TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
LALITPUR, NEPAL

THESIS NO: M-400-MSREE-2023-2025

Development and Analysis of Low Penetration Hybrid Renewable Energy Model for a Generic Military Battalion in UN Peacekeeping Operation (UNPKO)

by
Ghanashyam Chuhan

A THESIS
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
LALITPUR, NEPAL

APRIL, 2025

COPYRIGHT

Head,

Department of Mechanical and Aerospace Engineering,

Pulchowk Campus, Institute of Engineering,

Lalitpur, Nepal.

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Development and Analysis of Low Penetration Hybrid Renewable Energy Model for a Generic Military Battalion in UN Peacekeeping Operation (UNPKO)" submitted by Ghanashyam Chuhan (PUL079MSREE005) in partial fulfillment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

Supervisor, Dr. Shree Raj Shakya
Associate Professor,
Department of Mechanical and Aerospace Engineering.

External Examiner, Dr. Ranjan Prakash Shrestha
Senior Programme Manager,
Delegation of the European Union to Nepal.

Committee Chairperson, Dr. Sudip Bhattrai
Head of Department,
Department of Mechanical and Aerospace Engineering.

Date: April 10, 2025

ABSTRACT

The integration of Renewable Energy (RE) in UN Peacekeeping Operations (UNPKO) is an indispensable issue that addresses logistic sustainability, operational costs, UN energy targets and environmental concerns. Despite the UN policies promoting RE in peacekeeping framework, the progress remains slow. Troops Contributing Country (TCC) units, particularly Battalions (Bn) in sub-Saharan Africa, are key to accelerate RE integration, considering their strength and energy consumption volume.

This study assesses a Hybrid Renewable Energy (HRE) model with 35% power penetration for a generic battalion in UNPKO optimized for reimbursement; adhering to the UN standards and provisions. The optimal HRE system incorporates 2,473KVA DG Bank, 693KWp Solar PV, and 866KW Converter, achieving the maximum wet-lease reimbursement of $38,274/month. The NPV of the HRE system is estimated to be $1.67M with 47% contribution from RE resource, with the load and resource case of UNMISS, Rumbek, South Sudan. The payback and IRR of the system as calculated are 2.71year and 25.32% respectively, incurring a market based capital investment of $1.05M. The HRE system consumes 699,280L/year of diesel fuel. The potential fuel saving from a military Bn unit by implementing the optimized HRE system is estimated to be 141KL/year; while similar hybridization across all the military components could result in fuel saving of around 12.11ML/year. The HRE system with 35% power penetration is found to contribute only 17.3% in total electricity consumption; which indicates the need of higher RE penetration or energy storage system so as to attain the green energy targets in the UN peacekeeping framework.

Keywords: Hybrid energy modeling, Battalion, UN peacekeeping, Techno-economic analysis.

ACKNOWLEDGEMENT

I would like to grasp this opportunity to express my sincere gratitude and thankfulness to Assoc. Prof. Dr. Hari B. Darlami, the Program Coordinator of Master of Science in Renewable Energy Engineering and Asst. Prof. Dr. Sudip Bhattrai, the Head of Department, Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering, for providing the kind opportunity to conduct this study.

I am extremely indebted to my supervisor Assoc. Prof. Dr. Shree Raj Shakya for his relentless, insightful and precious guidance throughout my research work, that helped imperatively to complete my research work timely and successfully. My sincere appreciation also goes to the participants of the survey for providing their kind support and vital information required for this study.

Finally, I am obliged to all the faculty members of the Department of Mechanical and Aerospace Engineering, Pulchowk Campus and Centre for Energy Studies, Institute of Engineering for providing the necessary resource, training and insightful outlooks for this research work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating Current, Air-Conditioner
BESS	Battery Energy Storage System
BG	Backup Generator
Bn	Battalion
COE	Contingent Owned Equipment
Coeff.	Coefficient
Coy	Company
CRF	Capital Recovery Factor
DC	Direct Current
DFS	Department of Field Support
DG	Diesel Generator
DPKO	Department of Peacekeeping Operations
Eff.	Efficiency
FOB	Forward Operating Base
FOL	Fuel, Oil, Lubricants
GA	General Assembly
GFMV	Generic Fair Market Value
GHG	Greenhouse Gas
HOMER	Hybrid Optimization of Multiple Energy Resources
HQ	Headquarter
HRES	Hybrid Renewable Energy System
hr	Hour
Inf	Infantry
IRR	Internal Rate of Return
Intl’	International
KVA	Kilo-Volt Ampere
KW	Kilowatt
L/Ltrs	Liters

LCOE	Levelized Cost of Energy
Light Inf Bn	Light Infantry Battalion
M	Million
MDR	Monthly Dry-lease Rate
ME	Major Equipment
MG	Main Generator
MINURSO	United Nations Mission for the Referendum in Western Sahara
MINUSCA	United Nations Multidimensional Integrated Stabilization Mission in the Central African Republic
MMR	Monthly Maintenance Rate
MONUSCO	United Nations Stabilization Mission in the Democratic Republic of the Congo
MOU	Memorandum of Understanding
MWR	Monthly Wet-lease Rate
NPC	Net Present Cost
NPV	Net Present Value
O&M	Operation and Maintenance
PCC	Police Contributing Country
PCRS	Peacekeeping Capability Readiness System
pf	Power Factor
PKO	Peacekeeping Operations
POL	Petroleum, Oil and Lubricants
PV	Photovoltaic
PP	Power-Penetration
RDL	Rapid Deployment Level
RE	Renewable Energy
SC	Security Council
SDG	Sustainable Development Goal
SPM	Special Political Mission

SS	Self-Sustainment
STC	Standard Test Condition
SUR	Statement of Unit Requirement
TCC	Troops Contributing Country
TMR	Total Monthly Reimbursement
TOB	Temporary Operating Base
ToD	Time of Day
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
UN Light inf Bn	United Nations Light Infantry Battalion
UNDOF	United Nations Disengagement Observer Force
UNEP	United Nations Environment Programme
UNFICYP	United Nations Peacekeeping Force in Cyprus
UNHQ	United Nations Headquarters
UNIBAM	United Nations Infantry Battalion Manual
UNIFIL	United Nations Interim Force in Lebanon
UNISFA	United Nations Interim Security Force for Abyei
UNMIK	United Nations Interim Administration Mission in Kosovo
UNMISS	United Nations Mission in the Republic of South Sudan
UNMOGIP	United Nations Military Observer Group in India and Pakistan
UNOE	United Nations Owned Equipment
UNPKO	United Nations Peacekeeping Operations
UNSC	United Nations Security Council
UNSCAP	United Nations Secretariat Climate Action Plan
UNSG	United Nations Secretary General
UNTSO	United Nations Truce Supervision Organization
VR	Verification Report

CHAPTER ONE: INTRODUCTION

1.1 Background

The United Nations Peacekeeping Operation (UNPKO) is a unique global collaboration that comprehends activities, especially the military and political ones, envisioned to create and uphold the conditions for sustainable peace [1]. The UNPKO mainly consists of the Civilian, Police and Military components in the field deployment; of which the military constitutes the major share of around 75% share of the total peacekeeper numbers [2]. Within the military units in UNPKO, the Battalion (Bn) is the most common and largest formed unit by number of personnel claiming around 49% of the total peacekeepers in UNPKO [3].

The UNPKOs are energy intensive and energy sensitive processes. The cumulative annual energy consumption of UNPKOs is approximately 500GWh/year which is equivalent to the total electricity consumption of whole South Sudan country. The most headquarter (HQ) sites have the energy requirement in scale of Megawatts. The five largest energy consuming field missions according to the 2019/20 data are MINUSMA, UNMISS, UNSOS, MINUSCA and UNIFIL that consumed 75, 71, 59, 48 and 48GWh energy respectively [4].

The Renewable Energy (RE) integration is a very crucial issue that opens up the pathway for the green transformation of UNPKO by addressing the local sustainability, cost and environmental issues of the UNPKO, while aiding to the global leadership and partnership of the UN on Sustainable Development Goals (SDGs), Climate Change, Net-Zero Emission (NZE) etc.

1.2 The Logistic Power Supply System of Military (TCC) Units in UNPKO

The logistic power supply system in military units of UNPKO is a very crucial aspect that contributes to the logistic sustainment and operational resilience of the unit which is usually deployed in the conflicted, remote and energy deprived areas. Under the wet-lease provision; the TCC and the UN function collaboratively to form the logistic power supply system of the military or TCC unit complying to the doctrinal guidelines of the UN [5], [6]. The prevalent doctrines that guide the deployment, O&M requirement, reimbursement provisions and other relevant aspects of the logistic power supply system in TCC camp of UNPKO are as illustrated below [7].

- ✓ Statement of Unit Requirement (SUR)
- ✓ Contingent Owned Equipment (COE) Manual
- ✓ Memorandum of Understanding (MOU)

The system view of conventional DG-based logistic power supply system of the military (or TCC) units in UNPKO is explained briefly by the Figure 1.

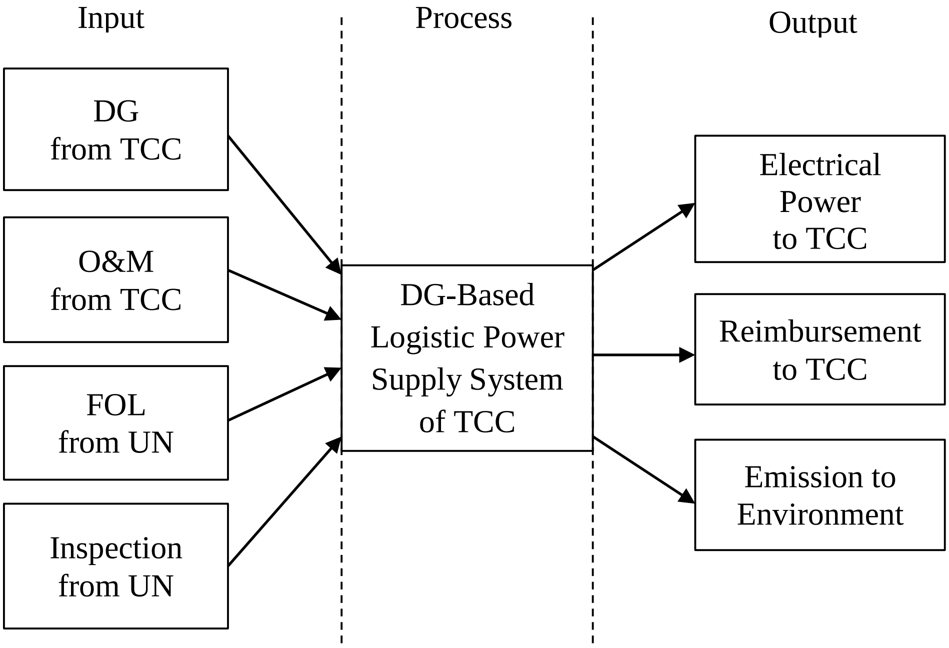


Figure 1: Logistic Power Supply System of TCC unit in Wet-Lease Provision (Source: [5], [6], [8])

The conventional logistic power supply system of military units in peacekeeping framework under wet-lease condition is briefly explained as followings [5], [6]:

- ➢ The military (or TCC) units deploy diesel generators (DG) in compliance with the SUR, COE manual and MOU to form the power supply system.
- ➢ The TCC organizes the necessary administrative and technical capacity for the O&M of the power supply system
- ➢ The UN Mission provides the fuel and other petroleum products required for the operation & maintenance of the DG.
- ➢ The designated UN mission conducts the periodic (generally quarterly) inspection and verification namely COE inspection of the power supply system which is reflected in the Verification Report (VR).
- ➢ The power supply system provides the necessary electrical power for the logistic sustainment of the TCC unit.

- The UN mission pays off the reimbursement to the TCC for the deployment, serviceability and maintenance of the power supply system on the basis of the VR.
- The power supply system emits the GHG gases, pollutants and noise during the operation and maintenance that affect the TCC camp, mission area, host country and ultimately the global environment.

1.3 Research Gap

The UNPKOs are energy intensive and energy sensitive process, there are very few (or almost no) literatures found in this genre that researches the objective Renewable Energy (RE) integration modelling and techno-economic analysis for uniformed units in UN Peacekeeping framework. Additionally, there is gap between the ambitious RE policies of the UN and the technical execution plan by the uniformed entities. Hence, research and studies are required to bridge the gap between the RE policies and the action plan needed by the uniformed entities in the UN Peacekeeping framework.

1.4 Research Problem

Traditionally, the logistic power supply system of TCC in UNPKO was solely based on the Diesel Generators (DG). Considering the different problems of DG based power supply system and need for the green transition of the UNPKO, the UN has disseminated different RE policies and provisions for UNPKO. Despite these policies, the current status and growth RE in TCC units is in very nascent phase and hence a way behind the expected standards. It needs a great acceleration and result oriented action plans to incorporate and realize the RE targets in UNPKO [9], [10].

Moreover, the RE policies, provisions & strategies for UNPKO are not well supplemented with unit specific working plans which are adaptable to the field components such as TCC and PCC. Hence, an appropriate hybrid RE modelling specific to a mission component and the mission framework is deemed necessary. Moreover, the Techno-Economic analyses of the RE model is also required to quantify and objectify the affordability, viability, sustainability and operational pathway of the hybrid RE model in UNPKO environment [10, p. 45].

Furthermore, there are very limited (or almost no) data, study and research work in this genre and issue. Hence, comprehensive research works are needed to aid to the green transformation of the UNPKOs & expand the horizon of this knowledge through the blending of Peace, Energy and Engineering principles; aligning to the pertinent UN policies, targets and commitments like UN SDGs, Climate Change etc.

1.5 Research Questions

The study primarily quests for the answering some vital questions regarding the RE integration in logistic power supply system in TCC units of UNPKOs. The questions basically streamline the different avenues throughout the research work. The questions; answers to which are considered imperative are as listed below:

1) What are the logistic energy supply variables, compliance standards and reimbursement modalities for a generic military Bn in UNPKO?
2) What is the optimum model of DG + Solar PV HRE system at 35% power-penetration that complies to the UN standards and delivers the maximum reimbursement to the TCC Bn unit?
3) How does the optimal hybrid RE model behave Techno-Economically in the mission environment?

1.6 Research Objectives

The research is streamlined to achieve the following main and specific objectives:

1.6.1 Main Objective

To develop a low power-penetration hybrid renewable energy model for a generic military battalion in UNPKO by optimizing the reimbursement and analyze the techno-economic implications of the model in the mission environment.

1.6.2 Specific objectives

- To identify logistic energy variables, compliance standards and reimbursement modalities for a generic military Bn in UNPKO.
- To model an optimum reimbursement DG + PV hybrid Renewable Energy system at 35% power-penetration for a Military Bn in UNPKO.
- To analyze the Techno-Economic implications of the hybrid RE model with the resource case of UNMISS, Rumbek, South Sudan.

1.7 Specifics of the Research

The deployments of UNPKOs are essentially characterized by geographical dispersion along with variation in strength, composition and logistic coherence of the constituting components. Hence, the study hereby is continued identifying the suitable specifics that will incorporate the most recurrent characteristics of UNPKOs which are as discussed below:

1.7.1 Component Choice: The Military (TCC) Component

The Military (TCC) is the major component by number or strength in UNPKOs. Hence, the RE transition and emission reduction in UNPKO can be realized effectively through the TCC [9], [10, p. 69].

1.7.2 Strength Choice: The Military (TCC) Battalion

The TCCs contribute military troops in different strengths and compositions. TCC Battalions (Bn) are the most common form of military deployment in UNPKO based on the mission mandates, tasks and cumulative weight of strength. There are around 56 Military (TCC) Bn accounting for the cumulative strength of around 49% of the total peacekeepers in UNPKOs [3]. Hence, the TCC Infantry Battalion units are considered to be the most suitable unit for the analysis of RE integration in UN Peacekeeping missions. More specifically, the study will be based on the UN Light Inf Bn with strength of 622 personnel as recognized by the UN for PKOs [6].

1.7.3 RE Penetration Choice: Low Power Penetration of 35%

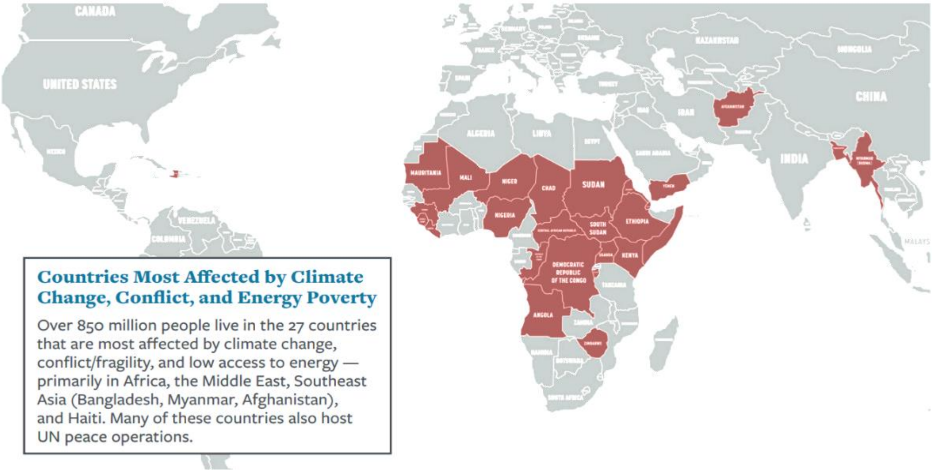
The COE manual 2023 establishes and encourages the provision of equipment that generates electricity from renewable energy to replace any or all of the fuel generators. It however explicitly acknowledges and proposes the reimbursement modality only for the low penetration (25-35%) of RE energy integrated into the DG + Solar PV hybrid power supply system of TCC/PCC component [5, p. 191]. Even within a particular point of low power-penetration range, there are multiple of possible combinations of DGs and PVs yielding the same value of power penetration but different reimbursement rates. This is basically because of the multiple slab provisions of energy components to form the energy system as available in UNPKO. Owing to the explicit reimbursement modality for RE integration, current status of RE integration in UNPKO, impending targets of UN, and the urgency to meet the policy targets and internalize the SDGs in UNPKO, the study is focused on the low power-penetration of 35%.

1.7.4 Optimization Strategy Choice: Maximization of Reimbursement

The energy supply system in UNPKO, while satisfying the supply constraints, demand load and other practical constraints, is largely concerned to the reimbursement as received by the uniformed or military (TCC) units in the form of wet-lease. It reflects the economic incentivization, lucrativeness and encouragement to the TCC to adopt the RE in the mission environment. Hence, the maximum reimbursement strategy that maximizes the monthly reimbursement paid by the UN to the TCC as the wet-lease rate is considered in this study.

1.7.5 Regional Choice: The Sub-Saharan Africa

UNPKO missions are densely deployed in Sub-Saharan Regions. More than 80% (counting to 57,151) UN peacekeeping personnel are deployed in this region [2]. Moreover, the sub-Saharan Africa region is the area most suffered by the risk of Climate change, Poverty, Conflict and Energy Poverty as depicted by the Figure 2.



Countries Most Affected by Climate Change, Conflict, and Energy Poverty

Over 850 million people live in the 27 countries that are most affected by climate change, conflict/fragility, and low access to energy — primarily in Africa, the Middle East, Southeast Asia (Bangladesh, Myanmar, Afghanistan), and Haiti. Many of these countries also host UN peace operations.

Figure 2: Countries most affected by Climate Change, Conflict and Energy

(Source: [10, p. 20])

Hence, the RE integration should be opted first for this region owing to the current status and future possibility of mission persistence/addition.

1.7.6 Location Choice: UNMISS, Rumbek, South Sudan

The UNMISS, Rumbek, South Sudan is selected to carry out the Techno-Economic analysis of the HRE model owing to the availability of the electric load data and energy resource data.

1.7.7 Sign Convention Choice: Positive and Negative Sign of Cash flow

The sign convention is particularly for the economic analysis part of the study, where the positive sign represents the increase in economic worth (or cash inflow) and the negative sign represents the decrease in economic worth (or the cash outflow). Also, the negative of cost is regarded as the credit earned wherever applicable in this study.

1.8 Significance of the Study

On generic basis, the research attempts to fulfill the gap as seen between the RE policies of the UN and the objective efforts to be made by the TCC/PCC units (and the other stakeholders), by delivering the relevant techno-economic details relevant to the mission framework. From the Top-Down view the study appraises the current RE policies of the UN and presents crucial recommendations; that cater the future RE policy reforms and interventions in UNPKO. From the Bottom-Up view, the outcomes of the study are certain to enhance the technical understandings and adaptability of the mission components to accelerate the RE integration in UNPKO.

On specific basis, the study is performed mainly in two parts. In the first part; a reimbursement optimization model of DG + PV hybrid system at 35% power penetration for a military Bn in UNPKO is designed. The outcomes of the model are implementable to all the TCC (and even the PCC) units of Bn and proximate strengths in UNPKO. It is also applicable to the TCC Bn units at different phases of deployment in UNPKO (e.g. PCRS, RDL) and also to the units upsizing or downsizing to the Bn strength and proximate strength. In the second part; the Techno-Economic behavior of the optimum HRE model is analyzed with base case of UNMISS, Rumbek, South Sudan; the technical outcomes of which are applicable to the case location as well as to the other Sub-Saharan Africa missions with similar load, resource and climatic condition as that of the UNMISS. However, the economic outcomes of the study are still applicable to the TCC Bn units of other missions as well; since these analyses are generic and incorporate the global market based inputs.

On collective basis, the research stands as the pioneer study of its genre and attempts to contribute positively to the energy autonomy, sustainability, adverse environmental footprint reduction and the holistic transition of UNPKOs to the cheaper, cleaner and greener ones.

1.9 Limitations of the Study

There are very few studies, data and literatures available that comprehensively and quantitatively deliver the objective information of the UNPKOs. Though, the study is novel of its kind blending the energy, peace and engineering it however suffers with the following limitations as:

- Though the study proposes a generic HRE model at 35% power-penetration for a Bn unit in UNPKO, it does not, however, include the detailed engineering design of the energy components.
- The study does not cover the sensitivity analysis and hence the robustness of the model could not be explored.
- The study does not explore the comprehensive effect on the operational capability of the TCC Bn unit due to the RE integration in logistic power supply system.
- The analysis of the HRE system with BESS is very much significant in the renewable energy framework, which is not covered in this study as the explicit policies and reimbursement provisions for the same is not yet laid down. This very part stands as a new outlet for the future policy reforms and further research in UN peace and energy framework.

CHAPTER TWO: LITERATURE REVIEW

The logistic power supply in UNPKOs needs minute considerations and specifications of multiple variables, parameters for comprehensive exploration, appropriate energy modelling and pertinent analyses. Some of the most substantial parameters are the unit strength or size, standard unit requirements, reimbursement provision, load profile, technical components, deployment location, guidelines and benchmarks of the mission etc. The adoption of RE integration in UNPKO also vitalizes the incorporations of the policies, provisions and strategic objectives as set forth by the UN missions.

The succeeding sections/sub-sections deliberate the important summary of pertinent literatures regarding the logistic power supply system, RE integration in the energy model and analysis, relevant provisions set by UN for PKOs etc. along with current status and future targets.

2.1 General Requirements of DG Based Logistic Power Supply System in UNPKO

The power generation capacity of a military (TCC) unit in UNPKO is dependent upon the Strength or the Troops number in the unit. The UN Light inf Bn features approximate strength of 622 troops [6, p. 64]. There are two other types of Bn that features approximate strength of 872 troops. The contingent units (TCC/PCC) are generally required to provide their own major power generators (>20 KVA) to meet their power requirements, which is reimbursed as Major Equipment (ME) at the rate laid down in the COE Manual. The TCC unit are required to have Electrical-Generators to produce 2.5 KVA per head plus 100% back up [6, p. 88].

