWp Surkhet Hospital Solar Project

| Financial Parameters | Actual Solar Insolation 4.69 $kWh/m^2/day$ | Low Solar Insolation 4.0 $kWh/m^2/day$ | Medium Solar Insolation 4.5 $kWh/m^2/day$ | High Solar Insolation 5.0 $kWh/m^2/day$ |
|---|---|---|---|---|
| Specific Yield from Solar PV (kWhac/kWp/Day) | 3.95 | 3.37 | 3.79 | 4.21 |
| Net Present Value (NPV) of Project in NRs | 136,277,498 | 129,972,338 | 134,873,752 | 139,786,864 |
| Project Internal Rate of Return (IRR) | 39.38% | 37.73% | 39.01% | 40.30% |
| Levelized Cost of Energy from Solar Plant (LCOE) in NRs/kWh | 7.01 | 8.22 | 7.30 | 6.57 |
| Simple Payback Period in Years | 2.53 | 2.64 | 2.55 | 2.47 |
| Discounted Payback Period in Years | 2.62 | 2.74 | 2.65 | 2.56 |
| Benefit Cost Ratio (B/C) | 6.68 | 6.44 | 6.63 | 6.81 |

(5.0 $kWh/m^2/day$), which represent different parts of Nepal. Across these three scenarios, the IRR varies between 37.7% and 40.3%, while the Payback Period ranges from 2.7 to 2.5 years. Additionally, the LCOE spans from 8.22 to 6.57 NRs/kWh.

Furthermore, the solar installation is anticipated to lower the unit cost of energy within the hospital. The computation of this outcome is detailed in Table 7 below:

Based on these calculations, it becomes evident that the solar plant contributes to a reduction of approximately 38% in the overall unit energy cost.

## 6. Socio-economic benefits of solar plant

The installation of a 150 kWp solar power system at Surkhet hospital to support the PSA oxygen plant brought forth a multitude of positive impacts that extend beyond financial returns. These impacts span across various aspects of society, the environment, the hospital itself, and the patients it serves. Here's a detailed breakdown of these positive impacts:

Table 7: Summary of Financial Analysis of a Reference 150kWp Surkhet Hospital Solar Project

| Comparison Parameters | PSA Plant without Solar | PSA Plant with 150kWp Solar | Remarks |
|---|---|---|---|
| Monthly Energy Consumption from NEA Grid Supply (kWh/Month) | 33,622.00 | 35,672.00 | - |
| Average Cost of Grid Electricity (NRs/kWh) | 11.95 | 11.95 | Demand Charge (NRs/kVA) not included |
| Monthly Diesel Fuel Consumption (Liter/Month) | 4,617.70 | 1,013.64 | - |
| Energy Supply from DG (kWh/Month) | 15,238.42 | 3,345.00 | - |
| Average Cost of Energy from DG (NRs/kWh) | 54.15 | 54.15 | Assume, 5% Overhead Cost per kWh for O&M of DG |
| Weighted Average Cost of Total Electricity (NRs/kWh) | 25.11 | 15.57* | - |
| Saving from Solar Power Plant (% per kWh) | | 38.01% | - |

### 6.1. Environmental benefits

**Reduction in Air Pollution:** One of the most significant benefits is the reduction of air pollution. Diesel generators emit pollutants such as nitrogen oxides, particulate matter, and carbon dioxide. By relying less on diesel generators, the hospital contributes to improving the air quality in the local area, leading to better health outcomes for the community.

**Mitigation of Noise Pollution:** Diesel generators are notorious for their noise pollution. The installation of solar panels eliminates the noise generated by generator operation, creating a quieter and more peaceful environment for patients, staff, and the surrounding community.

**Lower Carbon Emissions:** Solar power is a clean energy source that produces virtually no greenhouse gas emissions during operation. By using solar energy to power the PSA oxygen plant, the hospital significantly reduces its carbon footprint, contributing to global efforts to combat climate change. Installation of 150 kWp solar saved around 123 $tCO_2$ annually at Surkhet hospital.

### 6.2. Health and well-being

**Improved Patient Recovery:** The hospital environment became more conducive to patient recovery due to reduced noise pollution and better air quality. Quiet and clean surroundings can positively impact patients' mental and physical well-being, aiding in their healing process.

### 6.3. Economic and social benefits

**Reduced Dependence on Imported Diesel:** Nepal's reliance on imported diesel not only drains financial resources but also increases the country's trade deficit. By reducing the consumption of imported diesel, the solar installation contributes to a more sustainable trade balance, potentially benefiting the national economy.

**Job Creation:** The installation, maintenance, and operation of solar power systems created employment opportunities at various skill levels, contributing to local economic development.

## 7. Conclusion

Following are the conclusion made from this study:

1. **Energy Consumption Patterns:** Historical data spanning three years revealed an average yearly energy consumption of 238,048 kWh in the hospital.
2. **Solar Substitution Opportunity:** 51% of energy usage occurred during daylight hours, presenting an opportunity to substitute grid energy with solar power.
3. **Diesel Consumption:** Before solar panel installation, the hospital consumed 70,378 liters of diesel in a year, averaging 195.5 liters per day.
4. **Diesel Reduction:** Following solar panel instal-

lation, diesel consumption dropped to 3590 liters over 5.5 months, averaging 21.75 liters per day.

5. **Savings Calculation:** Using equations, significant savings were projected after solar panel implementation:
   - Diesel fuel saving: 3,604.07 liters/month
   - Electrical energy saving from diesel generator: 11,893.42 kWh/month
   - Cost saving from diesel generator: 644,082.64 NRs/month
   - Estimated energy generation from solar plant: 17,120.00 kWh/month
   - Saving cost of grid electricity by solar: 62,458 NRs/month
   - Total saving from solar plant: 706,540 NRs/month (8,478,488 NRs/year)
6. **Highly Attractive Financial Returns:**
   - Actual global solar insolation: 4.69 kWh/m$^2$/day in the site.
   - Specific yield from solar energy output: 3.95 kWhac
   - Levelized Cost of Electricity: NRs 7.01 per kWh
   - Internal Rate of Return (IRR): Near 40%, with a payback period under 3 years
   - Financial parameters showed IRR between 37.7% and 40.3%, payback period from 2.7 to 2.5 years, and LCOE ranging from 8.22 to 6.57 NRs/kWh when GHI ranges from 4.0 to 5.0 kWh/m$^2$/day.
7. **Substantial Energy Cost Reduction:**Solar plant contributed to about 38% reduction in overall unit energy costs.
8. **Environmental and Societal Benefits:** Solar panels had far-reaching positive impacts on environment, patients, society, hospital operations, and the economy. Reduction in pollution, improved patient recovery conditions, and sustainability example were notable achievements.

In summary, the installation of solar panels at Surkhet government hospital not only led to significant financial gains but also brought about positive transformations in multiple aspects of healthcare, environment, and society. Clean energy's potential in healthcare and broader societal development was clearly demonstrated.

## Acknowledgement

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