اتحاد الهيئات الأهلية البيئية الفلسطينية
Palestinian Environmental NGOs Network
PENGON-FoE Palestine

Technical report for recovering water and wastewater projects operated by solar energy: Medium and large-scale projects

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Contents

1. Purpose of the Study

Assessing the Damages of Water and Wastewater Projects Empowered by Solar Energy in Gaza

During the recent assault on Gaza, Israeli forces targeted solar panels at hospitals, development infrastructures, and other systems, causing environmental and human catastrophes. The damage to solar units at wastewater treatment plants (WWTPs) and water desalination plants (WDPs) has led to severe environmental damage, impacting all aspects of life in Gaza. Multiple large and medium-scale facilities were targeted, necessitating an assessment of the solar energy damage and a plan to recover these vital projects. Small-scale projects are excluded from this report.

2. Objective

The study aims to assess and evaluate the current technical situation of water and wastewater projects empowered by solar energy, focusing on large and medium-scale facilities.

3. The Role of PENGON

The Palestinian Environmental NGOs Network (PENGON) – Friends of Earth Palestine, is a coordinating body established in 1996 to advocate for and protect the Palestinian environment. PENGON works in various strategic areas, including water, agriculture, sustainable development, health, and sanitation. The network has implemented numerous initiatives related to climate justice, the right to water, pollution prevention, and advocacy against environmental rights violations. PENGON initiated this technical assessment to evaluate the damages to Gaza's solar-powered water and wastewater systems and to identify necessary interventions for recovery.

4. Executive Summary

PENGON's assessment focuses on:

- Determining the extent of solar energy system damage.
- Evaluating required interventions for solar energy and infrastructural recovery in large and medium-scale WDPs and WWTPs.

Water Desalination Plants (WDPs) and Wastewater Treatment Plants (WWTPs) in Gaza

Pre-War Status

Gaza's water crisis was critical even before the October 2023 conflict, with limited access to potable water and reliance on the Coastal Aquifer—97% of which was unfit for human consumption. Medium and large-scale desalination plants, powered partially by solar energy, played a vital role in addressing these challenges. Renewable energy contributed significantly, with medium-scale plants achieving an average solar energy contribution of 55% and large-scale plants at 7%.

Wastewater treatment plants also utilized renewable energy, with solar and combined heat and power (CHP) systems providing up to 40% of energy needs. However, maintenance and material import restrictions posed significant operational challenges.

Post-War Damage

The conflict caused widespread destruction of water infrastructure:

- **Medium-scale WDPs:** 75% are non-functional or partially operational. Seven out of sixteen sustained 100% damage, and three incurred damage levels between 60% and 70%.
- **Large-scale WDPs:** Two out of three remained operational, with damage levels ranging from 10% to 30%. One plant is entirely non-functional due to unclear damage.
- **WWTPs:** All five investigated plants are either non-functional or operating at drastically reduced capacity. Three plants sustained 100% damage, while the Rafah WWTP operates at just 14% of its original capacity.

Solar energy systems faced severe impacts:

- **Medium-scale WDPs:** Seven out of thirteen systems were completely destroyed.
- **WWTPs:** All PV systems sustained 100% damage, with total losses exceeding $10 million.

Key Issues Identified

1. **Energy Deficiencies:** Destruction of the electricity grid and solar energy systems left critical facilities reliant on diesel generators.
2. **Operational Challenges:** Lack of advanced systems, outdated technology, and restrictions on importing essential materials led to inefficiencies and higher energy consumption.
3. **Environmental Risks:** Non-functional WWTPs are discharging untreated wastewater into the sea, and land posing severe public health and environmental hazards.

Recommendations for Recovery

1. **Immediate Energy Solutions:**
    - Implement hybrid systems combining solar PV, diesel generators, and limited battery storage to ensure medium-scale WDP functionality.
    - Equip pumps with variable frequency drives (VFDs) to optimize energy use.
2. **Infrastructure Restoration:**
    - Prioritize repairs to Medium-scale WDPs and WWTPs, starting with partially damaged facilities.