2.2 DG Slabs and Reimbursement Modalities in UNPKO

The generic slabs and reimbursement modalities of DGs for the contingent units in UNPKO are outlined as in Table 1.

Table 1: COE Generators Slabs and Reimbursement Modalities

Equipment Category	**Equipment Slab**	**GFMV, $**	**Life, years**	**MWR, $**
Electrical equipment				
Generators, Stationary and mobile	20–30 KVA	43003	12	461
	31–40 KVA	45544	12	522
	41–50 KVA	60084	12	631

	51–75 KVA	72965	12	739
	76–100 KVA	77648	12	795
	101–150 KVA	88859	12	928
	151–200 KVA	116506	15	1115
	201–500 KVA	167360	14	1584
	> 500 KVA	Special case		

(Source: [5, pp. 190–191])

2.3 Problems of the DG based Logistic Power Supply System in UNPKO

The current UNPKOs are primarily based on traditional DG based logistic power supply system. Though, the heavy reliance on DG based logistic power supply system offers few flexibilities and apparent low upfront cost, it however adversely affects the peacekeeping components in a number of ways including but not limited to the following issues:

- **Reduced Power Autonomy and Resilience**: The DG based logistic power supply system significantly compromises the power autonomy, operational resilience etc. [9, p. 1].
- **Direct and Indirect Costs**: It incurs a huge cost/amount of fossil fuel, lubricants, spare parts, maintenance burdens and other hidden costs such as fuel spill, fuel fraud, fuel theft and other indirect losses [9, p. 1].
- **Security Issue and Fatality of Uniformed Personnel**: It wreaks the safety and security challenges and sometimes even the fatalities to the UN peacekeepers especially the Uniformed personnel. This is mainly suffered during the convoy protection of fuel transport through long distance, off-road terrain, conflicted areas and remote locations [10, p. 67].
- **Adverse Environmental Effects & Overheads**: It produces adverse environmental effects such as noise, pollution, GHG emissions and associated tangible and intangible overheads to the TCC/PCC, the UN, the Host country and the Global Environment. This issue is even more intensified by the fact that most of the host countries of UNPKOs fall among the most politically fragile and climate change vulnerable countries.

2.4 Benefits of Renewable Energy Integration in UNPKO

There are numerous benefits of renewable energy integration in UNPKOs. Some of the major benefits of RE integration in UNPKO from especially from TCC point of view are as illustrated below [5], [9]:

- Improving energy autonomy and contributing positively to the operational resilience
- Reducing the reliance on fossil fuel and petroleum products for electricity generation
- Reducing O&M requirements and extending economic life of DGs and other energy components
- Reducing the fire hazard and risk arising from the handling of diesel fuel and other flammable petroleum
- Reducing the need for fuel supply and related convoys, especially in areas with asymmetric attacks thereby improving the safety and security of peacekeepers
- Reducing the GHG emissions, Reducing Noise, Air and Water pollution and positive contribution to climate change, Reducing the overall environmental footprint of operations
- Possibility of redeploying of RE components to the other operational sites or donating to the host community when on mission termination/repatriation

2.5 The Concept of Power-penetration in UNPKO

The RE integration to replace any or all of the fuel generators is highly encouraged in UNPKO. The RE integration for the units in UNPKO basically refers to the solar PV integration in parallel to the conventional DG banks [5, pp. 31–32]. The RE integration is quantified and defined through Power-Penetration and calculated by using the formula as:

$$Power\ Penetration = \frac{Solar\ Photovoltaic\ Peak\ Power\ (KW_p)}{Generator\ 100\%\ load\ rating\ KW\ (KW{=}0.8*KVA)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

(Source: [5, pp. 31–32])

As of the current provisions, the low power-penetration (i.e. the power-penetration between value within the range of 25%-35%) is considered and incentivized explicitly by the different reimbursement modalities.

The Low-Penetration (25-35%) DG + PV hybrid system is considered a simple but efficient means of introducing RE in contingent camps. It incorporates solar PV with DGs in the easiest way for electricity generation system. In the low power-penetration mode, the PV components are designed for providing the power within the range of 25%-35% of the peak power production capacity in daytime, the rest being covered from the DGs. For the low power-penetration mode, the hybrid system doesn't need the BESS and hence can readily be combined with the DGs already employed by the contingent units. The Figure 3 represents the single line diagram of the hybrid model for Low-Penetration as proposed by the COE Working Group 2023 [9, p. 6].

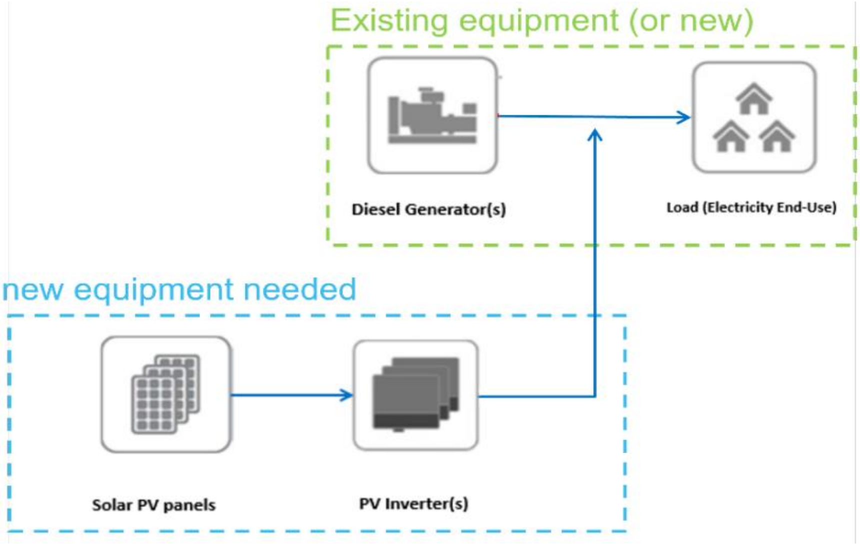


Figure 3: Low Penetration Solar PV System Single Line Diagram
(Source: [9, p. 6])

The medium to high penetration rate (above 35%) and the RE systems other than Solar PV are categorized as the special case; the deployment, reimbursement and other related provision of which are based upon the mutual agreements between in TCC and UN following a separate procedure of special case item as per Chapter 4 of the COE Manual 2023 [5, p. 191,201].

2.6 Provisions, RE Slabs and Reimbursement Modalities in UNPKO

The UN has proposed the provisions and reimbursement schemes to encourage and entice the TCC/PCC for deploying RE components/systems. The COE Manual 2023 explicitly outlines and encourages the provisions of Electrical Generator and RE components integrating at low-power penetration in peacekeeping camps. One of the most important part of this manual is the reimbursement rates of the different slabs of the DGs and RE (especially the solar PV; other RE components regarded as the special case equipment) components [5]. The overview of the reimbursement modalities for RE integration in TCC is as listed in Table 2.

Table 2: Slabs and Reimbursement modalities for RE components in UNPKO

Equipment Category	Equipment (PV) Slab	GFMV, $	Life, years	MWR, $
Renewable energy – Solar PV system integrated with diesel generators in a hybrid low penetration configuration	24-36KWp	49740	7	690
	37-48KWp	70434	7	978
	49-80KWp	106860	7	1483
	81-120KWp	166500	7	2311
	121-150KWp	224505	7	3116
	>151KWp	Special case		

(Source: [5, p. 191])

It should be noted out that the PV slab 24-36KWp is integrable to DG slab 101-150KVA. Similarly, the subsequent PV slabs to 24-36KWp slab are respectively integrable to the succeeding DG slabs to 101-150KVA slab in successive order as presented by the Table 1 and Table 2. This feature called slab integrability in this study is further characterized and exploited in the optimization modelling part of the study.

2.7 The O&M, Replacement Provisions of Energy Components in UNPKO

The O&M responsibilities of energy components in UNPKO under Wet-lease arrangement (as considered in this study) are assumed by the respective TCC unit. The TCC units must arrange the necessary administrative and technical capacity for the O&M responsibilities [5, pp. 6–7]. However, the provision of supply, storage and delivery of bulk POL (or FOL) for the operation and maintenance O&M of generators is arranged and provided by the Mission HQ [6, pp. 75–76].

The DGs upto 200KW are supposed to undergo regular maintenance and major overhauls in every 10,000hours or according to manufacturer’s manual whichever is lower [5, p. 48]. The PV systems however are simpler in operation & maintenance burdens. The modular nature of PV helps in the future expansions to meet the evolving demand, redeployment, donation or disposal [9, p. 6].

The DGs are considered to have a useful service life of 20,000Hrs unless explicitly otherwise indicated by the manufacturer [5, p. 48]. Under the wet lease arrangement, the contributor is responsible for the provision of replacement of equipment [5, p. 29]

2.8 The Energy and Emissions Related Targets in UNPKO

The Environmental Policy for Peacekeeping Operations and Field-Based Special Political Missions 2022; which applies to all phases and components of the UNPKO, sets out some ambitious RE and related objectives and expected standards in UNPKO [11]. Some of the specific objectives and expected standards as set and expected in UNPKO regarding the RE concerns (only those explicitly relevant to this study are listed) are illustrated in the Table 3.

Table 3: Emission and Energy Targets in UNPKO

Objectives	Expected Standards	Basis
Reduction in energy consumption	20% by 2025 & 35% by 2030	On per capita electricity consumption
Increase in conversion to renewable sources of energy	40% by 2025 & 80% by 2030	As proportion of consumed electricity
Reduction in GHG emission	25% by 2025 & 45% by 2030	On absolute & per capita GHG emission

(Source: [11, p. 6,8,9])

2.9 Current Status of Energy and Emissions in UNPKOs

The UN, having already articulated different provisions, policies, strategies and reimbursement modalities in UNPKOs, however stands at very nascent stage of RE integration in the UNPKOs [10], [12]. There are not much quantitative data and literatures available on pinpointing the current status of RE integration in UNPKO. Some of the important data in terms of performance indicators in concern of the logistic power supply system of UNPKOs for the period of 2017-2023 are illustrated as in the Table 4 (only those explicitly relevant to this study are listed).

Table 4: UNPKO Data on GHG, Fuel and Renewable Energy

Performance Indicator	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**	**Unit**
Generator fuel consumption (UNOE + COE)	4.1	4.1	3.3	3.4	3.9	3.7	Ltr/cap/day
Renewable energy	3%	3%	4%	5%	6%	7%	proportion of total consumed electricity
GHG emissions	8.4	8.3	7.5	7.3	7.6	7.5	tCO_2/Cap/year

(Source: [12, pp. 3–4])

Similarly, the Secretariat Issue Paper#21 and #36 present some recent fact-based information that are considerable for the DG based logistic power supply system of UNPKO as:

- ✓ Almost 90% of the electric energy in UNPKO is generated by DGs. In 2020-2021, approximately 35% of the electricity used was produced by COE (military and police units) DGs [9, p. 1].
- ✓ In 2021, the COE units received a total of around 103million liters of fuel, out of which 27% was delivered to contingents in bulk. [13, p. 1].
- ✓ In 2020-2021, COE DGs accounted for around 23% of the GHG emissions in UNPKO. COE generators stood as the third major source of GHG emissions in UN Peace Operations, succeeding UNOE DGs and Aviation which account for 32% and 27% respectively [9, p. 1].
- ✓ UNOE and COE generators in the field are responsible for the emission of more than 500,000tonnes of GHG on a yearly basis [9, p. 6].

All of these facts show that there is a great need of accelerating the RE integration in UNPKO and still a long way ahead to realize the RE integration targets for the green transition of the blue peace missions in UNPKO.

2.10 Challenges for RE Integration in UNPKOs

Some of the major challenges for the much expected energy transformation of UNPKO in context of TCC are discussed in following sub-topics as:

- Limited Deployment of RE resources [9, pp. 1–2].
- Low reimbursement & insufficient economic incentives [10, p. 45].
- High investment and payback of RE [12, p. 11].
- More research and future works required [10, p. 81].

2.11 Global Outlook of the UN for the RE integration in UNPKO

Beside the internal doctrinal, policy and strategic provisions for the RE integration in UNPKO, the UN also comprehends the several global leaderships, commitments and programs for the same. Some of the most beheld endeavors of them are as listed below:

- UN Sustainable Development Goals (UN SDGs especially the SDG7,13 and 16) [10], [14].
- SDG7 Energy Compact of Renewable energy for peacekeeping [4].
- United Nations Secretariat Climate Action Plan (UNSCAP) [15].
- Greening the Blue: the UNEP Program [16].
- United Nations Framework Convention on Climate Change (UNFCC) [17] etc.

These crucial endeavors encourage and oblige the UN and the involved stakeholders to adopt the RE integration in the peacekeeping framework too. These commitments on the other hand also open up the opportunities for the UN and the stakeholder entities to take the leadership and opt for the RE integration and green transition of the UNPKOs despite the considerable challenges in the peace operation spectrum.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Methodological Framework

The research is conducted fundamentally in two methodological parts as outlined below.

3.1.1 Part 1: Capacity Optimization of HRE System at 35% PP

Part 1 of the methodology outlines the optimization modeling of the HRE system at 35% power penetration, aimed at maximizing the Monthly Wet-lease Reimbursement (MWR) for the hybrid system in compliance with UN requirements and standards. It includes the mathematical formulation of variables, constraints, and objective functions, followed by optimization using the Microsoft Excel Solver tool.

The results provide the optimal size, capacity, and quantity of DG and PV sets for 35% power penetration, as well as the maximum MWR for the TCC Bn, mobile DG capacity, PV capacity, reimbursement composition, GFMV-based investment, and payback of the HRE system. These outputs are generic and applicable to all TCC Bn units in any deployment phase under UNPKO. Moreover, the optimized sizing and selection of energy components supplement the Techno-Economic analysis of the HRE system.

3.1.2 Part 2: Techno-Economic Analysis of HRE System at 35% PP

The Part-2 of the methodology covers the Techno-Economic behavior analysis (also called the grid performance in this study) of the optimum HRE system under the optimum components and given constraints, load, resource and environmental conditions. This is achieved by modeling and grid simulation of the hybrid mini-grid model using the HOMER Pro software. The technical inputs are derived from the optimum model obtained from the Part-1 of the methodology while the economic inputs are based on the market data as available in the open source. The electric load data applied for this study are primary data while the RE resource and climatic data applied are furnished by the software platform. The technical outputs of the mini-grid model are applicable to the specific location and settings selected for this study while the economic outputs are still applicable to all the generic TCC Bn units of UNPKO.

The algorithm of methodology that is followed to achieve the objectives set by the research is depicted by the Figure 4.

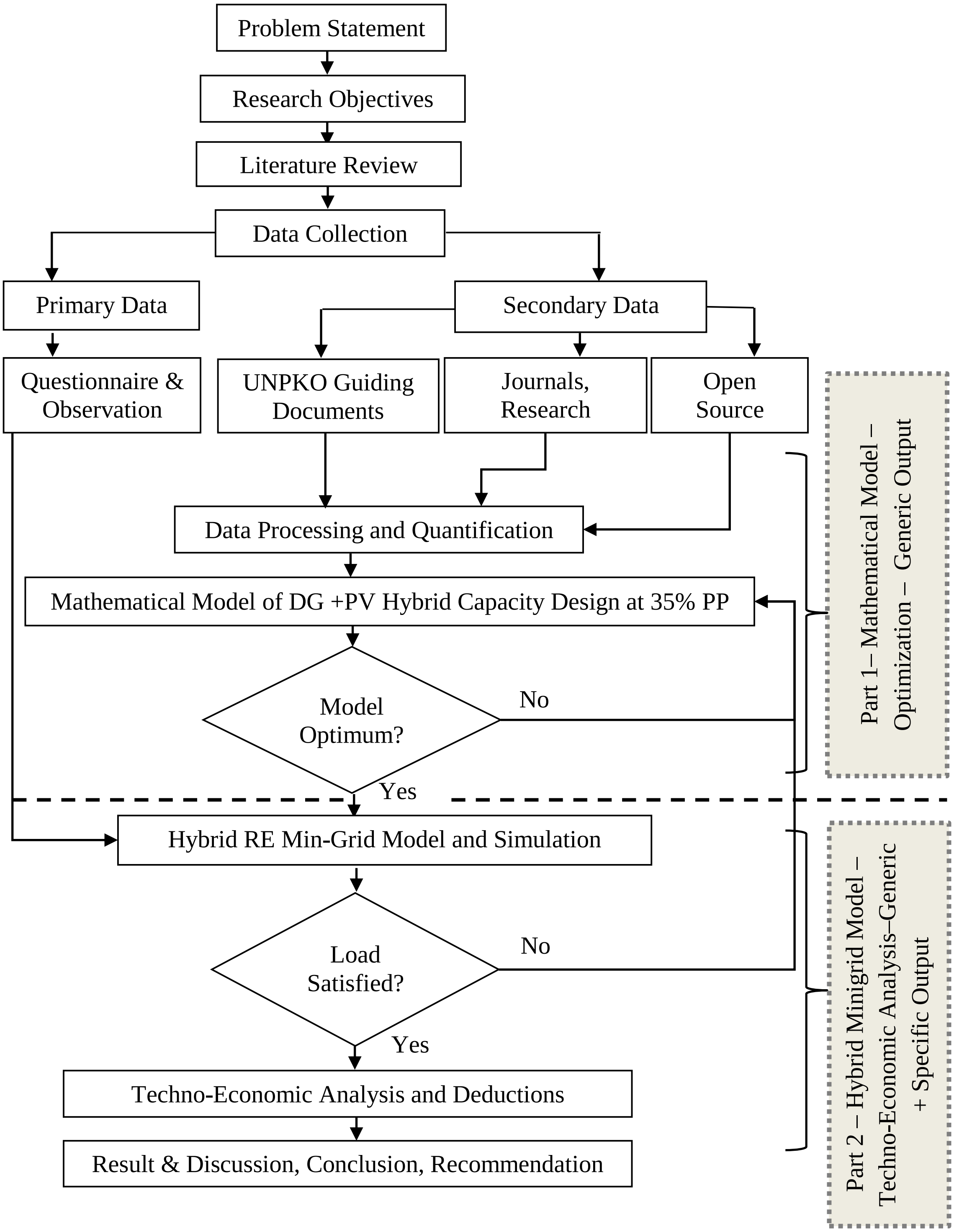


Figure 4: Research Methodology Flowchart

3.2 Details of Part 1: Capacity Optimization of HRE System at 35% PP

The DG + PV HRE system is modeled and optimized based on the discussions made on the succeeding sub-headings as:

3.2.1 DG System Compliances and Requirements

The crucial compliance standards for DG system along with the pertinent deductions are as outlined below:

i. The unit must have a Minimum Capacity or Running Capacity with the requirement of 2.5KVA per person that amounts to 622person×2.5KVA/person = 1555KVA = 1244KW (pf = 0.8) [6, p. 93].

ii. The unit should have a Backup Capacity upto 100% of the Main Capacity that can complement the alternate 12-Hours operation in case of traditional Generator only model. Hence, Backup Capacity = 1555KVA. This Backup Capacity upto 100% of Minimum Capacity is reimbursable as per the COE Manual 2023 [5, p. 47].

iii. The Maximum Capacity of Generic Battalion is, Maximum Capacity = Minimum Capacity + Surplus Capacity = 1555KVA + 1555KVA = 3110KVA (or 3110KVA×0.8 = 2488KW) which stands as the Upper limit of the total DG capacity for a generic BN unit.

iv. Analyzing each of the available slabs of DG as provisioned in COE Manual 2023, it consists a Lower and a Higher capacity where the lower capacity is nearly 70% of the higher capacity. Owing to the preference to have higher rather than lower capacity, it is justifiable to have a lower capacity of DG as 80% of Maximum reimbursable DG capacity. Hence, for the modelling purpose the lower limit of DG capacity for DG only model is set as 3110KVA×80% = 2488KVA (or 2488×0.8 = 1990KW), which is consistent with the requirement of minimum unit capacity of 1555KVA [5, p. 190].

3.2.2 DG + PV System Compliances and Requirements at 35% PP

Traditionally, the logistic power capacity requirement was supposed to be fulfilled by DG only model. As per the current policy, provisions and reimbursement modalities in UNPKO; the RE integration to replace any or all of the DGs is encouraged [5, p. 31]. Hence, the above generation capacity can be supposed to be fulfilled by DG + PV hybrid RE resources. Let us introduce following pertinent variables regarding the capacity of hybrid system for the sake of better understanding as:

i. Total Diesel Generator Capacity in KW = *DG*, where Main Generator Capacity in KW = MG & Backup Generator Capacity in KW = *BG* then, $DG = MG + BG$
ii. Total Solar PV Capacity, KWp = *PV*

Hence,

$DG + PV = 2488\text{KW}$……………………………….Equation 2

Incorporating the definition of RE Power Penetration as defined by COE Manual 2023 [5, p. 201], we have the Power Penetration (r_{COE}) as:

$$r_{COE} = \frac{PV\ (KWp)}{DG\ (KW = KVA*0.8)} = \frac{PV}{DG}$$

i.e. $PV = r_{COE} \times DG$……………………………………….…….Equation 3

combining the Equation 2 and Equation 3, we get:

$$DG + r_{COE} \times DG = 2488$$

i.e. $DG = \frac{2488}{(1+r_{COE})}$…………………….………………..Equation 4

As per the COE Manual 2023, the power penetration in the range 25%-35% i.e. r_{COE}:$25\% \leq r_{COE} \leq 35\%$ is regarded as the low power penetration. The low power penetration can keep up the mini-grid reliability and the maintenance requirement are also very low. Hence, the low-power penetration is considered adequate for the field contexts [5, p. 32]. The Low power-penetration hybrid systems do not require the BESS and can be readily incorporated to the DGs already used by the contingents [9, p. 6].

From the Equation 4, thus it can be deduced that:

If, $r_{COE} = 25\%$; $DG = \frac{2488}{(1+25\%)}$ = 1990.40KW = 1990.40/0.8KVA = 2488KVA.

If, $r_{COE} = 35\%$; $DG = \frac{2488}{(1+35\%)}$ = 1842.96KW = 1842.96/0.8KVA = 2304KVA.

Hence, the total DG capacity of low power penetration can be expected to lie within the range 2304KVA-2488KVA, and rest of the capacity for the target power-penetration to be fulfilled by the solar PV which will be selected optimally by the optimization model. This range of DG capacity is consistent with the minimum BN requirement of DG which is 1555KVA. This low penetration range is now exploited to design the capacity of the DG + PV hybrid RE system at any power-penetration within the 25%-35%, provided that the load satisfaction is not compromised later on the hybrid RE mini-grid model and simulation, or else the capacity design has to be reviewed.

The slabs of DG and PV available along with their reimbursement provisions are as depicted in the Table1 and Table 2 respectively; to be studied in conjunction with one another [5, p. 190,191]. It should be noted that, each slab of Solar PV is integrable to only a particular slab of DG as provisioned by the COE Manual 2023, so that an apparent low power penetration is maintained on an average for that particular hybrid slot of DG and PV system. However, the actual power penetration may differ from the low penetration range if the calculation is made on extreme or Total capacity basis. The integability feature of a particular slab of DG and PV system to form a hybrid RE system is further elaborated and characterized mathematically in the constraint section of the optimization model formulation.

3.2.3 Other Relevant Considerations and Assumptions

Some other important considerations and assumptions that are important from O&M, Logistic and Operational viewpoint are discussed and elaborated as below:

i. The Interchangeability: In order to maintain the interchangeability (of the DG itself or the spare parts) from Operational and Maintenance viewpoint, it is preferred to have maximum number of similar or identical generators. This is particularly of crucial importance in UNPKO owing to the fact that it is very difficult to have an adequate quality and quantity of spare parts and accessories and hence stands as one of the major O&M challenge to the wet-leasing units and sometimes even diminishes the reimbursement volume paid by the UN. Hence, in order to have the maximum number of similar DGs, the strategy of having the same number and capacity of Backup DGs as the Main DGs is employed in this study. This strategy is further supported by the provision of having employed paired Main Generators [8, p. B-4].

ii. Total No. of DGs: The Minimum numbers of Generators owing to the deployability of the unit is calculated as per general convention as: 3Gensets per Coy×4Coy + 2Gensets for Bn HQ i.e. 3×4+2 = 14Gensets. Similarly, the Maximum number of generators is the 1.5 times the minimum number i.e. 14×1.5 = 21Gensets, owing to the unit deployability, O&M burdens and flexibility etc.
iii. The Mobile DG capacity: To maintain the operational mobility and low-load operation of the grid, it is preferred to have lower size or mobile generators (individual capacity of 20-100KVA range) with cumulative capacity of at least 10% of the total DG capacity. This is particularly to serve the outdoor mobile operations (e.g. SDP, LDP, TOB, FOB, Cimic actions etc.) as part of PKOs and also to economically serve the low-load demand especially during early morning and rainy time.
iv. The RE Integrability: The overall range of generators is divided into two main categories. Firstly, the low-capacity generators (within 20-100KVA capacity range) are regarded as non-integrable to Solar PV. Secondly, the high-capacity generators (within 101-500KVA capacity range) are regarded as integrable to Solar PV in compliance with the provisions made in COE Manual 2023.
v. The Slabs of DG & PV: The sizing/selection of DGs and Solar PVs is based upon the Slab provisions and integrability made by the COE Manual 2023. Within the prescribed slabs, it is assumed that each capacity of DG or PV is available and compatible for the integration and formation of power supply system of the BN unit in UNPKO.
vi. The Generators of 500-625KVA or higher capacity are not considered in this study as no explicit reimbursement and other provisions (being special equipment) are made in COE Manual 2023 and also the DGs above 500KVA are hardly found in field applications. The same applies for the Solar PV of 121-150KWp and higher capacity.

vii. The electric load demand of a generic military (TCC) battalion is assumed to be similar to that collected by observation data for a military battalion of 700 strengths in UNMISS, Rumbek, South Sudan.

viii. The System Converter efficiency is modified to incorporate for the whole solar system efficiency owing to the input compatibility of the grid modelling software.

ix. For the project model of Hybrid system at 35% PP, the project cash outflow is mainly based upon the market-based Capital Cost, COE manual based O&M and Replacement provisions of the major components. Similarly, the project cash inflow is mainly based upon the Wet-lease reimbursement rates (without mission factors) and Salvage values of the major components.

x. The payback period and the IRR are calculated on the basis of discounted project cash flow.

3.2.4 Design Strategies of the HRE Model

Some of the major strategies while which are important from modeling and designing of the energy supply system in UNPKO are as followings:

i. Maximum Reimbursement Strategy: This is the strategy to maximize the monthly reimbursement paid by the UN to the TCC as the wet lease of the DG only or the hybrid RE system.

ii. Other Strategies: The other strategies such as GFMV based Minimum Investment, Minimum Payback-period, Maximum Renewable Energy capacity etc. can also be employed and assessed to design the model.

The maximum reimbursement strategy is the most opted and preferred strategy for the TCC deployed in the field missions. This strategy, at first sight reflects the profitability and lucrativeness of hybrid model to entice the TCC adopt the RE hybridization in the field missions. Hence, the optimization model is based on this strategy while satisfying the capacity requirements.

3.2.5 Mathematical Formulation of the Optimization Model

A mathematical model of DG + Solar PV hybrid for capacity design is formulated by incorporating the specific requirements of the hybrid system in UNPKO for Bn unit along with the pertinent deductions and assumptions made.

The hybrid system is the combination of the DG and PV system. It incorporates all the variables and constraints of DG system except that the total DG capacity changes to incorporate the Solar PV integration at low power-penetration. Further to it, the hybrid model with power-penetration of 35% (i.e. higher side of low power-penetration), is considered in this study, owing to the urgency of green transformation needed to meet impending policy targets in UNPKOs and alignment with the SDGs target. The purpose of this model is to select the optimum size and numbers of DG and PV while maximizing the monthly reimbursement acquired by the TCC. Confirming to the provisions made in COE Manual 2023, a model of DG + Solar PV hybrid system for a generic BN unit can be visualized in tabular form as below:

i. The DG System optimization as:

SN	**Slab, KVA**	**Selected Capacity, KVA**	**No. of Main Generator**	**No. of Backup Generator**	**Total No.**	**MWR, $**	**GFMV, $**
1							
…							
i	L_i - H_i	DG_i	n_i	n_i	$2n_i$	$MWR_{DG,i}$	$GFMV_{DG,i}$
…							
9							

ii. The PV system optimization as:

SN	**Slab, KWp**	**Selected Capacity, KWp**	**No. of PV Sets**	**MWR, $**	**GFMV, $**
1					
…					
j	L_j - H_j	PV_j	m_j	$MWR_{PV,j}$	$GFMV_{PV,j}$
…					
4					

Where, DG slabs i = 1 to 5 are PV Non-integrable slabs & i = 6 to 9 are PV Integrable slabs, j = 1 to 4; j exists only for i = 6 to 9.

Variables of the Model

Followings are the variables characterized for modelling purpose along with their significance.

i. DG slab (or category) serial number indicator, i = 1 to 9, i = integer
ii. Mobile (lower size) or PV Non-integrable slab is i = 1 to 5, i = integer

iii. PV Integrable slabs of DG are $i = 6$ to 9
iv. Lower and higher capacity of each slab = Li & Hi
v. Capacity of each generator = DGi
vi. No. of Main Generator from each slab = ni
vii. No. of Backup Generator from each slab = ni
viii. Total no. of generators from each slab = $2n_i$
ix. Monthly Wet-lease Reimbursement for each slab of generators = $MWR_{DG,\, i}$
x. Generic Fair Market Value (GFMV) of each Slab of generator; as defined by COE Manual 2023 = $GFMV_{DG,\, i}$
xi. Solar PV Slab serial number indicator, $j = 1$ to 4, corresponding to the PV Integrable Slab of generators i.e. $i = 6$ to 9. Hence it can be deduced that $j = i–5$ for $i = 6$ to 9, j = integer.
xii. Lower and higher range of each slab = L_j & H_j
xiii. Capacity of each PV set = PV_j; capacity in KWp
xiv. No. of PV sets from each slab = m_j
xv. Monthly Wet-lease Reimbursement for each slab of PV system = $MWR_{PV,\, j}$
xvi. Generic Fair Market Value (GFMV) of each slab of PV system; as defined by COE Manual 2023 = $GFMV_{PV,\, j}$
xvii. Decision variables = DG_i, n_i, PV_j

Constraints of the Model

The constraints derived for the modelling, simulation and optimization are as stated below

i. Capacity of each generator = DG_i where, $L_i \leq DG_i \leq H_i$
ii. Total No. of generators, $N = \sum_{i=1}^{9} 2n_i$ where, $14 \leq N \leq 21$
iii. Total DG Capacity, $DG = \sum_{i=1}^{9} 2n_i \times DG_i$ where, $2304 \leq DG \leq 2488$; capacities in KVA
iv. Mobile or Non-Integrable DG Capacity, $NDG = \sum_{i=1}^{5} 2n_i \times DG_i$
where, $NDG \geq 10\%$ of DG; capacities in KVA
v. Capacity of each PV set = PV_j where, $L_j \leq PV_j \leq H_j$
vi. Total No. of PV system, $M = \sum_{j=1}^{4} m_j$ where, $m_j = 2n_{j+5}$

vii. Integrability of DG and Solar PV characterized by variables i & j where, $j = i–5$ & $i,j > 0$; meaning j exists only for $i = 6$ to 9

viii. Renewable Power Penetration, $r_{COE} = \frac{PV\ (KWp)}{DG\ (KW = KVA * 0.8)}$

i.e., $r_{COE} = \frac{\sum_{j=1}^{4} m_j * PV_j}{\sum_{i=1}^{9} 2n_i * DG_i * 0.8}$

where, $j = i–5$; $i,j > 0$ & i,j = integee & $r_{COE} = 35\%$

ix. Variables i, n_i = integer, All variables non-negatives

Objective Function of the Model

The objective function of concern is Maximization of reimbursement maximization while satisfying the constraints stated as below:

Maximization of Total Monthly Reimbursement (TMR) of the hybrid system,

i.e. Max. $TMR_{hybrid} = TMR_{DG} + TMR_{PV}$

Hence, Max. $TMR_{hybrid} = \sum_{i=1}^{9} 2n_i \times MWR_{DG,i} + \sum_{j=1}^{4} m_j \times MWR_{PV,j}$;

where, $j = i–5$; $i,j > 0$ & i,j = integer.

Other Relevant Outcome Functions of the Model

Some other relevant functions that are important from Techno-Economic aspect of the designed system that are calculated by the model are as stated below:

i. Total PV system capacity,

i.e. $PV = \sum_{j=1}^{4} m_j \times PV_j$; Capacity in KWp; where, j = integer.

ii. GFMV based Total Investment on PV system

i.e. $TI_{PV} = \sum_{j=1}^{4} m_j \times GFMV_{PV,j}$; where, j = integer.

iii. GFMV based Simple Payback period of PV system,

i.e. $Payback_{PV}$ (years) = $\frac{\text{Total Investment}}{\text{Total Yearly Reimbursement}}$

i.e. $Payback_{PV}$ (years) = $\frac{TI_{PV}}{TMR_{DG} \times 12}$

Hence, $Payback_{PV}$ (years) = $\frac{\sum_{j=1}^{4} m_j \times GFMV_{PV,j}}{\sum_{j=1}^{4} m_j \times MWR_{PV,j} \times 12}$; where, j = integer.

iv. GFMV based Total Investment of hybrid system,

i.e. $TI_{hybrid} = TI_{DG} + TI_{PV}$

Hence, $TI_{hybrid} = \sum_{i=1}^{9} 2n_i \times GFMV_{DG,i} + \sum_{j=1}^{4} m_j \times GFMV_{PV,j}$

where, $j = i–5$; $i,j > 0$ & i,j = integer.

v. GFMV based Simple Payback period of hybrid system,

i.e. $Payback_{hybrid}$ (years) = $\frac{\text{Total Investment}}{\text{Total Yearly Reimbursement}} = \frac{TI_{hybrid}}{TMR_{hybrid} \times 12}$

Hence, $Payback_{hybrid}$ (years) = $\frac{\sum_{i=1}^{9} 2n_i \times GFMV_{DG,i} + \sum_{j=1}^{4} m_j * \times GFMV_{PV,j}}{\left(\sum_{i=1}^{9} 2n_i * \times MWR_{DG,i} + \sum_{j=1}^{4} m_j \times MWR_{PV,j}\right) \times 12}$

where, $j = i–5$; $i,j > 0$ & i,j = integer.

vi. RE Reimbursement Percentage,

i.e. $RE_{Reimb,\%} = \frac{\sum_{j=1}^{4} m_j \times MWR_{PV,j}}{\sum_{i=1}^{9} 2n_i \times MWR_{DG,i} + \sum_{j=1}^{4} m_j \times MWR_{PV,j}}$

where, $j = i–5$; $i,j > 0$ & i,j = integer.

3.2.6 Model Optimization

The mathematical model so formed is then optimized using the Microsoft excel solver tool to get the optimal selection, sizing and capacity of the DGs and PVs so that it results in maximum Total Monthly Reimbursement of the hybrid system at 35% power penetration. The outputs and other relevant deductions of the model are discussed in “Results and Discussions” chapter. Moreover, the optimal slab selection, sizing and quantity selection of the energy components are subsequently used for the Techno-Economic analysis of the HRE mini-grid model.

3.3 Details of Part 2: Techno-Economic Analysis of HRE System at 35% PP

The Techno-Economic analysis is performed after formulating the mini-grid model of the HRE system and imposing the load and resource conditions upon the model. The HOMER Pro software is used in this study to perform the grid simulation and asses the Techno-Economic analysis of the HRE system in this study.

3.3.1 Electric Load Demand for TCC Bn Unit

Demand loads are the reason, for serving of which the mini-grid systems are designed and exist [18, p. 393]. The reference electric demand load for TCC Bn unit as considered in our case is the load data collected for a military Bn unit of 700 strengths. The measurement was taken for the 24hrs on the 15th day of each month throughout the year. The monthly load data for this strength is as presented in “Appendix A”. This reference load data collected on monthly basis over a year is then linearly interpolated for a generic TCC Bn of strength 622 based on strengths. Accordingly, the average monthly variation of energy demand for a generic TCC Bn unit is shown in the Figure 5. It clearly shows the maximum load occurring in March and minimum in August and this argument is well supported by the survey conducted and available climatic data [19].

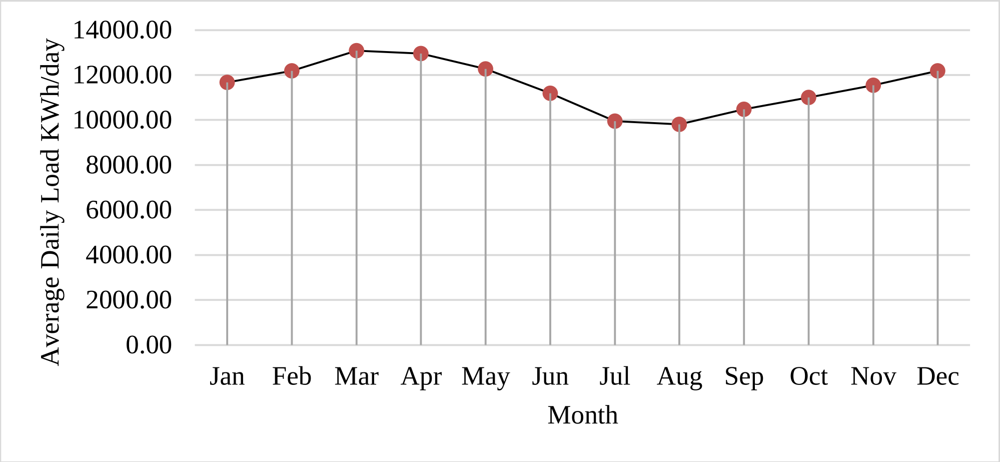


Figure 5: Monthly Average Variation of Electric Load

Since, the major share of the electric load in UNPKO of sub-Saharan Africa is constituted by the continuous cooling load, this justifies the maximum and minimum load occurring in March and August month respectively. Based on the data in “Appendix A”, the hourly average variation of electric load w.r.t. the ToD is shown in the Figure 6. These data and arguments are confirmed by the survey conducted and available open source data as well [20, p. 13].

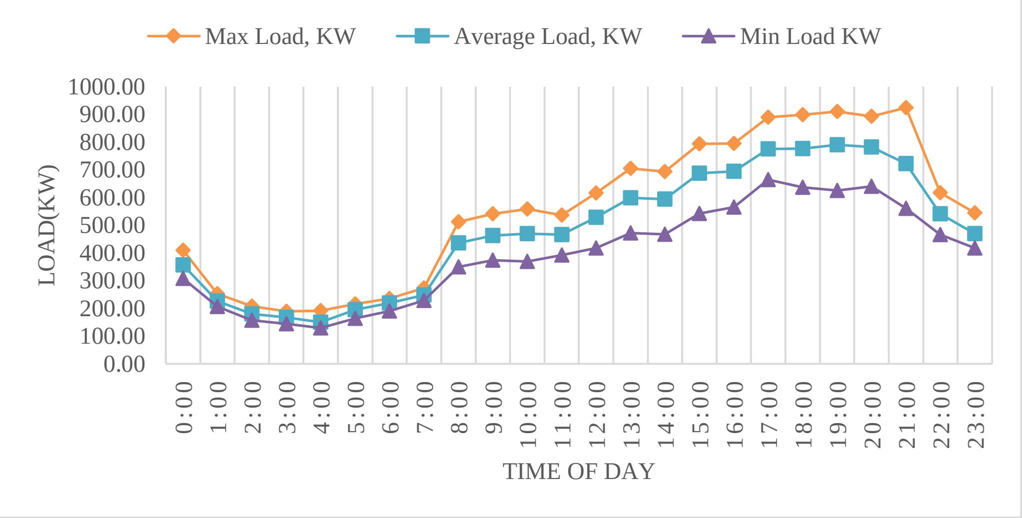


Figure 6: Daily Electric Load Variation with Time of Day

A survey was also conducted to collect and analyze the data regarding the electric load pattern and profile of the TCC Bn camp in sub-Saharan Africa. The survey followed the initial screening and then the snowball sampling method to identify the potential respondents who were/are found to be deployed at least once in UNPKO of sub-Saharan Africa as TCC members and assigned the specifically the role of logistic energy and power management during their tenure. The questionnaire included the closed-ended format for the crucial queries to comfort the respondent answering and data analysis. The details of the survey questionnaire and response analysis are outlined in “Appendix B” and “Appendix C” respectively. The summary of the survey analysis is outlined briefly as below which are applicable to the TCC Bn unit in sub-Saharan Africa:

i. All of the respondents at least once were deployed in TCC units of strength similar to Bn unit in sub-Saharan Africa. Hence, the survey data can be expected to be applicable to the TCC Bn unit in sub-Saharan Africa.

ii. The cooling load is the major constituent of the electric load constituting more than 75% share in the total electric load in TCC Bn unit.

iii. The March and August are the peak and base load month respectively; and the Evening and Morning time are the peak and base load ToD from the viewpoint of electric load in the TCC camp.

iv. The peak and base electric load generally ranges from as high as 600-900KW and as low as 100-300KW for the TCC Bn unit.

v. The electric load profile of TCC camp can be regarded as subjectively similar to the typical community load.

vi. The ambient temperature is the major factor responsible for the variation in the electric load profile. Thus, it is possible to the most extent that the temperature profile may be used to represent the electric load pattern of the TCC Bn unit.

3.3.2 Resources

Resource is something from outside the system which is used by the system to generate electric (or thermal) energy. HOMER Pro basically includes the resources like Fuel, Solar, Wind, Biomass, Hydro etc. [18, p. 395].

The Fuel: The HOMER Pro software offers a database library of common fuels and also the options for customization and addition of fuels by users [18, p. 397]. The diesel fuel is selected and used in our study.

The Solar Resource: For HOMER Pro mini-grid system containing a Solar PV array, the user must provide solar resource data for the location of interest. The Solar resource data indicate the amount of global solar radiation that strikes Earth's surface in a typical year [18, p. 395]. The Solar resource available for the study site selected as available in HOMER Pro platform is as illustrated in the Figure 7.

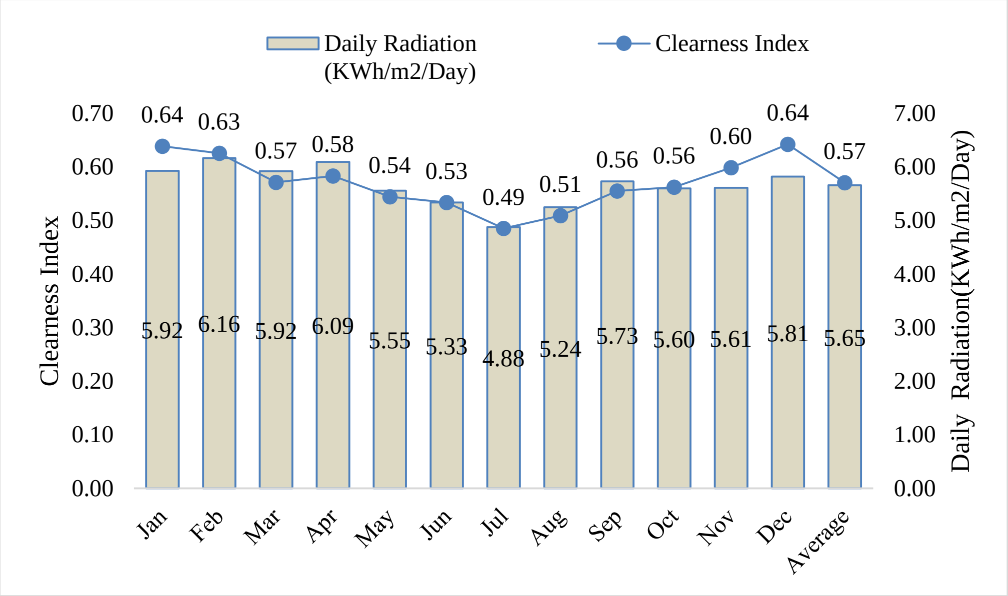


Figure 7: Solar Resource Data of UNMISS, Rumbek, South Sudan

(Source: [21])

3.3.3 Solar PV

The output power calculation of the solar PV system (P_{PV}) is performed by using the formula in Equation 5.

$$P_{PV} = Y_{PV} \times x_{PV} \times \frac{G_T}{G_{T,STC}} \times [\alpha_P \times (T_C - T_{C,STC})] \text{...........Equation 5}$$

(Source: [22, p. 18])

Where, Y_{PV} is the rated capacity of the PV array (KW), x_{PV} is the PV derating factor (%), G_T is the solar radiation incident on the PV array in the current time step (KW/m2), $G_{T,STC}$ is the incident radiation at Standard Test Conditions (1KW/m2), α_P is the temperature coefficient of power (%/^{0}C), T_c is the PV cell temperature in the current time step (^{0}C), $T_{c,STC}$ is the PV cell temperature under standard test conditions (25^{0}C).

3.3.4 Diesel Generator

The generator is an energy component that consumes fuel to produce electricity. HOMER Pro assumes a straight line fuel curve while modelling DG as depicted by Equation 6.

$$F = F_0 \times Y_{gen} + F_1 \times P_{gen} \quad \text{Equation 6}$$

(Source: [22, p. 19])

Where, F is the fuel consumption rate at current time step (L/hr), F_0 is the fuel curve intercept coefficient (L/h/KW$_{\text{rated}}$), Y_{gen} is the rated capacity of the generator (KW), F_1 is the fuel curve slope (L/h/KW$_{\text{output}}$) and P_{gen} is the electrical output of the generator (KW).

3.3.5 Convertor

A converter is a device that converts electric power from AC to DC by the process called Rectification or from DC to AC by the process called Inversion to fulfill the imposed load constraints of the design. The decision variables for choosing a converter are the size, cost and life of the converter that the user needs to specify for HOMER Pro modelling [18, p. 407].

3.3.6 Economic Analysis

The Economic Analysis in HOMER Pro encompasses a number of economic and financial principles and approaches. Some of the most common economic parameters in concern with our study are as elaborated below:

Net Present Cost (NPC): Usually the objective function of HOMER Pro modelling is the minimization of the Net Present Cost (NPC) or the Life Cycle Cost (LCC). NPC is the cumulative present values of all the system costs (e.g. capital, O&M, replacement etc.), minus the cumulative of the present values of the revenue earned over the system lifetime. The Annualized cost is first calculated by using the formula in Equation 7.

$$C_{ann,i} = \sum_i C_{capital,i} + C_{operating,i} + C_{replacement,i} + C_{fuel,i} \quad \text{Equation 7}$$

(Source: [22, p. 15])

Where, $C_{ann,i}$ is Annualized Cost, $C_{capital,i}$ is Capital Cost(used market-based capital cost in this study), $C_{operating,i}$ is O&M Cost (including the lease received), $C_{replacement,i}$ is Replacement Cost ,$C_{fuel,i}$ is Cost of Fuel and i is the equipment type.

HOMER Pro uses then uses the Annualized cost to calculate the **Net Present Cost** i.e. C_{NPC} as:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})} \text{...Equation 8}$$

(Source: [22, p. 15])

Where, $C_{ann,tot}$ is the total annualized cost, i is the annual discount rate, R_{proj} is the project lifetime, and CRF is the capital recovery factor given by Equation 9.

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \text{.....................................Equation 9}$$

(Source: [22, p. 15])

Where, N is the project life in years. The NPC incorporates all of these costs and revenues over the project lifetime into a single value in today's value with user defined discounting rate [22, pp. 14–16].

Internal Rate of Return (IRR): The IRR is that particular discount rate at which the NPC (or NPV) value assumes the zero value. It is calculated by using the the Equation 10.

$$\sum_{t=0}^{N} \frac{CF_t}{(1+IRR)^t} = 0 \text{..Equation 10}$$

(Source: [23])

Where, CF_t is the net cash flow in the year t, N is the project life in years, IRR is the internal rate of return value to be calculated.

Discounted Payback Period (DPB): The discounted payback is calculated manually by observing the yearly discounted cash flow throughout the project life and finding the point of time (in years) where the capital is just recovered. It is calculated by using the Equation 11.

$$DPB(years) = YBB + \frac{C_{rem}}{CF_{BEY}} \text{..................................Equation 11}$$

(Source: [24])

Where, *YBB* is the Year Before Breakeven, C_{rem} is the capital recovery remaining, CF_{BEY} is the discounted cash flow of the breakeven year.

Levelized Cost of Energy (LCOE): The average price of energy per kilowatt-hour provided by the mini-grid system designed is referred to as the Levelized Cost of Energy. HOMER Pro calculates the Levelized Cost of Energy using Equation 12.

$$LCOE = \frac{C_{ann,tot}}{E_{Prim}+E_{def}+E_{grid,sales}} \text{……………………..…..Equation 12}$$

(Source: [22, p. 16])

Where, E_{prim} is Primary Load, E_{def} is Deferrable Load and $E_{grid,sales}$ is Electrical Energy sold to the grid (if any) each year.

Salvage Value: To calculate the salvage value of each component at the end of the project lifetime, HOMER Pro uses the formula in Equation 13.

$$S = C_{rep} \times \frac{R_{rem}}{R_{comp}} \text{…………..…………………..…….……Equation 13}$$

(Source: [18, p. 415])

Where, S is Salvage Value, C_{rep} is Replacement Cost of component, R_{rem} is Remaining Life of component, and R_{comp} is Total Lifetime of the component.

3.3.7 Emission Analysis

The environmental concerns related to carbon emissions are one of the crucial and indispensable problems in any hybrid mini-grid system configuration. The amount of CO_2 emissions can be calculated based on Equation 14.

$$T_{CO2} = 3.667 \times V_f \times X_c \times F_{hv} \times F_{cef} \text{………………………Equation 14}$$

(Source: [25, p. 9])

Where, T_{CO2} is the amount of CO_2 emissions, V_f is the fuel consumption in liter, and X_c is the oxidized carbon fraction, F_{hv} is the heating value of fuel (MJ/L) and F_{cef} is the carbon emission factor (ton carbon/TJ).

3.3.8 Summary of the Hybrid Mini-grid Model

The Hybrid RE Mini-grid system based on the mathematical model of optimum capacity design is imposed with the Electric Load, Resources and other relevant mini-grid parameters using the HOMER Pro software. The summary of the parameters set for DG + PV Hybrid system in HOMER Pro model is depicted in the Table 5.

Table 5: Summary of HRE Mini-grid Model in HOMER Pro

Parameters	**Value**	**Details**	**Reference/Comment**
Load			
Load Profile		Based on Collected Monthly data throughout the year	Appendix A
Annual Average of Daily Load	11520.31KWh/day	Based on Collected Monthly data throughout the year	Appendix A
Random Variability			
Day-to-Day	10%		User Defined; Only 10% random variation allowed
Time step	5%		User Defined; more adherence to the collected data for time step variability
Components			
DG: Customized for UNPKO Framework			
DG Capacity	990KW per DG Bank×2DG Banks	MG Bank = 990KW, BG Bank = 990KW	From Mathematical Model for capacity design, DG + PV Hybrid mode, Low-power penetration of 35%.
Capital Cost	250$/KW	Market Observation of DG Price; Jakson CUMMINS Model, No shipment charge incurred to TCC; Shipment by the UN	[26], [5, p. 141]
Replacement Cost	250$/KW		Same As Capital Cost
O&M Cost			Considered in Maintenance

			section of respective DG component
Minimum Load Ratio	3.29%	Smallest independent DG Unit in the DG Bank	From Mathematical Model for capacity design
Lifetime Hours	20,000Hrs	As recommended by COE Manual 2023	[5, p. 48]
Minimum Runtime	6Hrs		Alternate and continuous running
Fuel Cost	0		No POL/FOL cost incurred to TCC since it is provided by UN
Fuel	Diesel		
Fuel Curve		Generic for Medium size DG, Linear fuel curve	[27]
Emission		Generic for Medium size DG; Based on fuel composition	HOMER Pro defined for diesel fuel
Maintenance			
Rest	After 6Hrs	Operating hour; Downtime 6 Hrs., Cost = 0	Scheduled Rest
Servicing	After 1,000Hrs	Operating Hour; Downtime 2 Hrs., Cost = 250×1%×990= 2475$	Cost Assumption: Average of 1% of capital cost incurred at each servicing for spare-parts and tools.
Overhaul	After 10,000Hrs	Operating Hour; Downtime 6 Hrs., Cost = 250×10%×990 = 24750$	Cost Assumption: Average of 10% of capital cost incurred at each Overhaul.
Reimbursement	In every 1 Month = 24×30 = 720Hrs	Calendar Hour, Downtime = 0, Value = -22064/2 = -11032$	Mathematical Model for capacity design, Reimbursement earned every month.

PV: Generic Flat Plate PV, Customized for UNPKO Framework			
PV Capacity	693KWp		Mathematical Model for capacity design, Low-power penetration of 35%.
Capital Cost	758$/KWp	Installation of complete PV set without BESS	[28]
O&M Cost	-280.93$/KWp/Yr	Negative sign represents the lease rate earned by the TCC Bn for PV System.	Mathematical Model for capacity design, Based on Reimbursement earned every month.
Life	7Yrs		[5, p. 191]
Derating Factor	80%		Generic for PV
Consider Temperature Effect		Enabled	
Temperature Coeff.	-0.5%/Deg.C		Generic for PV
NOCT	47Deg.C		Generic for PV
Eff. At Test Condition	13%		Generic for PV
Converter: Generic System Converter, Customized for UNPKO Framework			
Capacity	866KW	693×1.25=866KW; 1.25Times the PV Capacity	Converter Capacity KW = PV Capacity KWp×1.25
Capital Cost	40$/KW	Average of Data Available	[29]
Efficiency	71.25%	Efficiency = PV Eff.×Conv. Eff. = 75%×95% = 71.25%	Efficiency for the whole Solar PV as a single system is accounted for
Resources			
Solar Resource Data	Location specific Data		Provided by NREL source at HOMER Pro platform

Projects			
Nominal Discount Rate	8%		User defined
Inflation Rate	2%	Inflation rate for Dollar	[30]
Annual Capacity Shortage	0%		No Capacity shortage allowed
Project Life	12yrs	Average of durations of the previous and ongoing UNPKO deployment	[31]
Location	Lat, Long: 6^{0}50.3’N, 29^{0}40.3’E	UNMISS Camp, Rumbek, South Sudan	HOMER Pro Location Tracker. Refer the Note

Note: The location selection for the grid performance analysis is as depicted in Figure 8.

Figure 8: UNMISS Camp Location Selection for Grid Performance Analysis

3.3.9 Hybrid Mini-grid Performance Evaluation Tool

The hybrid mini-grid model is injected in HOMER Pro for simulation to assess the Techno-Economic outcomes of the mini-grid. The simulation yields the comprehensive technical as well as economic data of the hybrid mini-grid model for the whole 8,760hours of a year throughout the project life years. The techno-economic data are then analyzed to assess the concrete results which are useful for the TCC Bn unit in UNPKO.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Optimum Capacity of DG + PV HRES at 35% Power-Penetration

The capacity design model for maximum reimbursement strategy yields the optimum decision variable as elaborated in the Table 6 and Table 7 as:

Table 6: DG System optimum sizing and capacity for hybrid system at 35% PP

SN	From, KVA	To, KVA	Selected, KVA	Nos. Main	Nos. Backup	Nos. Total	GFMV, $	MWR, $
1	**20**	**30**	**20.37**	**2**	**2**	**4**	**43003**	**461**
2	31	40	31.00	0	0	0	45544	522
3	**41**	**50**	**42.58**	**2**	**2**	**4**	**60084**	**631**
4	51	75	51.00	0	0	0	72965	739
5	76	100	76.00	0	0	0	77648	795
6	**101**	**150**	**101.00**	**1**	**1**	**2**	**88859**	**928**
7	151	200	151.00	0	0	0	116506	1115
8	**201**	**330**	**201.91**	**5**	**5**	**10**	**167360**	**1584**
9	331	500	331.00	0	0	0	167360	1584

Table 7: PV System optimum sizing and capacity for hybrid system at 35% PP

SN	From, KWp	To, KWp	Selected, KWp	Set	GFMV, $	MWR, $
1	**24**	**36**	**36.00**	**2**	**49740**	**690**
2	37	48	45.21	0	70434	978
3	**49**	**80**	**62.04**	**10**	**106860**	**1483**
4	81	120	118.69	0	166860	2311

The output Tables clearly show the selection and number of DGs from the slabs 20-30KVA, 41-50KVA, 151-200KVA, 101-150KVA & 201-330KVA while other slabs being not optimal and hence not selected. Similarly, the PVs are selected from 24-36KWp and 49-80KWp while other slabs being not optimal. It should also be noted that the integrability of DGs and PVs is well complied by the model both in numbers and slab compatibility of the components.

(**Note**: The Bold values within the optimization tables represent the optimal selections and sizing, while the shaded cells represent the slab RE integrability on sequential order).

Furthermore, the objective function and summary of other relevant model outputs are as illustrated in the Table 8.

Table 8: The Objective Function and other Model Outputs of Optimum System

Strategy	**Design Selection (Nos.×KVA or KWp)**	**Output**	**Values**	**Remarks**
Maximum Reimbursement	DG: 4×20.37+4×42.58+2×101+10×201.91 (MG = BG = 2×20.37+2×42.58+1×101+5×201.91 = 1236.46KVA = 989.2KW)	**DG System**		
		Number of generators	20	
		Main Generator Capacity, KW	989.2	
		Backup Generator Capacity, KW	989.2	
		Total DG Capacity, KVA	2,472.91	
		Mobile DG Capacity, KVA	251.77	
		DG Reimbursement, $/Month	22,064.00	
		GFMV Based DG Investment, $	2,263,666.00	
		DG System Simple Payback, years	8.55	
	PV: 2×36+10×62.04	**PV System**		
		Total PV Capacity, KWp	692.42	
		PV Reimbursement, $/Month	16,210.00	
		GFMV Based PV Investment, $	1,168,080.00	
		PV System Simple Payback, years	6.00	
	DG + PV	**Hybrid System**		
		Total Reimbursement, $/Month	38,274.00	Max
		RE Penetration in Total	35.00%	35%
		GFMV based Total Investment, $	3,431,746.00	
		GFMV based Simple Payback, years	7.47	
		RE Reimbursement % (PV Reimbursement/Total Reimbursement), %	42.35%	

The Table 8 clearly shows that the monthly reimbursement for the optimized DG + PV hybrid system is 38,274.00$/Month, with total of 20 DGs from different slabs and cumulative DG capacity of 2472.91KVA (~2,473KVA) along with cumulative PV capacity of 692.42KWp (~693KWp). Each of the Main and Backup generator capacity is 989.2KW (~990KW). The GFMV based upfront investment is around $3.4M and simple payback period is 7.47years for the optimal hybrid system. Also, the RE component occupy the share of 42.35% in total reimbursement.

It can also be assessed from the same model that if the system is not properly optimized or if the DG and PV selections are poor, the monthly reimbursement may reduce as low as 26,134.00$/Month satisfying all the constraints and still maintaining the same power-penetration of 35% (Details in “Appendix D”). This is possible due to the slab provision and integrability feature of the DG and PV components. The selection movement within the slab causes the capacity to change while fixing the reimbursement, whereas the selection shifting through the slabs causes the variation both in capacity and reimbursement. This is where the reimbursement maximization strategy even for a particular value of power penetration finds its application. It constrains the model along with optimally selecting the physically and economically significant values in terms of the selection, sizing and profitability of the model.

4.2 Techno-Economic Analysis of DG + PV HRES at 35% Power-penetration

4.2.1 System Architecture

The system Architecture of DG + PV hybrid system at 35% Power-penetration system is shown in Figure 9.

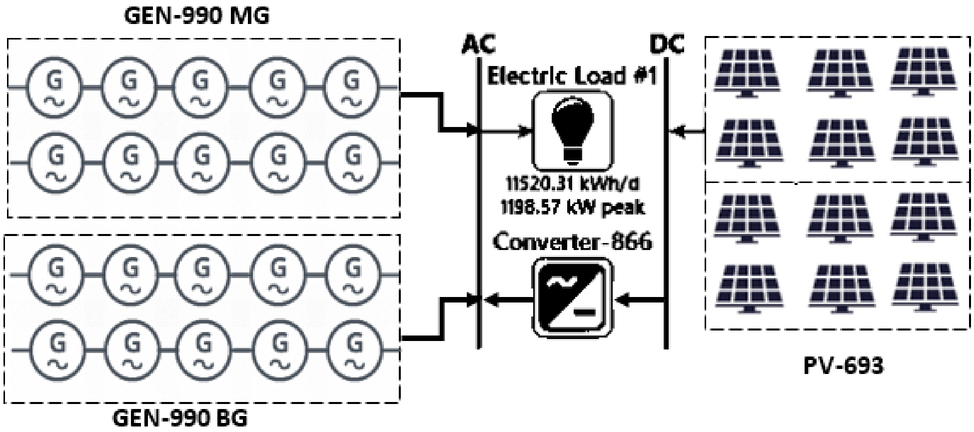


Figure 9: System Architecture of HRE System at 35% PP for Bn Unit in UNPKO

The Architecture consists of two DG banks of MG and BG each bank consisting of DG capacity of 990KW and total cumulative DG capacity of 1980KW connected to AC bus along with solar PV of capacity 693KWp connected to DC bus and system converter of capacity 866KW that bridges the AC and DC buses. The hybrid system is able to satisfy the electric load of Bn unit.

4.2.2 Electrical Summary

The electrical summary is outlined in production and consumption basis as in the Table 9.

Table 9: Electrical Summary of HRE System at 35% PP

Production Summary			**Consumption Summary**		
Component	**Production (KWh/yr)**	**Share, %**	**Component**	**Consumption (KWh/yr)**	**Share, %**
PV-693	1,019,758	22.7	AC Primary Load	4,201,867	100
Gen990-MG	1,437,883	32.0	DC Primary Load	0	0
Gen990-BG	2,037,542	45.3	Deferrable Load	0	0
Total	**4,495,183**	**100**	**Total**	**4,201,867**	**100**

The system total energy production is 4,495,183KWh/yr where the contributions of system components viz. Gen990-MG, Gen990-BG and PV-693 are 32.0%, 45.3% and 22.7% respectively. The contribution of DG Bank Gen990-BG is highest due to the fact that it is scheduled to run during the peak load hours by the HOMER Pro for optimized performance. On the other hand, AC Electric load being the only load consumes all the energy produced by the hybrid system after deducting the losses.

4.2.3 Generator Performance: Gen990-MG & Gen990-BG

The overall summary of generator performance is elaborated in the Table 10:

Table 10: Generators Grid Performance Summary

Generator Summary	**Parameter**	**Value**	
		Gen990-MG	**Gen990-BG**
Electrical Summary	Electrical Production, KWh/yr	1,437,883	2,037,542
	Mean Electrical Output, KW	328	465

	Minimum Electrical Output, KW	32.6	32.6
	Maximum Electrical Output, KW	990	990
Fuel Summary	Fuel Consumption, L/yr	291,376	407,904
	Specific Fuel Consumption, L/KWh	0.203	0.200
	Fuel Energy Input, KWh/yr	2,867,140	4,013,780
	Mean Electrical Efficiency, %	50.2	50.8
Other Statistics	Hours of Operation, hrs/yr	4,380	4,380
	Number of Starts, starts/yr	730	730
	Operational Life, yr	4.57	4.57
	Capacity Factor, %	16.6	23.5
	Fixed Generation Cost, $/hr	17.3	17.3

The minimum electrical output of 32.6KW is possible as the DG bank has minimum load ratio of 3.29%. Also, the maximum electrical output of 990KW is allowed because the generators are expected to operate upto the 110% of the nominal power rating for instantaneous basis [5, p. 47].

Gen990-MG Output (KW) Profile: The MG bank is scheduled to operate in the 00.00-06.00hrs & 12.00-18.00hrs, designated as the 1st and 2nd shift respectively in this context.

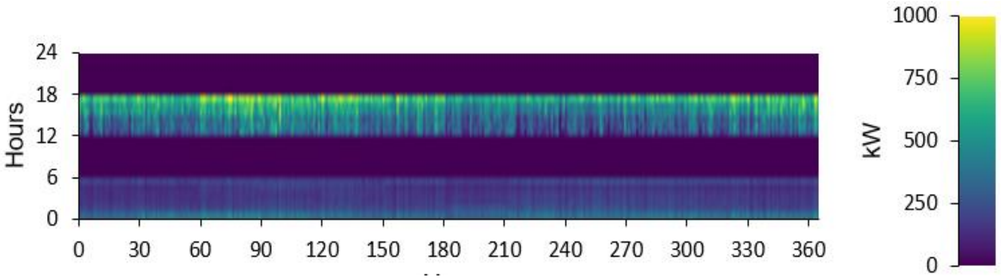


Figure 10: Gen990-MG Output (KW)

In the 1st shift, the MG bank is mostly operational at around below 50% of its total capacity, which is sufficient in the 1st shift particularly due to the lower load. While in the 2nd shift, it is mostly operational at around above 50% of its total capacity. This is because, in the 2nd shift, the load peaks up and solar PV is also available. The load is preferably satisfied by the solar PV, but at the time of solar PV being insufficient and solar resource being absent, the load has to be satisfied by the MG bank and hence the MG bank generation upsurges.

Gen990-BG Output (KW) Profile: The BG bank is scheduled to operate in the 00.60-12.00hrs & 18.00-24.00hrs, designated as the 1st and 2nd shift respectively in this context.

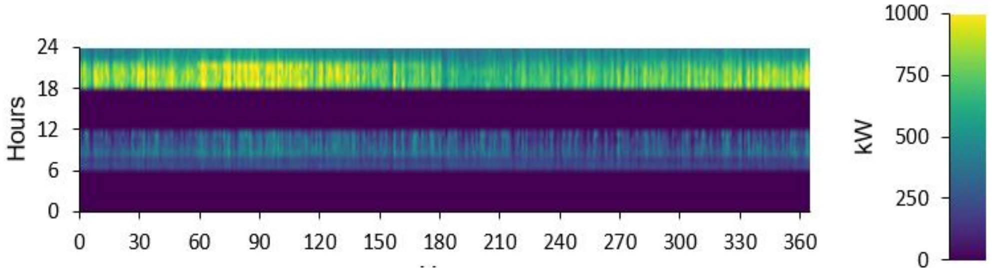


Figure 11: Gen990-BG Output (KW)

In the 1st shift, the BG bank is mostly operational at around below 50% of its total capacity, which is sufficient in the 1st shift due to the lower load and consumption preference from solar PV which is possible at this time. However, in the 2nd shift, it is mostly operational at around above 50% of its total capacity, because in the 2nd shift, the load peaks up and the solar PV is not available, and hence the BG bank generation upsurges.

4.2.4 PV Performance: PV-693

The performance of PV-693 is elaborated in the following Table 11.

Table 11: Solar PV Grid Performance Summary

PV-693 Summary	Parameter	Value
General Statistics	Rated Capacity, KW	693
	Mean Output, KW	116
	Mean Output, KWh/d	2,794
	Capacity Factor, %	16.8
	Total Production, KWh/yr	1,019,758
Electrical Summary	Minimum Output, KW	0
	Maximum Output, KW	543
	Hours of Operation, hrs/yr	4,380
	Levelized Cost, $/KWh	-0.0977

The solar PV mean output is 116KW on power basis and 2,794KWh/d on daily energy basis. The capacity factor of solar PV i.e. the ratio of mean output (KW) to rated capacity (KWp) is 16.8%.

The output of solar PV ranges from 0 to 543KW with the PV being operational for half of the yearly hour on cumulative basis. Also, the levelized cost of electric energy generated from PV being -0.0977$/KWh, negative sign indicating that actually a levelized revenue is generated from solar PV on net basis to the TCC.

PV-693 Output (KW) Profile: The solar PV output is obviously being dependent upon the solar resource available, is abundant from morning to evening and peak generation occurring around noon. In some of the days of the year, the solar power generation is low or even zero. This is because of the unavailability of solar resource due to the cloudy and rainy circumstances, the data for which are provided by NREL data at HOMER Pro platform.

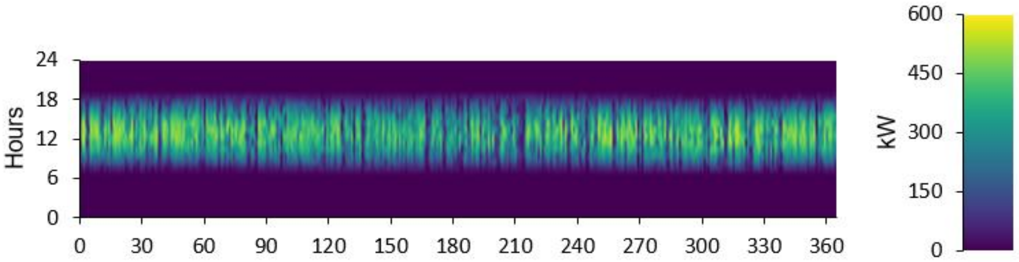


Figure 12: PV-693 Output (KW)

4.2.5 Converter Performance: System Converter-866

The performance of System Converter-866 is elaborated in the Table 12.

Table 12: System Converter Grid Performance Summary

System Converter-866 Summary	**Parameter**	**Value**
General Statistics	Capacity, KW	866
	Mean Output, KW	82.9
	Minimum Output, KW	0
	Maximum Output, KW	387
	Capacity Factor, %	9.58

Electrical Summary	Hours of Operation, hrs/yr	4,380
	Energy Out, KWh/yr	726,442
	Energy In, KWh/yr	1,019,568
	Losses, KWh/yr	293,126

The mean, minimum and maximum output of the System Converter are 82.9KW,0KW and 387KW, with a capacity factor of 9.58%. The maximum output of 387KW also implies that the same hybrid system at 35% power penetration can also be modeled with a System Converter of around 387KW×SF = 387KW×1.25 ≅ 484KW (SF being the user defined safety factor, generally taken as 1.25).

The system converter is operational for around half of the hours of the yearly hour, parallel to the solar PV. The losses occurring in system converter is 293,126KWh/yr, it also incorporates the various system losses in a complete solar PV system such as columbic loss, dust & cable loss, converter loss etc.

System Converter-866 Output (KW) Profile: The System Converter output is similar in pattern to the solar PV output due to their simultaneous operation during the time of solar resource availability. The difference in magnitude of output implies the incorporation of losses in the System Converter.

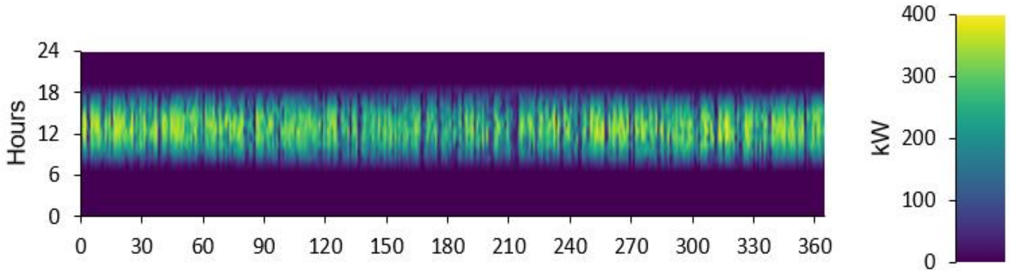


Figure 13: System Converter-866 Inverter Output (KW)

4.2.6 Fuel Consumption Summary

The fuel consumption by the hybrid min-grid at 35% PP is as summarized in following sub-topics as:

Diesel Consumption Statistics: The total diesel fuel consumed by the hybrid system is 699,280L/yr, with average fuel per day and hour being 1,916L/day and 79.8L/hour respectively.

Table 13: Diesel Consumption Statistics of the HRES for Bn unit at 35% PP

Quantity	**Value**
Total fuel consumed, L/yr	699,280
Average fuel per day, L/day	1,916
Average fuel per hour, L/hour	79.8

The average generator fuel consumption per capita per day for BN unit can be calculated as 1,916L/day ÷ 622cap = 3.08L/day/cap. The all mission average of this value (UNOE and COE) in 2022/23 was found to be 3.7L/day/cap when Renewable Energy integration was at 7% on consumed electricity basis [12, p. 3]. Owing to this fuel data of the year 2022/23, it can easily be deduced that; with the hybrid RE power-penetration of 35%; the generator fuel consumption would reduce by around (3.7-3.08)÷3.7 = 0.1676 = 16.76%, yielding a total fuel saving of around (3.7-3.08)L/day/cap×622cap×365days/yr = 141KL/yr for a military Bn unit. The same pattern of RE hybridization; if followed in all the military components of the UNPKO; would save the generator fuel of around (3.7-3.08)L/day/cap×53,549cap×365days/yr = 12.11ML/yr on an average.

Diesel Consumption (L/hr) Profile: The diesel consumption pattern of the HRES min-grid is elaborated as follows:

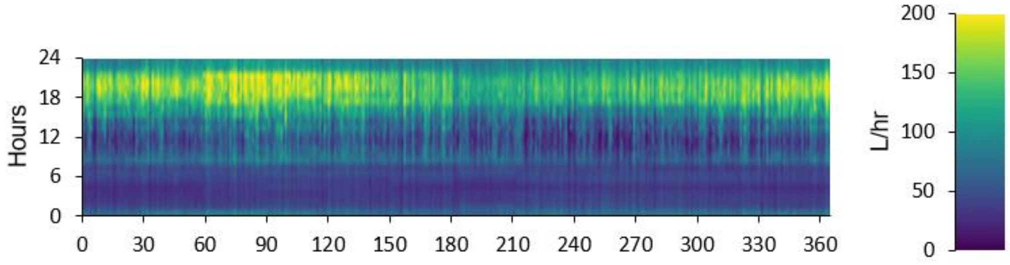


Figure 14: Diesel Consumption (L/hr) of HRES for Bn in UNPKO at 35% PP

The pattern of daily diesel fuel consumption is mostly at around 50% of its peak value. However, at around 20.00hours of the day, the consumption pattern upsurges upto the peak value of around 200L/hr. The upsurge is primarily because of the peak load occurring at this time and the load is fully satisfied by the DG bank only; as the solar resource is insignificant or absent. In some of the days usually in rainy season, the electric load doesn't peak as regular due to the cooling electric load reduction by the rainfall, which reduces the generator fuel consumption.

4.2.7 Emissions Summary

The summary of emission by the HRES is expressed in Table 14.

Table 14: Emissions Summary of Hybrid system for Bn in UNPKO at 35% PP

Pollutants	**Quantity**
Carbon Dioxide, kg/yr	1,833,671
Carbon Monoxide, kg/yr	9,486
Unburned Hydrocarbons, kg/yr	503
Particulate Matter, kg/yr	81.1
Sulfur Dioxide, kg/yr	4,482
Nitrogen Oxides, kg/yr	1,818

The Carbon dioxide (CO_2) emission because of the fossil fuel burn in DGs of the hybrid system is 1,883,671kg/yr, which when calculated in tonnesCO_2/yr/cap basis yields (1,883,671kg/yr÷1000tonne/kg)÷622cap = 3.03tonnesCO_2/yr/cap. The all mission average of GHG emission for the year 2022/23 was reported to be 7.5tonnesCO_2/yr/cap [12, p. 3]. The huge discrepancy in these values is because of the fact that the calculated emission value accounts for the GHG emission from COE generators only, while the latter sourced emission value accounts for the GHG emission from the UNOE DGs, mission Aviation, COE DGs, Transport and other miscellaneous sectors of the mission. The argument is further supported by the fact that the COE generators are the third major source of GHG emissions in UNPKO, the first and the second major contributor being the UNOE DGs and the mission Aviation [9, p. 1].

The GHG emission reduction; if followed the same pattern of RE hybridization in all the military contingent units of the UNPKO as calculated from the DG fuel saving is 12.11ML/yr×10^6L/ML×2.6KgCO_2/L×1tonne/1000Kg) ÷ 53,549Cap = 0.59tonneCO_2/Cap/yr on an average basis (CO_2 Emission per Liter of diesel taken as 2.6Kg/L [32]).

4.2.8 Renewable Energy Summary

The Renewable Energy part of the HRES can be summarized based on capacity, energy or peak-value based metrics.

Table 15: Renewable Energy Summary of the HRE system at 35% PP

Renewable Metrics	Parameters	Values
Capacity-Based Metrics	Nominal renewable capacity divided by total nominal capacity, %	25.9
Energy-Based Metrics	Total renewable production divided by generation, %	22.7
	One minus total nonrenewable production divided by load, %	17.3
Peak-Value Metrics	Renewable output divided by total generation, %	93.9

The Capacity-Based Metrics present the renewable data based on design capacity. The link between Nominal Renewable capacity divided by total nominal capacity (denoted here as r_{Homer}) and RE integration in COE Manual 2023 (denoted here as r_{COE} can be expressed as below:

Let us denote, the Solar PV Capacity in KWp = PV

& DG Capacity in KW = DG

Then, the total Generation Capacity = PV + DG

RE Penetration as per COE Manual 2023, $r_{COE} = PV/DG$

RE Penetration as per Homer Pro, $r_{Homer} = PV/(DG + PV) = 1/(1+DG/PV)$

i.e. $r_{Homer} = r_{COE}/(1+ r_{COE})$

Hence, for $r_{COE} = 35\% = 0.35$; $r_{Homer} = 0.35/(1+0.35) = 0.259 = 25.9\%$

The Energy-Based Metrics are calculated on hourly basis for the whole year. One of the important energy-metric is ‘One minus total non-RE production divided by load’. This value typically represents the share of pure renewable energy in consumed load, which is 17.3% for the designed hybrid system at 35% RE penetration. The similar metric on mission average basis was reported to have 7% value in 2022/23 when the RE integration was in very introductory stage [12, p. 3]. Hence, it is deemed essential for the UN to opt for medium or high power-penetration and renewable energy storage system (such as BESS) so as to achieve the ambitious and impending renewable energy targets in peacekeeping framework.

The Peak-Value Metrics represent the instantaneous behavior of the hybrid system. It implies that in some of the times of entire mini-grid operation the renewable output reaches as high as 93.9% of the total generation.

Renewable Output Profile as Percentage of Total Generation

The instantaneous renewable output on daily basis throughout the year shows that the RE output share significant from around 07.00-18.00hrs and is maximum around the midday throughout the year.

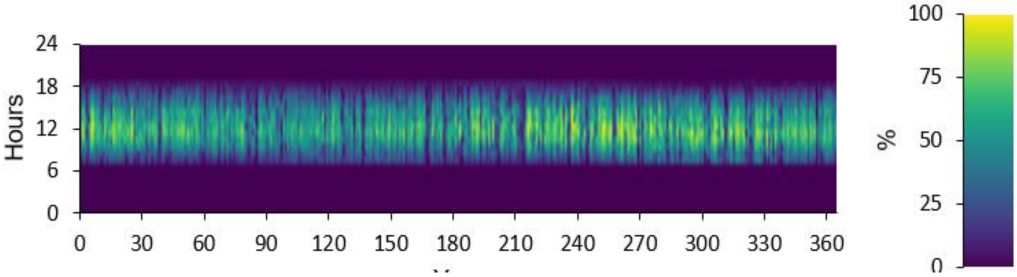


Figure 15: Instantaneous Renewable Output Percentage of Total Generation

4.2.9 Mini-Grid Hourly Operational Plan

The hourly mini-grid operational plan for the whole year i.e. 8,760hrs is deduced in the form of graphical chart from the time-series data of HOMER Pro simulation result. The operational plan is important tool to overview the technical functioning of the various energy components, demand load satiation and power supply pattern of the hybrid mini-grid system.

The grid operational plan is also important from the viewpoint of O&M administration and technical planning of the mini-grid. A typical sample of the designed HRE mini-grid for 15th of March (the Peak-load month of the year) is depicted in the Figure 16. The other Mini-Grid Hourly Operational Plan of the hybrid system for 15th day of each month over a year is depicted in “Appendix E”.

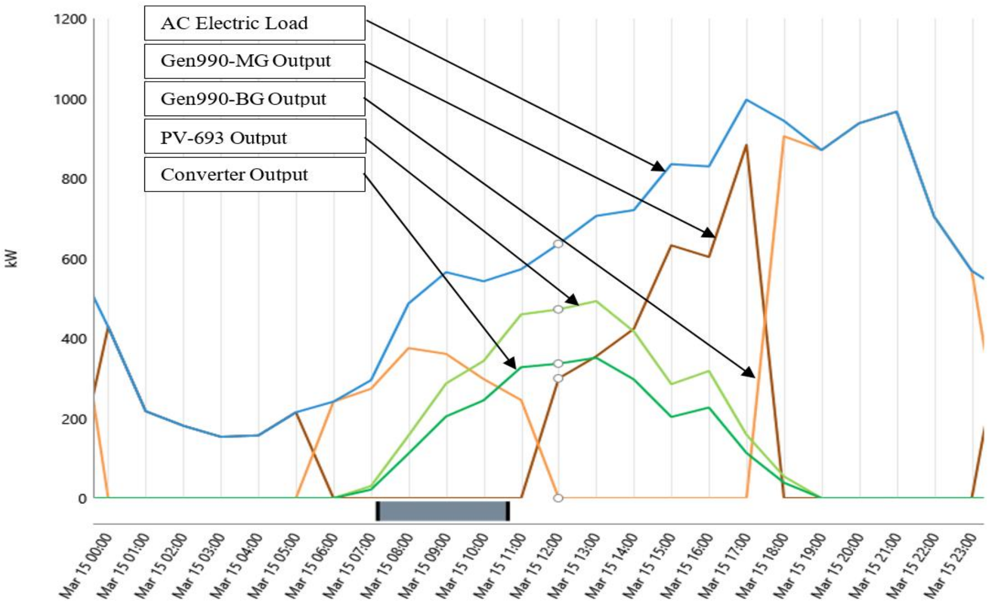


Figure 16: Mini-Grid Hourly Operational Plan on 15th of March

4.2.10 Cost Summary

The NPC of the hybrid system over the project life time is -$1.67M. The negative sign indicating the credit (or the positive cash flow) to the TCC as a result of wet-lease of the system for UNPKO by the TCC. Similarly, the LCOE for the system is -0.0472$/KWh; negative sign indicating the credit is earned per unit energy by the TCC.

Table 16: NPC Summary of HRE System at 35% PP for Bn Unit in UNPKO

Name	Capital	Operating	Replacement	Salvage	Total
Gen990-BG	$247,500	-$979,375	$337,496	-$48,037	-$442,416
Gen990-MG	$247,500	-$979,375	$337,496	-$48,037	-$442,416
PV-693	$525,294	-$1.64M	$352,077	-$75,588	-$841,000
Converter-866	$34,640	$0.00	$23,217	-$4,985	$52,873
System	$1.05M	-$3.60M	$1.05M	-$176,646	-$1.67M

The Capital and Replacement costs occupy the major share to increase the NPC (i.e. reduce NPV) value while the Operating revenue which is basically the wet-lease reimbursement) and Salvage value occupy the major share to decrease the NPC (i.e. increase NPV) value. Also, the cost of the resource is zero as the resource i.e. Fuel and Solar resource cost nothing to the TCC. The replacement cost of DGs exceed the original capital cost as there are two replacements needed, while that of PV and converter is less than the original capital cost due to only one replacement of the same during the entire project life.

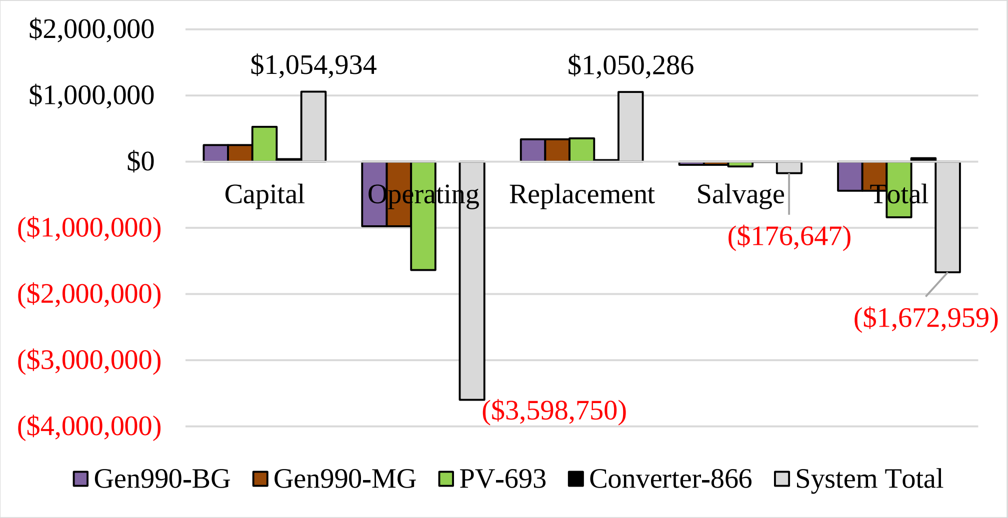


Figure 17: NPC Composition of HRE System at 35% PP for Bn in UNPKO

Additionally, the green share or the contributions from renewable resource on the total NPV is 47% as depicted in the Figure 18.

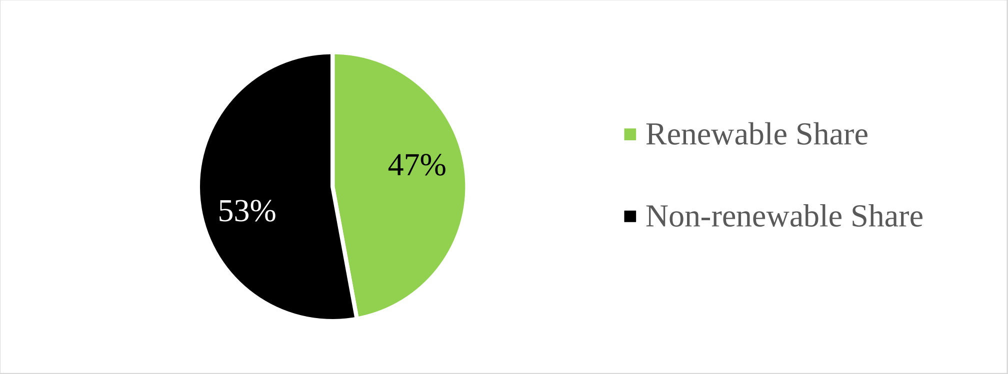


Figure 18: NPV Contribution from Renewable and Non-renewable Source

4.2.11 Cash Flow

The cash flow of the DG + PV hybrid system at 35% PP is similar to the typical investment (lending) project cash flow. The cash flows for the entire project life are shown in the Figure 19 and Figure 20:

The cash flow charts clearly show that the project cash flow initially consists of the upfront investment cost for DG, PV and System converter. The successive years then generate revenue i.e. cash inflow via wet-lease reimbursement along with the regular reduction in the cash inflow due to discounting effect and DG servicing/overhaul cost incurred to the TCC.

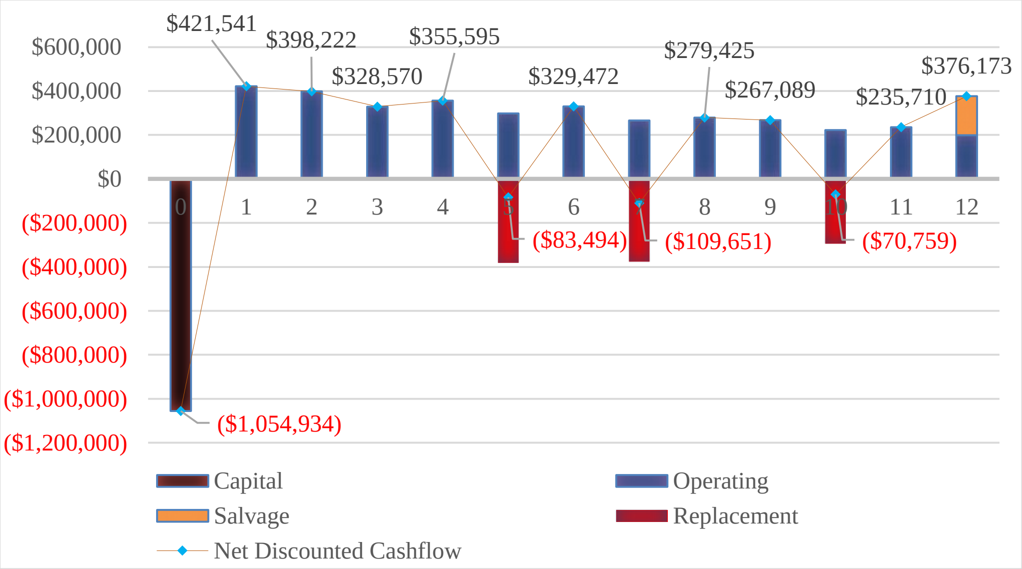


Figure 19: Discounted Project Cash Flow Based on Cost Type

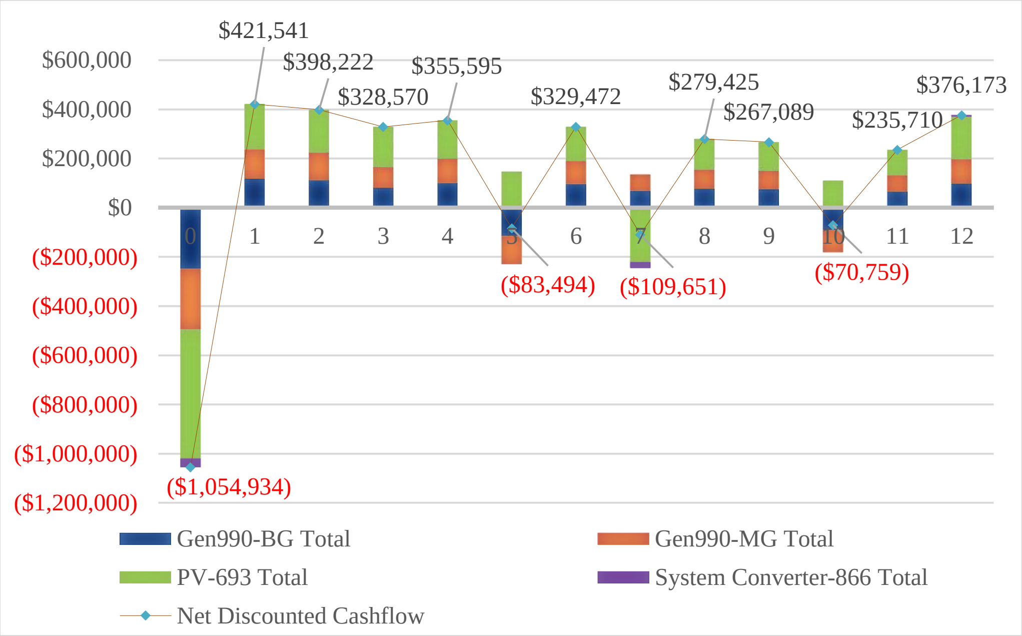


Figure 20: Discounted Project Cash Flow Based on Component Type

Also, the high replacement cost that occurs in the 5th, 7th and 10th year causes the cash outflow on net basis in these particular years. The 12th year observes an appreciable increase in the cash inflow due to the salvage value of the system. Analyzing the project cash flow based on market costs, the discounted payback of the project evaluated to be 2.71years; which when calculated on GFMV basis is found to be 7.47years. Similarly, the IRR of the system is found to be 25.32% as calculated based on discounted cash flow of the project.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Followings are the conclusions and Recommendations made based on this research study in reference to the Hybrid Renewable Energy (HRE) system at 35% Power Penetration for a generic military battalion (Bn) unit in UN Peacekeeping framework.

5.1 Conclusions

i. The logistic energy variables, compliance standards and reimbursement modalities relevant to a generic military Bn unit in UNPKO are identified.

ii. The Hybrid Renewable Energy (HRE) System at 35% Power-penetration for a generic military Bn unit in UNPKO is modeled and optimized for maximum reimbursement of \$38,274/month, with optimal size as total generator bank of 2,473KVA, Solar PV of 693KWp and System Converter of 866KW; while adhering to the relevant UN standards and provisions.

iii. The Techno-Economic implications of the optimal HRE system are analyzed with the solar resource case of UNMISS, Rumbek, South Sudan. The solar PV in the optimal HRE system contributes appreciably to reduce the diesel fuel consumption during the day-time by preferably satiating the electric load demand. Accordingly, the diesel fuel consumption reduction of around 16.76% or 141KL/year can be achieved by the optimal HRE system for a Bn unit in UNPKO; as compared to that of 2022/23 data. The optimal HRE system at 35% power-penetration contributes to only around 17.3% of RE share on the yearly total electricity consumption of the Bn unit in UNPKO. The 12-year project overview of the optimal HRE system yields an attractive NPV of \$1.67M, a quick payback of 2.71years and a striking IRR of 25.32% while incurring a capital investment of around \$1.05M; calculated based on market-based costings and discounted project cash flow.

5.2 Recommendations

Followings are the recommendations made based on this research study:

i. It is recommended to take into consideration of the storage based (such as BESS) hybrid RE system for full-fledged exploitation of RE benefits and pursue the RE related targets in the UNPKOs. Also, the explicit policy and reimbursement modalities for higher RE penetration and of energy storage system could be opted to establish and encourage the same.

ii. It is suggested to conduct a comparative study of the DG + PV HRES and the traditional DG only energy system of the uniformed units in UN peace framework so as to outline the relative viability, adaptability and profitability of the energy models. Moreover, the sensitivity analysis of the study covering the variation of various major variables can be studied so as to assess the effect of those variables on the model.

iii. It is probable that the mobile operational capability of the military units might be hindered by the higher RE integration. Thus, it is endorsed to discourse and advise the limit of the RE power-penetration for TCC units either on mission specific basis or the unit specific basis.

iv. It is suggested to study and research in prior the after-life or the second-life options for the RE components upon their life expiry or mission termination. Some of the pertinent considerations for the same could be handover to the community as part of mission legacy, refurbishing, recycling, redeployment in new area, repatriation, disposal etc.

REFERENCES

[1] "What is peacekeeping," United Nations Peacekeeping. Accessed: Jul. 15, 2024. [Online]. Available: https://peacekeeping.un.org/en/what-is-peacekeeping

[2] "United Nations Peacekeeping Operations Fact Sheet 31 Mar 2024." United Nations, 2024. Accessed: Jul. 15, 2024. [Online]. Available: https://peacekeeping.un.org/sites/default/files/peacekeeping_fact_sheet_march_2024_english_revision_2.pdf

[3] "Peace operations/deployment | Geospatial, location data for a better world." Accessed: Jul. 15, 2024. [Online]. Available: https://www.un.org/geospatial/unite-web-topic/peace-operationsdeployment

[4] United Nations, "Energy Compact Template." United Nations, 2021. Accessed: Mar. 24, 2025. [Online]. Available: https://www.un.org/sites/un2.un.org/files/2021/11/energy_compact_template_version_renewables_for_peacekeeping.final_.pdf

[5] "Manual on Policies and Procedures concerning the Reimbursement and Control of Contingent-Owned Equipment of Troop/Police Contributors Participating in Field Missions." United Nations, 2023. Accessed: Jul. 14, 2024. [Online]. Available: https://operationalsupport.un.org/en/contingent-owned-equipment-working-group

[6] "United Nations Infantry Battalion Manual (UNIBAM) Second Edition January 2020." United Nations, 2020. Accessed: Jul. 15, 2024. [Online]. Available: https://peacekeeping.un.org/sites/default/files/3._military_-_1_united_nations_infantry_battalion_manual_unibam.pdf

[7] "Deployment and reimbursement," United Nations Peacekeeping. Accessed: Mar. 09, 2025. [Online]. Available: https://peacekeeping.un.org/en/deployment-and-reimbursement

[8] "Generic Statement of Unit Requirements for the Light Infantry Battalion (640)." United Nations, 2023.

[9] "CLARIFY THE LANGUAGE ON RENEWABLE ENERGY, Secretariat Issue Paper #36." United Nations 2023 COE Working Group, 2023. Accessed: Jul. 15, 2024. [Online]. Available:

https://operationalsupport.un.org/sites/default/files/secretariat_issue_paper_36_-_clarify_the_language_on_renewable_energy.pdf

[10] V. K. Holt and A. R. Hopkins, “SHIFTING POWER Transitioning to Renewable Energy in United Nations Peace Operations,” 2021.

[11] “Environmental Policy for Peacekeeping Operations and Field-Based Special Political Missions 2022.” United Nations, 2022. Accessed: Jul. 14, 2024. [Online]. Available: https://operationalsupport.un.org/sites/default/files/dos_2022.01_environmental_policy_for_peackeeping_operations_and_special_political_missions.pdf

[12] “The Way Forward: Environment Strategy for Peace Operations 2023-2030.” United Nations, 2022. Accessed: Jul. 14, 2024. [Online]. Available: https://operationalsupport.un.org/sites/default/files/the_way_forward_-_environment_strategy_2023-2030.pdf

[13] “COE FUEL CONSUMPTION MONITORING AND T/PCC ACCOUNTABILITY, Secretariat Issue Paper #21.” United Nations 2023 COE Working Group. Accessed: Jul. 16, 2024. [Online]. Available: https://operationalsupport.un.org/sites/default/files/secretariat_issue_paper_21_-_coe_fuel_consumption_monitoring_and_t-pcc_accountability.pdf

[14] “THE 17 GOALS | Sustainable Development.” Accessed: Mar. 26, 2025. [Online]. Available: https://sdgs.un.org/goals

[15] “UNITED NATIONS SECRETARIAT CLIMATE ACTION PLAN 2020-2030 SEPTEMBER 2019.” United Nations, 2019. Accessed: Jul. 14, 2024. [Online]. Available: https://www.un.org/management/sites/www.un.org.management/files/united-nations-secretariat-climate-action-plan.pdf

[16] “Greening The Blue.” Accessed: Mar. 26, 2025. [Online]. Available: https://greeningtheblue.org/

[17] “UNFCCC.” Accessed: Mar. 26, 2025. [Online]. Available: https://unfccc.int/

[18] F. A. Farret, *Integration of Alternative Sources of Energy*. 2006. doi: 10.1002/0471755621.

[19] "Rumbek Climate, Weather By Month, Average Temperature (South Sudan) - Weather Spark." Accessed: Jan. 26, 2025. [Online]. Available: https://weatherspark.com/y/95911/Average-Weather-in-Rumbek-South-Sudan-Year-Round

[20] A. Hyde, A. Khatri, A. Lord, D. Mozersky, and N. D. Nhial, "A Case Study in Improving Environmental Management in UN Peacekeeping".

[21] "Resource Data HOMER." Accessed: Mar. 12, 2025. [Online]. Available: https://homerenergy.com/products/pro/docs/3.15/finding_data_to_run_homer.html?anchor=solar_resource

[22] R. Sethi, "Techno-economic analysis of a Microgrid with solar PV, Battery Energy Storage and Power to Hydrogen (P2H) System," *2020,* Accessed: Jul. 16, 2024. [Online]. Available: https://escholarship.org/uc/item/5k80b5sd

[23] "Internal Rate of Return (IRR): Formula and Examples," Investopedia. Accessed: Mar. 13, 2025. [Online]. Available: https://www.investopedia.com/terms/i/irr.asp

[24] "Discounted Payback Period: What It Is and How to Calculate It," Investopedia. Accessed: Mar. 13, 2025. [Online]. Available: https://www.investopedia.com/terms/d/discounted-payback-period.asp

[25] T. M and Y. Sawle, "A Comparative Study of the Optimal Sizing and Management of Off-Grid Solar/Wind/Diesel and Battery Energy Systems for Remote Areas," *Frontiers in Energy Research*, vol. 9, Nov. 2021, doi: 10.3389/fenrg.2021.752043.

[26] "Online Generator in Nepal | Bazarpapa.com." Accessed: Jan. 12, 2025. [Online]. Available: https://bazarpapa.com/items?subcategory_id=4

[27] "Approximate Diesel Generator Fuel Consumption Chart." Accessed: Dec. 20, 2024. [Online]. Available: https://devgeneratorsource.bluemod.us/Diesel_Fuel_Consumption.aspx

[28] "Solar PV installation cost worldwide 2023," Statista. Accessed: Jan. 12, 2025. [Online]. Available: https://www.statista.com/statistics/809796/global-solar-power-installation-cost-per-kilowatt/

[29] “Solar Inverters,” LOOM SOLAR. Accessed: Jan. 12, 2025. [Online]. Available: https://www.loomsolar.com/collections/solar-inverters

[30] “US Inflation Rate Monthly Analysis: Consumer Price Index | YCharts.” Accessed: Jan. 12, 2025. [Online]. Available: https://ycharts.com/indicators/us_inflation_rate

[31] “List of United Nations peacekeeping missions,” *Wikipedia*. Dec. 29, 2024. Accessed: Jan. 12, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=List_of_United_Nations_peacekeeping_missions&oldid=1265895789

[32] A. Jakhrani, A. Rigit, A.-K. Othman, S. Samo, and S. Kamboh, *Estimation of Carbon Footprints from Diesel Generator Emissions*. 2012. doi: 10.1109/GUT.2012.6344193.

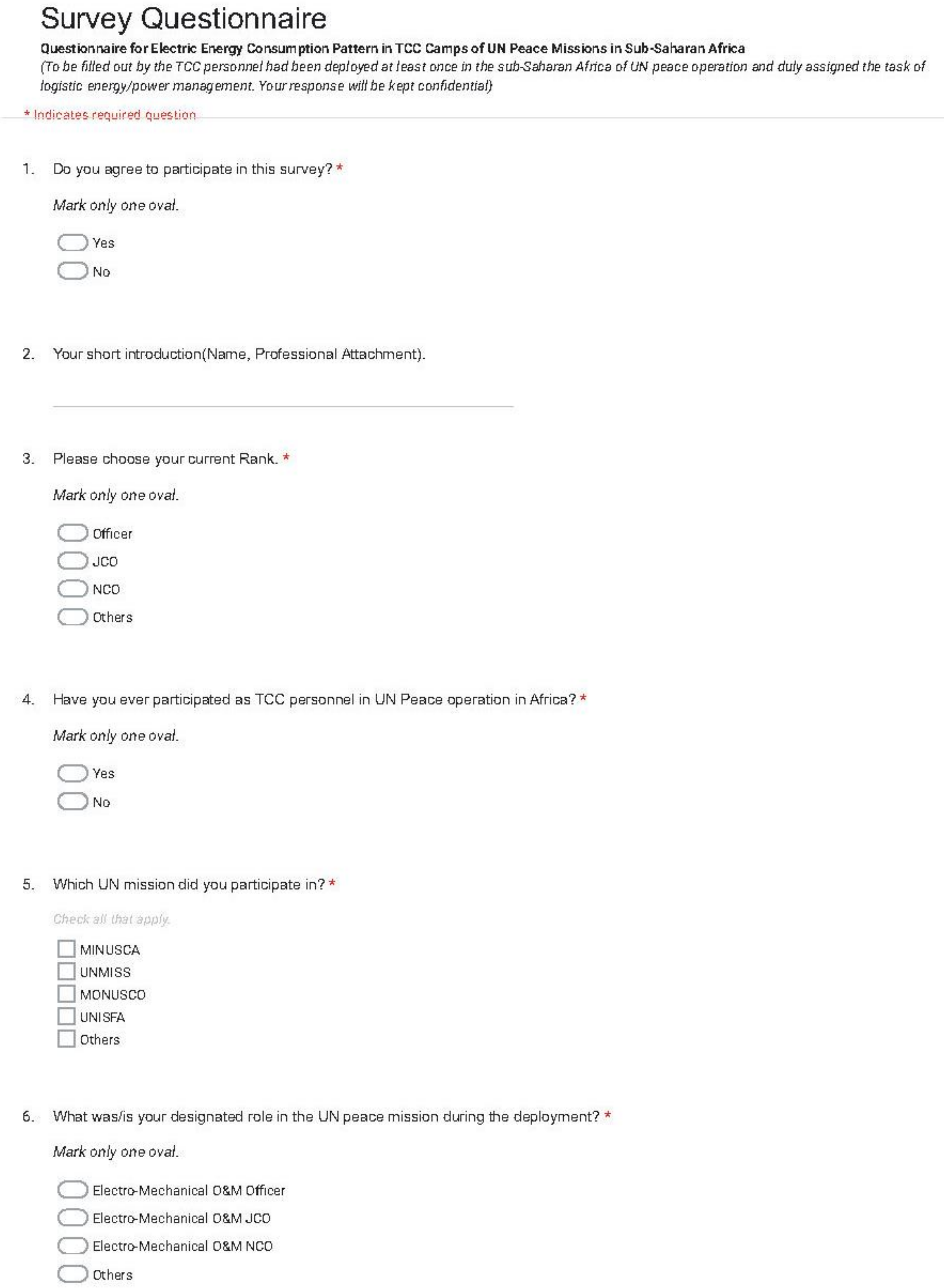
APPENDICES

Appendix A: Monthly Load Data (in KW) for a TCC Bn Unit of 700 strengths in UNMISS, Rumbek, South Sudan.

ToD (Hrs)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00	364	441	461	422	392	362	347	382	391	409	421	364
1:00	233	237	240	258	264	235	278	270	283	265	252	233
2:00	177	182	192	208	207	198	186	218	233	223	215	177
3:00	163	167	184	178	202	181	177	202	212	209	196	163
4:00	154	148	191	215	204	160	145	161	174	169	161	154
5:00	211	212	217	215	208	219	184	227	243	237	237	211
6:00	250	254	259	264	266	257	251	227	243	237	237	250
7:00	279	283	308	302	303	268	281	257	271	260	257	279
8:00	492	516	551	576	520	491	469	393	425	457	479	492
9:00	515	546	580	608	569	528	484	420	455	491	503	515
10:00	523	556	598	628	584	545	490	415	448	502	508	523
11:00	534	559	582	603	554	518	478	441	466	482	517	534
12:00	609	638	665	692	637	596	520	470	518	557	582	609
13:00	685	729	762	793	715	676	571	530	584	626	670	685
14:00	688	717	758	780	703	663	572	525	576	618	660	688
15:00	839	841	893	873	825	743	622	610	666	712	775	839
16:00	829	838	894	880	843	771	636	646	650	694	798	829
17:00	875	861	1000	910	961	878	748	750	802	859	918	875
18:00	903	956	1011	977	899	842	715	733	787	824	880	903
19:00	937	970	1024	992	966	810	703	742	808	845	885	937
20:00	944	978	1004	995	961	803	720	726	775	811	879	944
21:00	864	830	1040	976	908	793	630	662	694	754	778	864
22:00	578	668	694	664	607	565	524	551	578	607	635	578
23:00	493	580	612	569	517	489	469	481	505	530	555	493

(Source: Author, Survey)

Appendix B: Survey Questionnaire



Survey Questionnaire

Questionnaire for Electric Energy Consumption Pattern in TCC Camps of UN Peace Missions in Sub-Saharan Africa

(To be filled out by the TCC personnel had been deployed at least once in the sub-Saharan Africa of UN peace operation and duly assigned the task of logistic energy/power management. Your response will be kept confidential)

* Indicates required question

1. Do you agree to participate in this survey? *

Mark only one oval.

○ Yes
○ No

2. Your short introduction(Name, Professional Attachment).

3. Please choose your current Rank. *

Mark only one oval.

○ Officer
○ JCO
○ NCO
○ Others

4. Have you ever participated as TCC personnel in UN Peace operation in Africa? *

Mark only one oval.

○ Yes
○ No

5. Which UN mission did you participate in? *

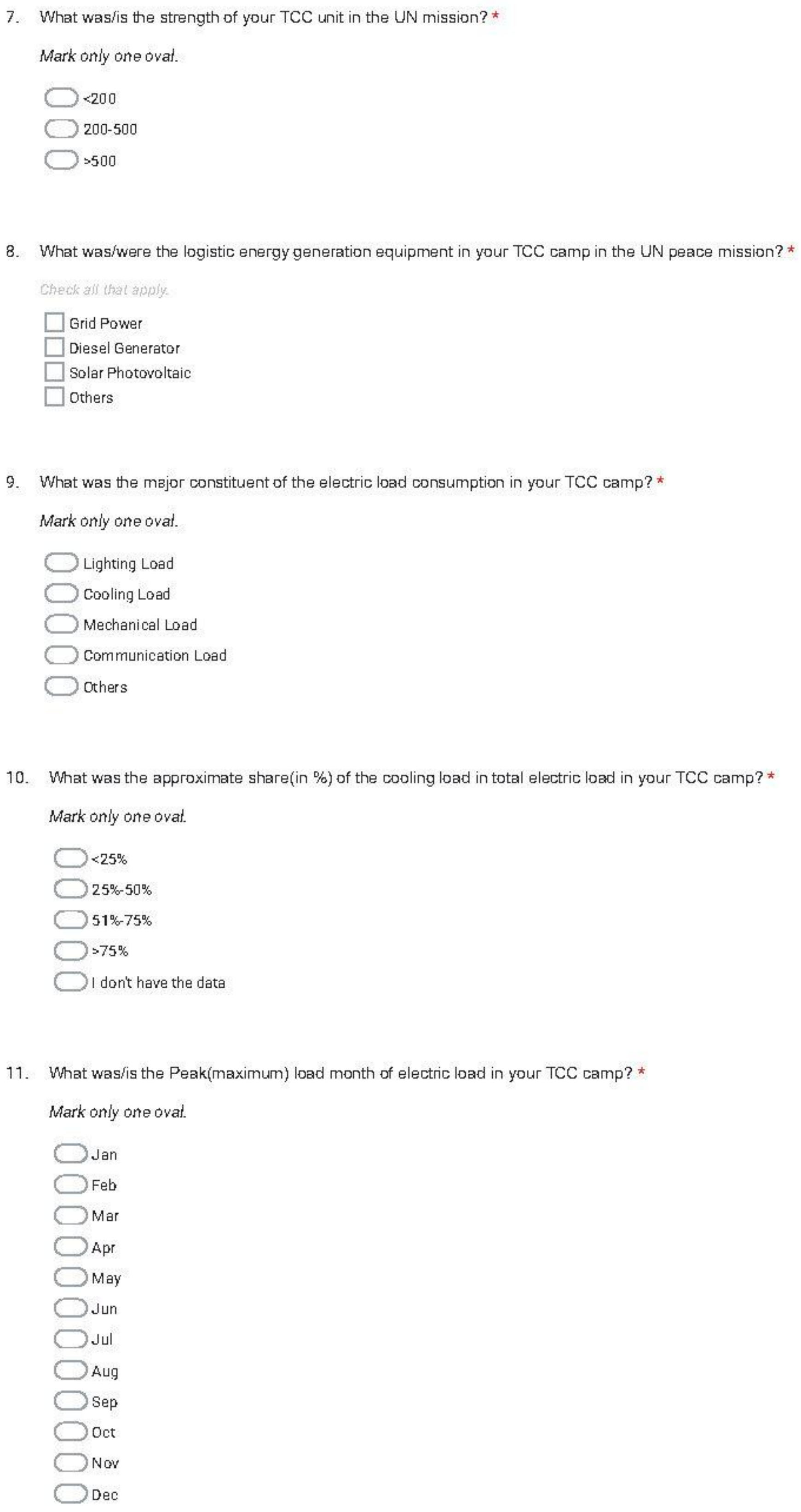
Check all that apply.

☐ MINUSCA
☐ UNMISS
☐ MONUSCO
☐ UNISFA
☐ Others

6. What was/is your designated role in the UN peace mission during the deployment? *

Mark only one oval.

○ Electro-Mechanical O&M Officer
○ Electro-Mechanical O&M JCO
○ Electro-Mechanical O&M NCO
○ Others



7. What was/is the strength of your TCC unit in the UN mission? *

Mark only one oval.

○ <200
○ 200-500
○ >500

8. What was/were the logistic energy generation equipment in your TCC camp in the UN peace mission? *

Check all that apply.

☐ Grid Power
☐ Diesel Generator
☐ Solar Photovoltaic
☐ Others

9. What was the major constituent of the electric load consumption in your TCC camp? *

Mark only one oval.

○ Lighting Load
○ Cooling Load
○ Mechanical Load
○ Communication Load
○ Others

10. What was the approximate share(in %) of the cooling load in total electric load in your TCC camp? *

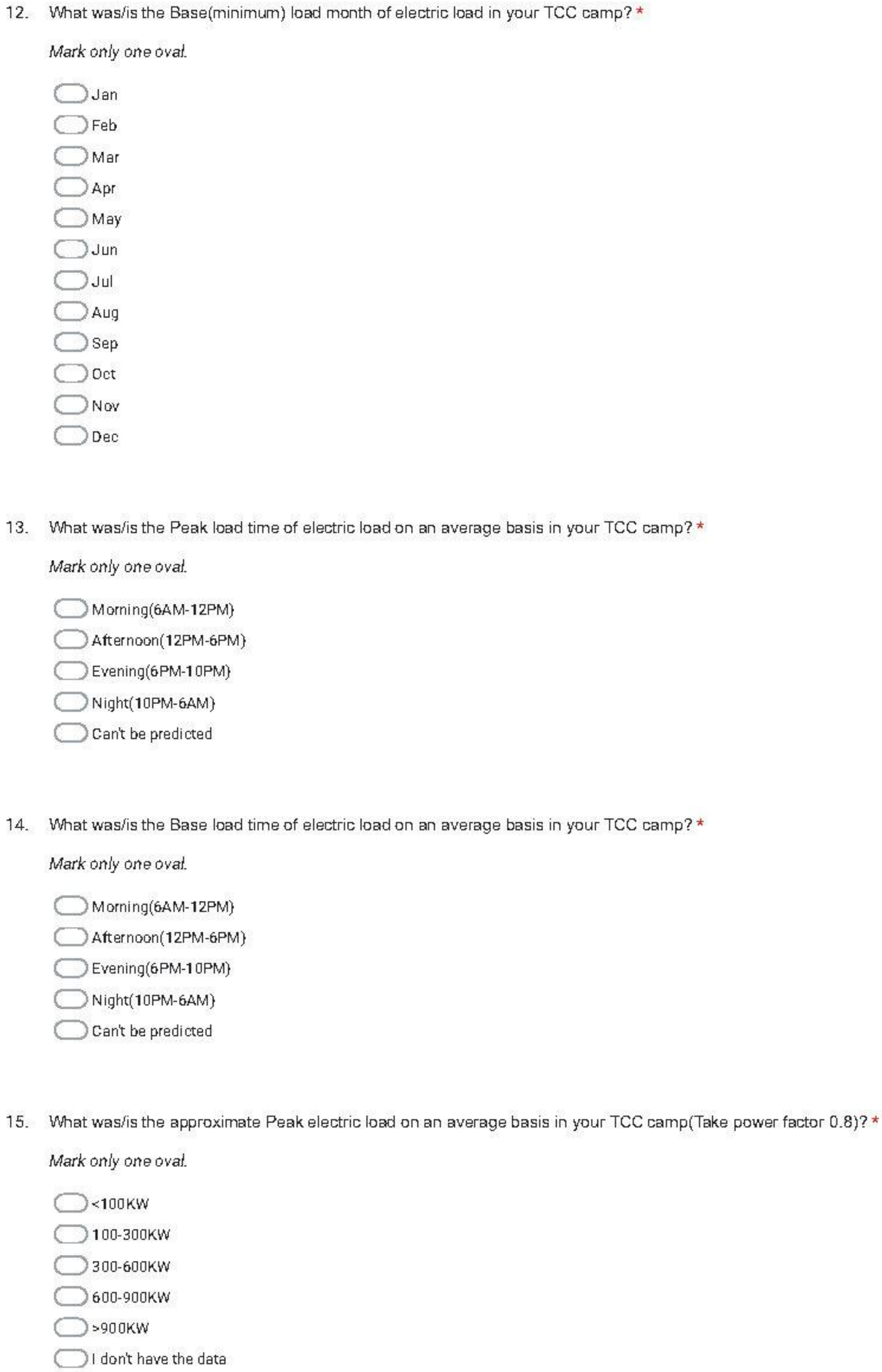
Mark only one oval.

○ <25%
○ 25%-50%
○ 51%-75%
○ >75%
○ I don't have the data

11. What was/is the Peak(maximum) load month of electric load in your TCC camp? *

Mark only one oval.

○ Jan
○ Feb
○ Mar
○ Apr
○ May
○ Jun
○ Jul
○ Aug
○ Sep
○ Oct
○ Nov
○ Dec



12. What was/is the Base(minimum) load month of electric load in your TCC camp? *

Mark only one oval.

○ Jan
○ Feb
○ Mar
○ Apr
○ May
○ Jun
○ Jul
○ Aug
○ Sep
○ Oct
○ Nov
○ Dec

13. What was/is the Peak load time of electric load on an average basis in your TCC camp? *

Mark only one oval.

○ Morning(6AM-12PM)
○ Afternoon(12PM-6PM)
○ Evening(6PM-10PM)
○ Night(10PM-6AM)
○ Can't be predicted

14. What was/is the Base load time of electric load on an average basis in your TCC camp? *

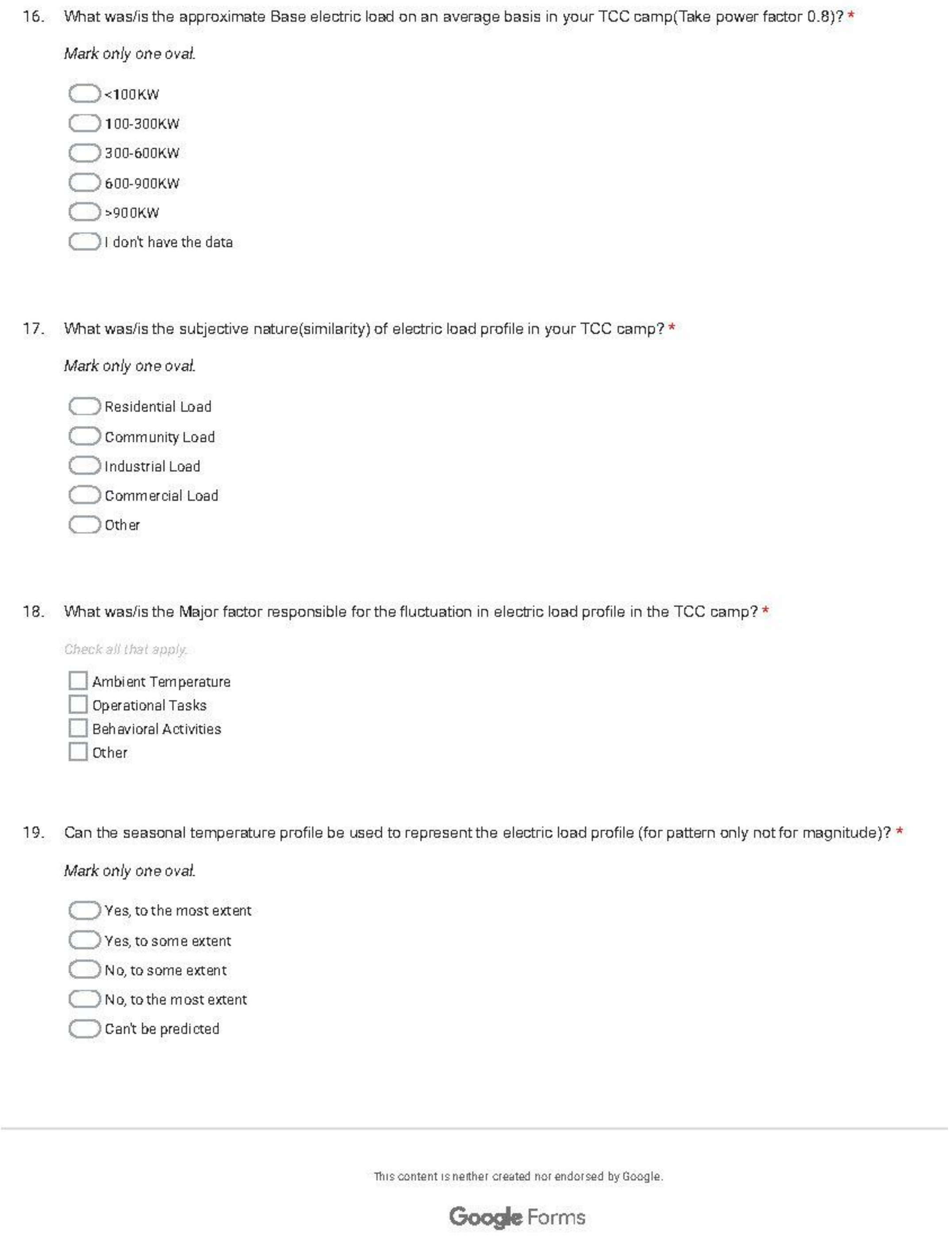
Mark only one oval.

○ Morning(6AM-12PM)
○ Afternoon(12PM-6PM)
○ Evening(6PM-10PM)
○ Night(10PM-6AM)
○ Can't be predicted

15. What was/is the approximate Peak electric load on an average basis in your TCC camp(Take power factor 0.8)? *

Mark only one oval.

○ <100KW
○ 100-300KW
○ 300-600KW
○ 600-900KW
○ >900KW
○ I don't have the data



16. What was/is the approximate Base electric load on an average basis in your TCC camp(Take power factor 0.8)? *

Mark only one oval.

○ <100KW
○ 100-300KW
○ 300-600KW
○ 600-900KW
○ >900KW
○ I don't have the data

17. What was/is the subjective nature(similarity) of electric load profile in your TCC camp? *

Mark only one oval.

○ Residential Load
○ Community Load
○ Industrial Load
○ Commercial Load
○ Other

18. What was/is the Major factor responsible for the fluctuation in electric load profile in the TCC camp? *

Check all that apply.

☐ Ambient Temperature
☐ Operational Tasks
☐ Behavioral Activities
☐ Other

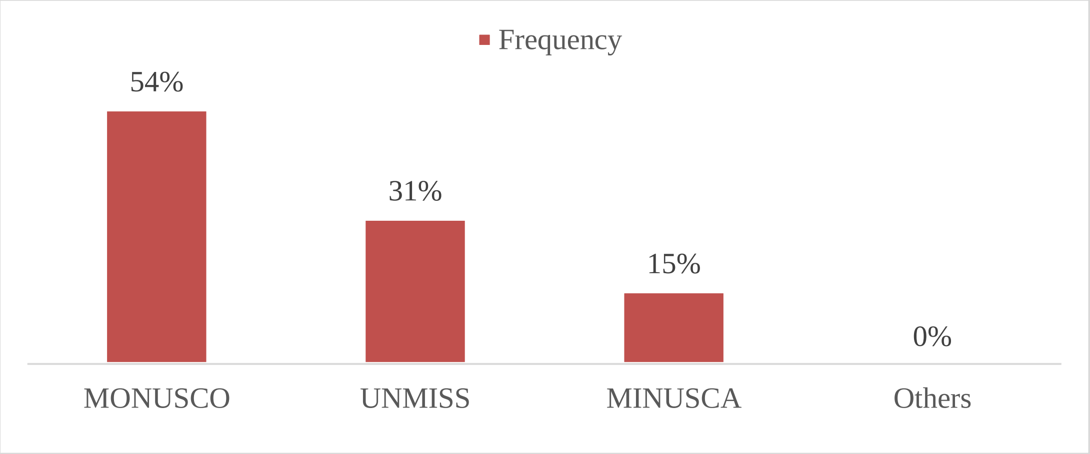
19. Can the seasonal temperature profile be used to represent the electric load profile (for pattern only not for magnitude)? *

Mark only one oval.

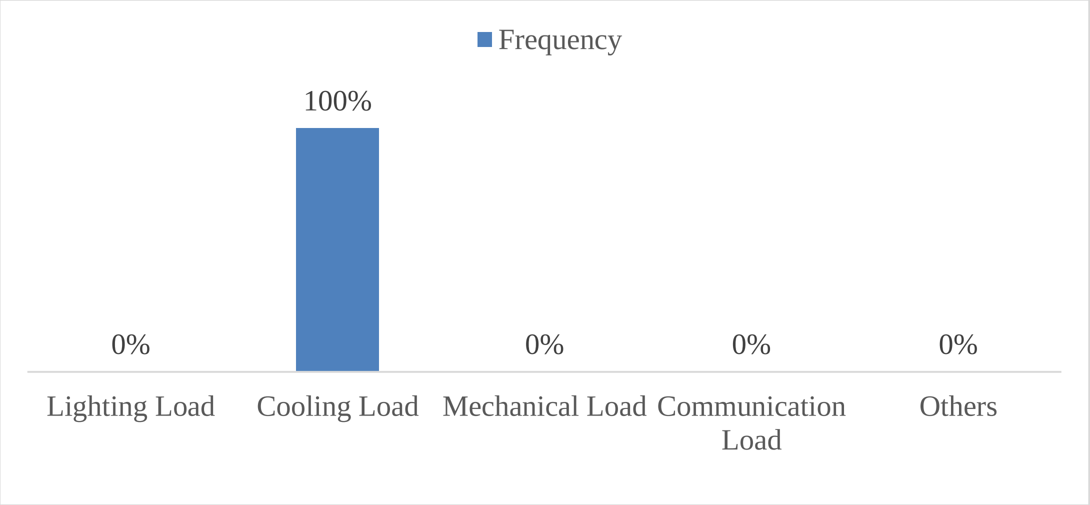
○ Yes, to the most extent
○ Yes, to some extent
○ No, to some extent
○ No, to the most extent
○ Can't be predicted

Appendix C: Survey Response Analysis

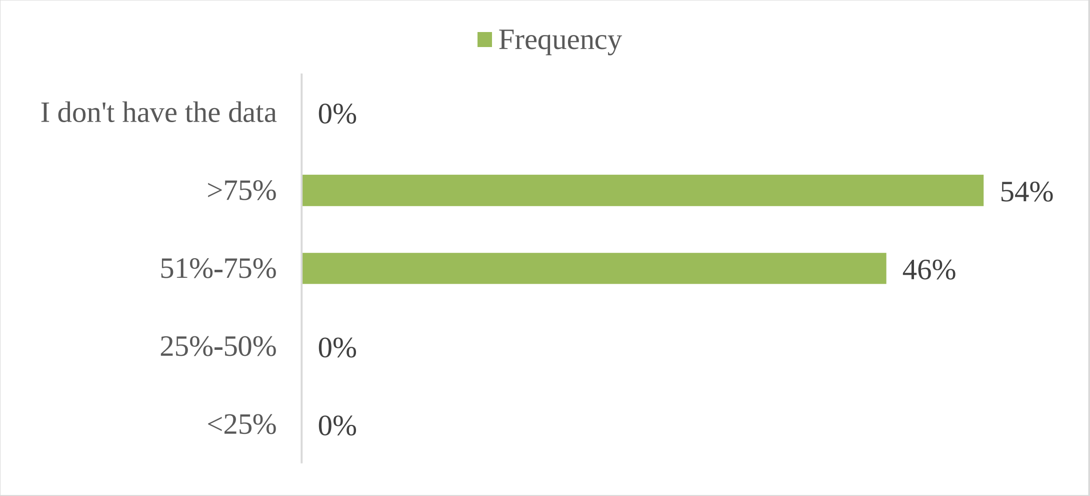
A. Survey Response: Mission Participation of Respondents



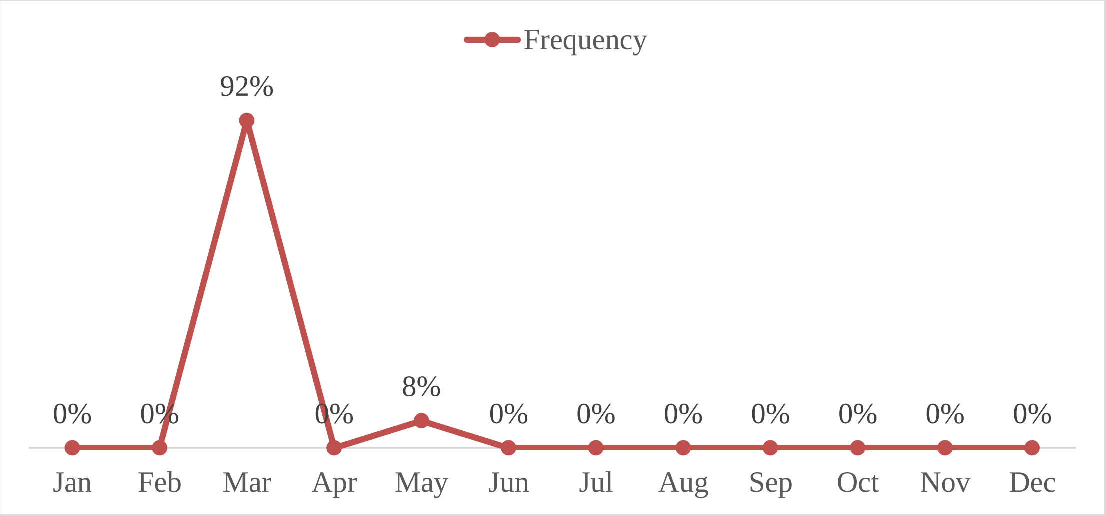
B. Survey Response: The Major constituent of electric load in TCC camp



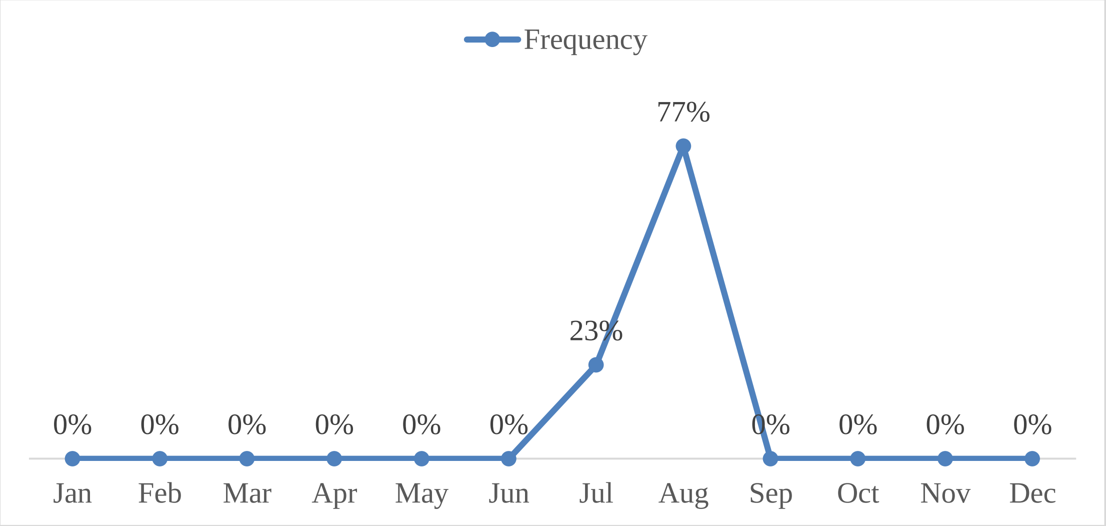
C. Survey Response: Approximate Share of Cooling Load on Total Electric Load in TCC Camp



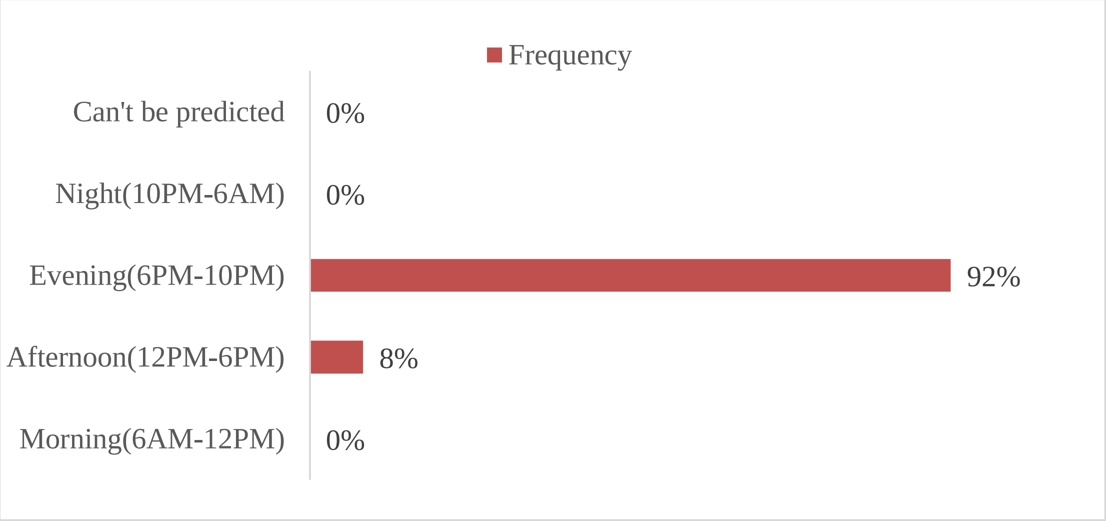
D. Survey Response: Peak Load Month in TCC Camp



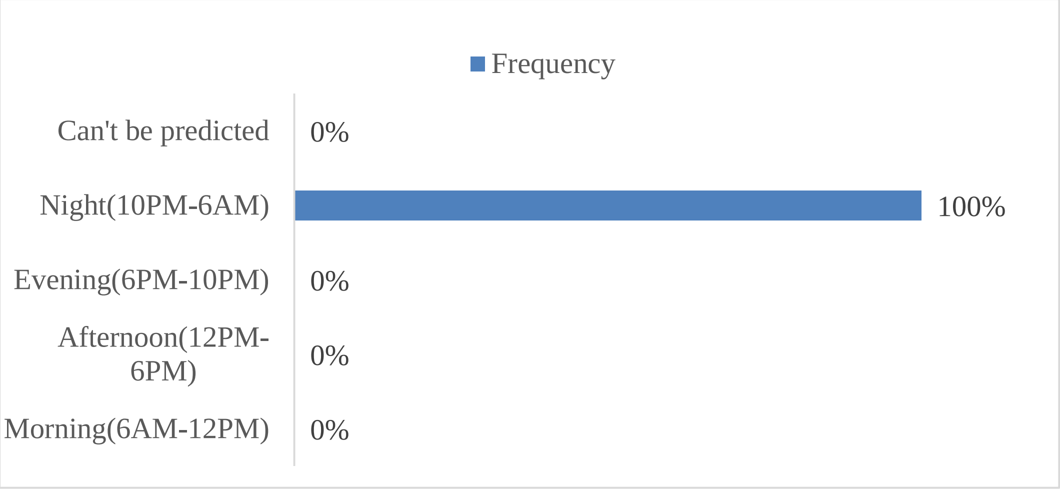
E. Survey Response: Base Load Month in TCC Camp



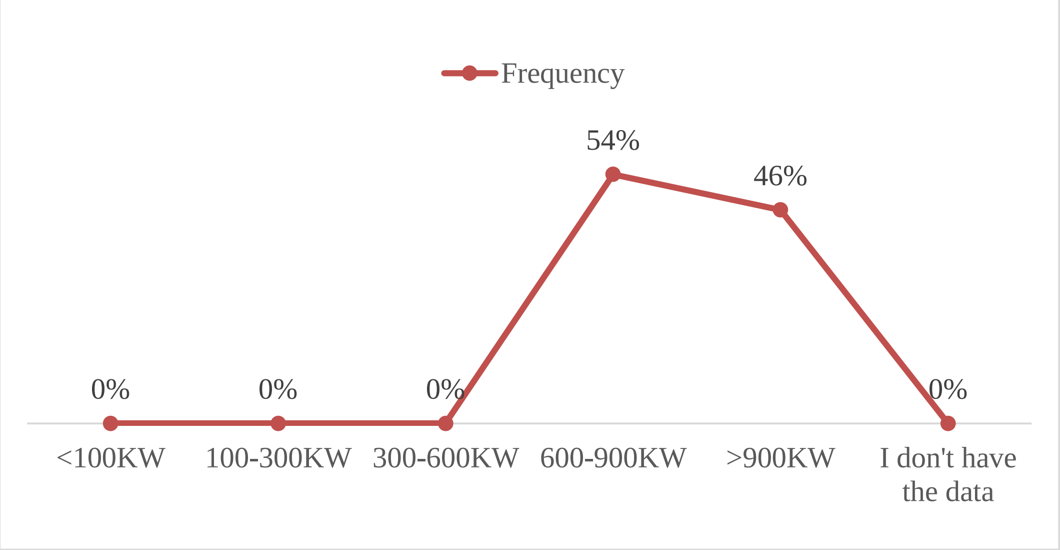
F. Survey Response: Peak Load ToD in TCC Camp



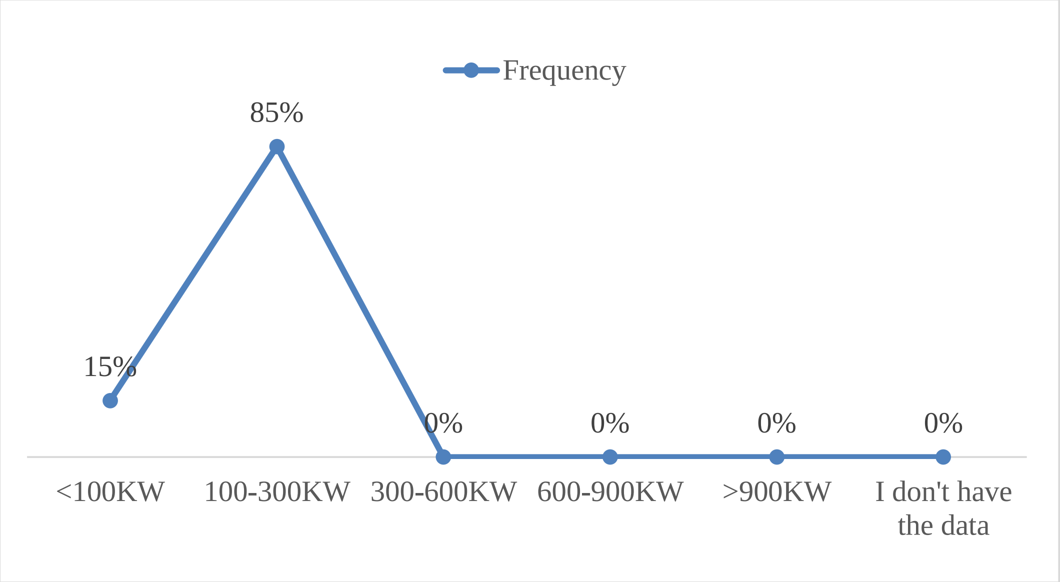
G. Survey Response: Base Load ToD in TCC Camp



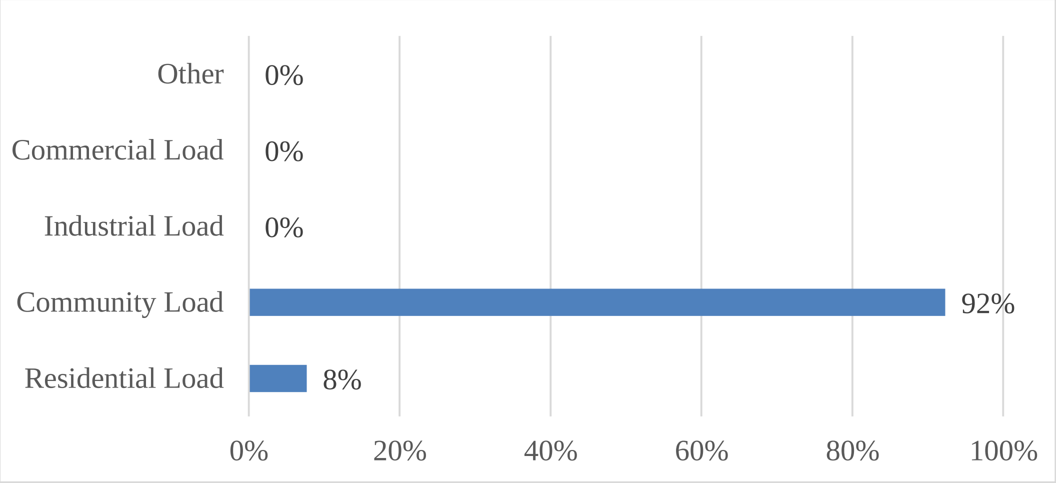
H. Survey Response: Approx. Peak Electric Load in TCC Camp



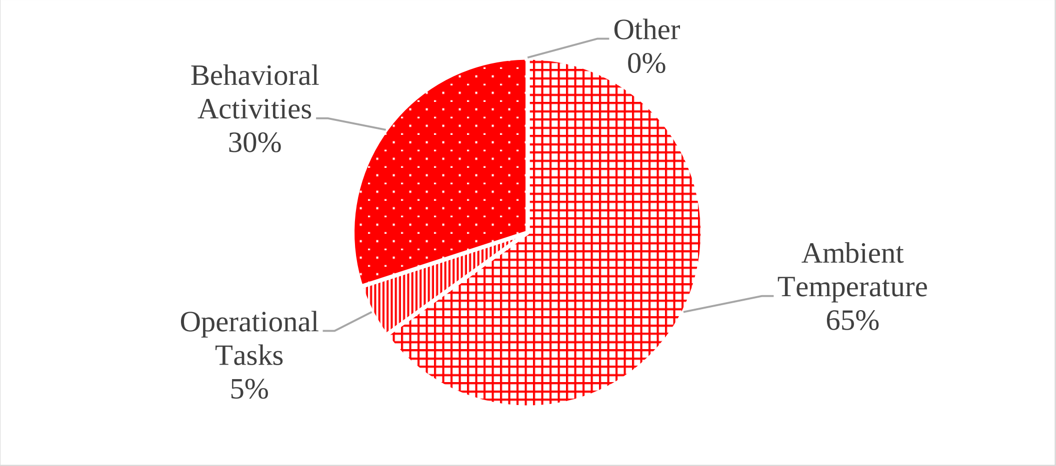
I. Survey Response: Approx. Base Electric Load in TCC Camp



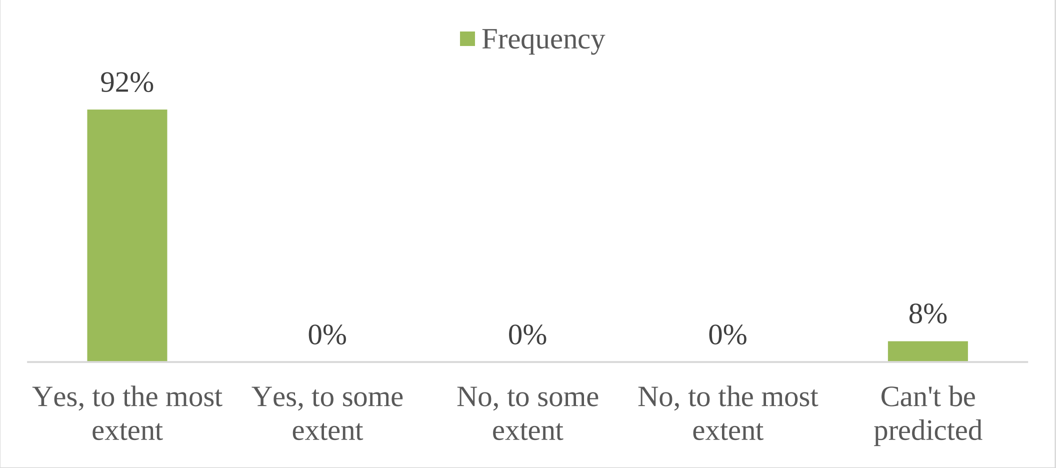
J. Survey Response: Similarity of Electric Load Profile in TCC Camp



K. Survey Response: Major Factor Responsible for the Fluctuation of Electric Load in TCC Camp



L. Survey Response: Possibility of Representing Electric Load Pattern by Temperature Profile in TCC Camp



Appendix D: Minimum Reimbursement Case Possible Due to the Poor Sizing and Selection of HRE System Combinations.

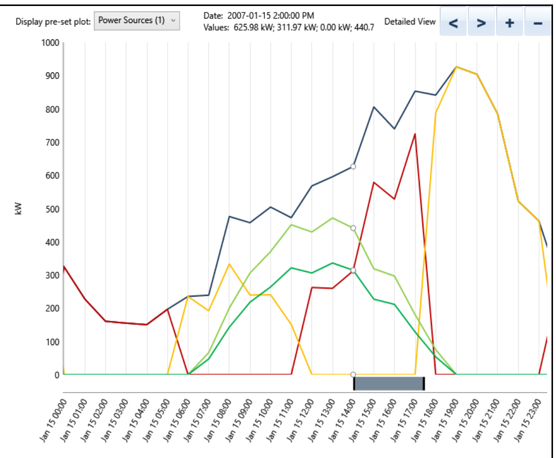
Design Selection (Nos.× KVA or KWp)	Output	Values	Comment
DG: 4×20.37+4×42.58+ 2×101+10×201.91	**DG System**		
	Number of Generators	14	
	Main Generator Capacity, KW	922.1	
	Backup Generator Capacity, KW	922.1	
	Total DG Capacity, KVA	2305.24	
	Mobile DG Capacity, KVA	233.70	
	DG Reimbursement, $/Month	13,554.00	
	GFMV Based DG Investment, $	1,353,434.00	
	DG System Simple Payback, years	8.32	
PV: 2×36+10×62.04	**PV System**		
	Total PV Capacity, KWp	645.47	
	PV Reimbursement, $/Month	12,580.00	
	GFMV Based PV Investment, $	907,788.00	
	PV System Simple Payback, years	6.01	
DG + PV	**Hybrid System**		
	Total Reimbursement, $/Month	26,134.00	Min.
	RE Penetration in Total	35.00%	35%
	GFMV based Total Investment, $	2,261,222.00	
	GFMV based Simple Payback, years	7.21	
	RE Reimbursement % (PV Reimbursement/Total Reimbursement), %	48.14%	

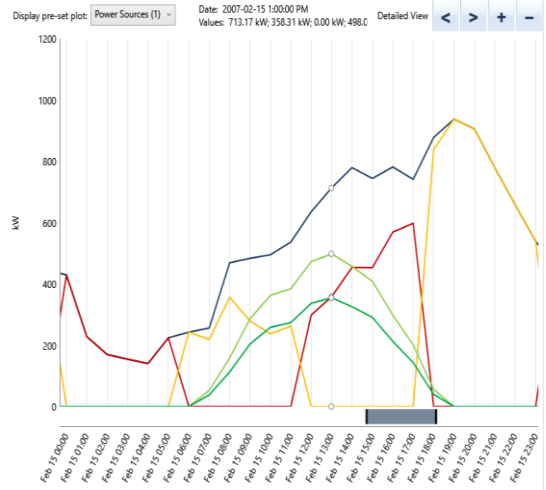
Appendix E: The Hybrid Mini-Grid Hourly Operational of 15th day of each month

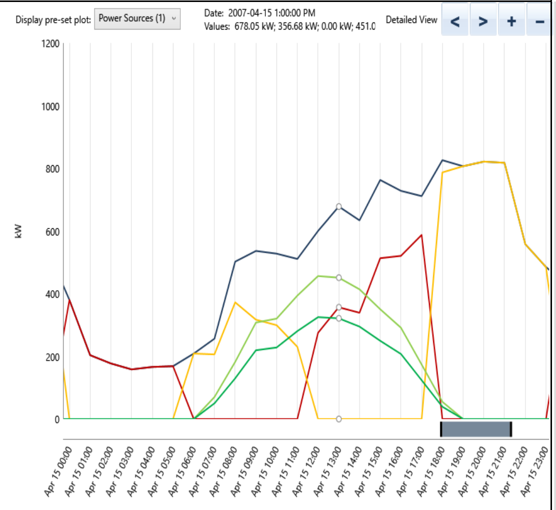
(Sequentially from 15 Jan to 15 Dec except for 15 Mar which is included in the main Report).

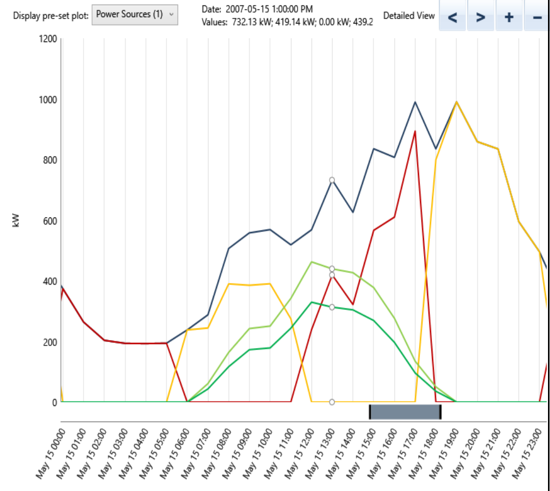
Color Legend

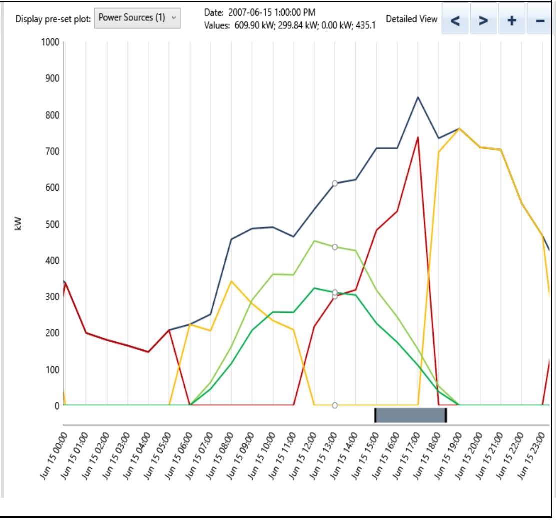
🟩 PV-693 Power Output
🟥 Gen990-MG Power Output
🟨 Gen990-BG Power Output
🟦 Total Electrical Load Served
🟩 Inverter Power Output

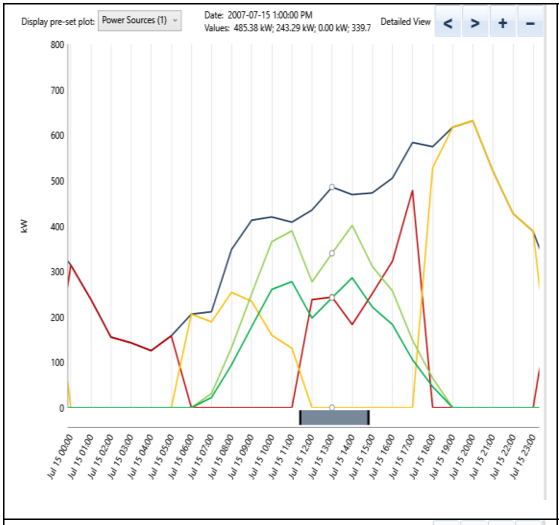

Display pre-set plot: Power Sources (1)
Date: 2007-01-15 2:00:00 PM
Values: 625.98 kW; 311.97 kW; 0.00 kW; 440.7


Display pre-set plot: Power Sources (1)
Date: 2007-02-15 1:00:00 PM
Values: 713.17 kW; 358.31 kW; 0.00 kW; 498.0

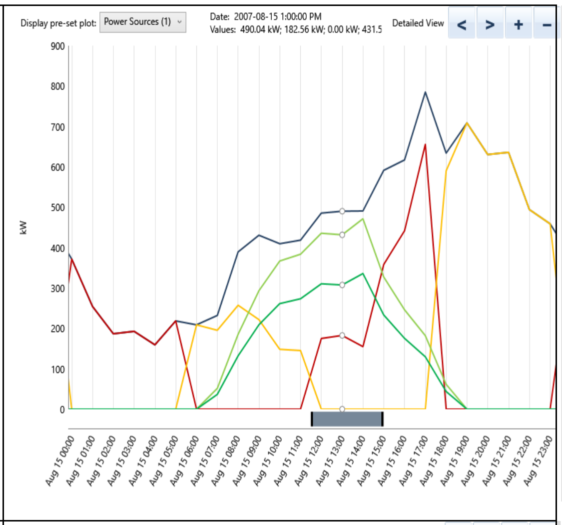

Display pre-set plot: Power Sources (1)
Date: 2007-04-15 1:00:00 PM
Values: 678.05 kW; 356.68 kW; 0.00 kW; 451.0


Display pre-set plot: Power Sources (1)
Date: 2007-05-15 1:00:00 PM
Values: 732.13 kW; 419.14 kW; 0.00 kW; 439.2

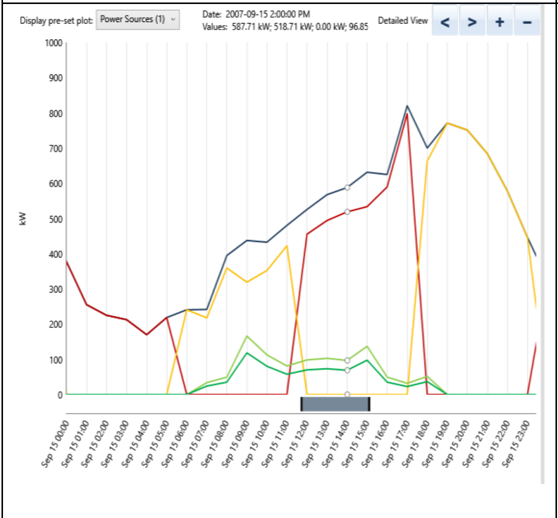

Display pre-set plot: Power Sources (1)
Date: 2007-06-15 1:00:00 PM
Values: 609.90 kW; 299.84 kW; 0.00 kW; 435.1



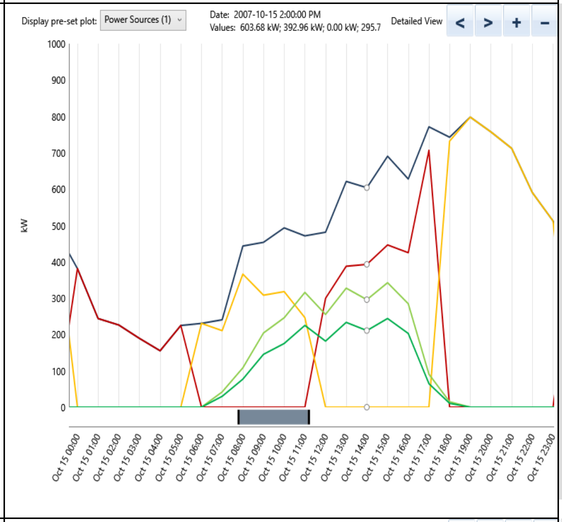
Date: 2007-07-15 1:00:00 PM
Values: 485.38 kW; 243.29 kW; 0.00 kW; 339.7



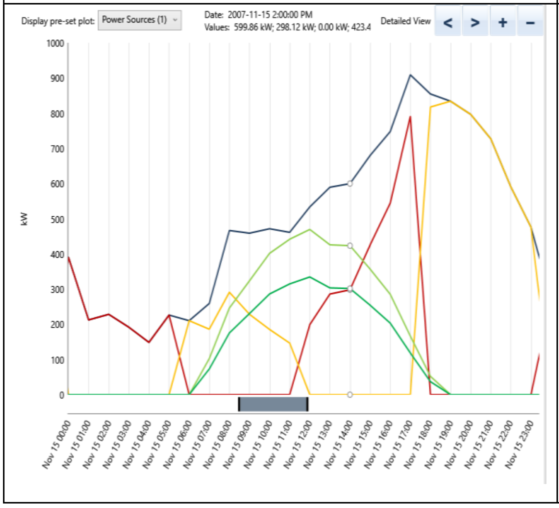
Date: 2007-08-15 1:00:00 PM
Values: 490.04 kW; 182.56 kW; 0.00 kW; 431.5



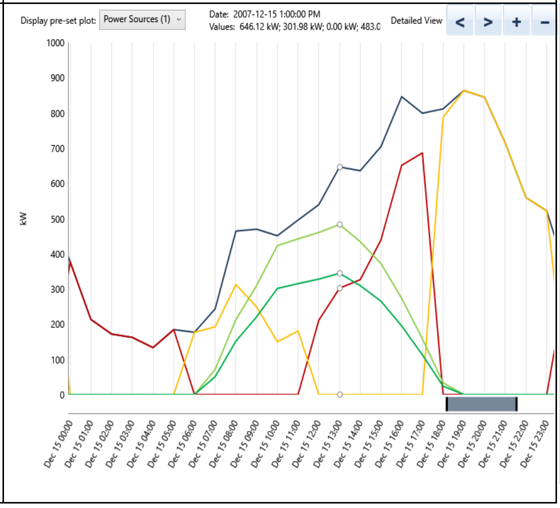
Date: 2007-09-15 2:00:00 PM
Values: 587.71 kW; 518.71 kW; 0.00 kW; 96.85



Date: 2007-10-15 2:00:00 PM
Values: 603.68 kW; 392.96 kW; 0.00 kW; 295.7

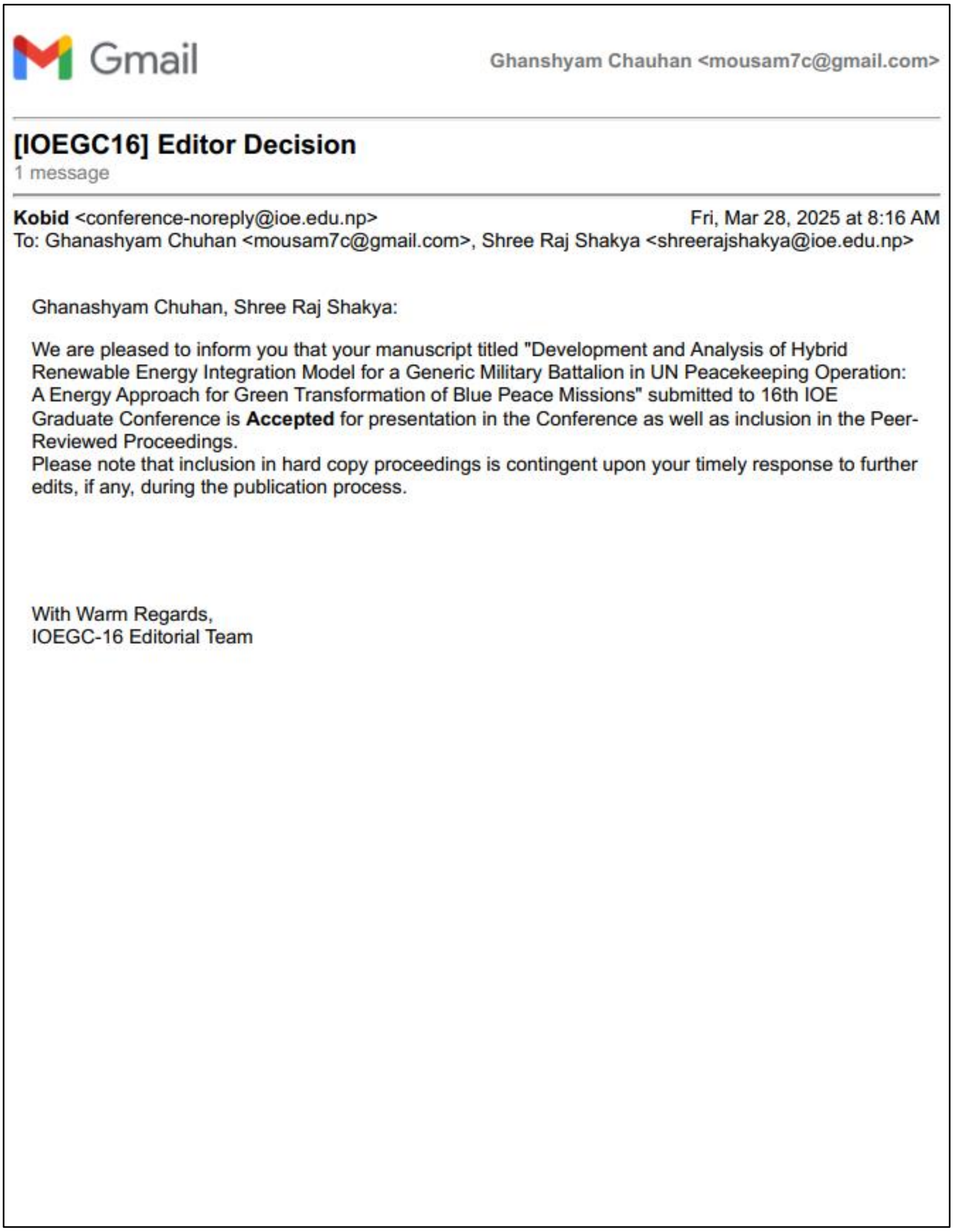


Date: 2007-11-15 2:00:00 PM
Values: 599.86 kW; 298.12 kW; 0.00 kW; 423.4



Date: 2007-12-15 1:00:00 PM
Values: 646.12 kW; 301.98 kW; 0.00 kW; 483.0

Appendix F: Paper Acceptance Email for Publication



Ghanshyam Chauhan <mousam7c@gmail.com>

[IOEGC16] Editor Decision

1 message

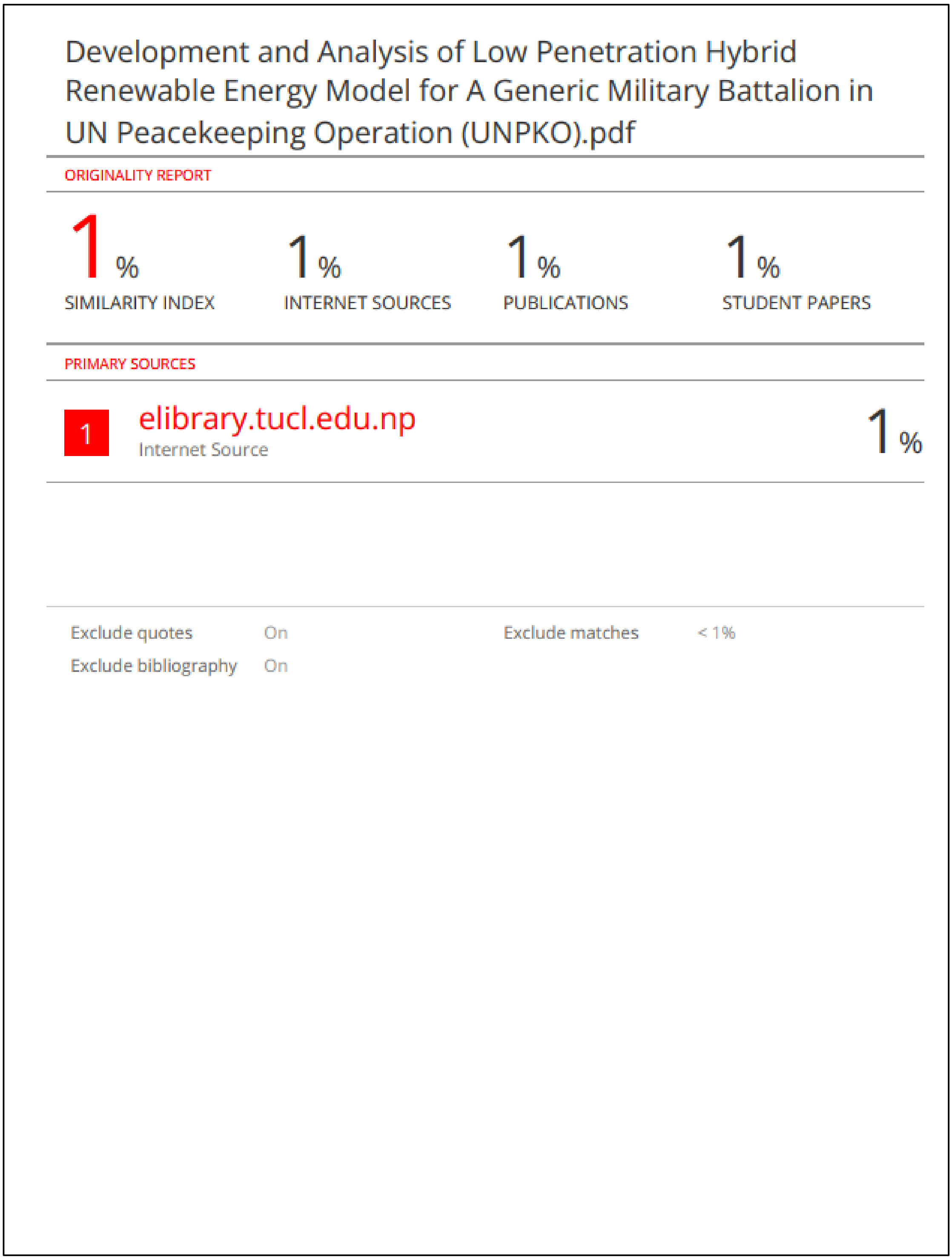
Kobid <conference-noreply@ioe.edu.np> Fri, Mar 28, 2025 at 8:16 AM
To: Ghanashyam Chuhan <mousam7c@gmail.com>, Shree Raj Shakya <shreerajshakya@ioe.edu.np>

Ghanashyam Chuhan, Shree Raj Shakya:

We are pleased to inform you that your manuscript titled "Development and Analysis of Hybrid Renewable Energy Integration Model for a Generic Military Battalion in UN Peacekeeping Operation: A Energy Approach for Green Transformation of Blue Peace Missions" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings.
Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

Appendix G: Turnitin Originality Check Report.



Development and Analysis of Low Penetration Hybrid Renewable Energy Model for A Generic Military Battalion in UN Peacekeeping Operation (UNPKO).pdf

ORIGINALITY REPORT

1 %	1 %	1 %	1 %
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	elibrary.tucl.edu.np Internet Source	1 %

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		