5. Introduction

Even before the escalation of conflict in October 2023. Gaza was facing a catastrophic water crisis, characterized by extreme scarcity and severe contamination. The region's population of approximately 2.2 million had access to an average of 80 liters of water per person per day, which fell short of the WHO-recommended minimum of 100 liters for basic needs.

The primary source of drinking water was the Coastal Aquifer, which provided about 90% of the supply; however, 97% of this water was deemed unfit for consumption due to over-extraction, saltwater intrusion, and pollution from sewage and chemicals. WDP plays a crucial role in addressing the water crisis in Gaza. Before the war, there were over 150 WDPs operating throughout Gaza, primarily focused on treating brackish water from the Coastal Aquifer. These plants provide essential drinking water to many residents, as reliance on the aquifer has become increasingly problematic.

The situation worsened dramatically after the conflict began, with average water availability dropping to between 1 to 3 liters per person per day, far below the emergency standard of 15 liters set by international guidelines. Many residents are now resorting to unsafe sources, including brackish water and untreated supplies, leading to widespread health issues such as dehydration and communicable diseases. The destruction of water infrastructure due to military actions has further exacerbated these challenges, leaving only a fraction of pre-war water production capacity operational and severely limiting access to safe drinking water.

6. Methodology

This methodology outlines the systematic approach undertaken to evaluate and restore the functionality of Water Desalination Plants (WDPs) and Wastewater Systems (WWSs), with a particular emphasis on incorporating solar power systems for sustainable recovery. The process is divided into seven key activities, each detailed below:

Activity 1: Design of Evaluation Forms and Data Processing Tools

1. **Development of Tools**:
    - Designed Excel-based forms/survey to facilitate data entry, gap analysis, and reporting for WDPs and WWSs.
2. **Testing and Refinement**:
    - Conducted initial tests of the tools to ensure their accuracy and usability.
    - Refined the tools based on feedback and trial runs to guarantee effective data collection and analysis.

Activity 2: Data Collection

1. **Source Identification**:
    - Obtained comprehensive lists of WDPs and WWSs from relevant authorities, including the Palestinian Water Authority, Coastal Municipalities Authority, and Environmental Authority.

2. **Data Gathering**:
    - Data was gathered using three methods:
        1. Surveys in the form of Excel sheets sent via email, which included technical, financial, and operational data, and represented the most common method of data collection.
        2. Phone interviews used to verify and clarify technical, financial, and operational data provided in the survey Excel sheets.
        3. Field visits conducted by engineers to collect direct observations and validate information.

Activity 3: Data Processing, Verification, and Reprocessing

1. **Preliminary Analysis**:
    - A team of two engineers analyzed the data to identify initial gaps and deficiencies in the systems.
2. **Validation**:
    - Compared collected data with engineering and industry standards to ensure consistency and reliability.
3. **Data Collection Follow-Up**:
    - Directed the data collection team to gather missing data and verify doubtful entries to enhance accuracy.
4. **Tool Modification and Reanalysis**:
    - Updated data processing forms based on findings to enhance their applicability and precision.
    - Reprocessed data using the updated tools to ensure that gap analysis and assessments reflected the latest, most accurate information.

Activity 4: Gap Analysis and Assessment

1. **Identification of Deficiencies**:
    - Performed a thorough gap analysis to pinpoint critical deficiencies in infrastructure and resources of the WDPs and WWSs, with a particular focus on solar energy integration and its role in sustainable recovery.
2. **Technical Needs Assessment**:
    - Compiled a detailed technical list of equipment, materials, and processes required to restore the functionality of stations and associated solar systems, with an emphasis on integrating solar energy solutions.

Activity 5: Proposed Potential Intervention:

6.1 Scope of the Investigation for both WDPs and WWTPs

Water desalination plants (WDPs) can be categorized based on their production capacity into small, medium, and large-scale facilities. According to industrial standards, small-capacity WDPs produce between 0 and 10 m³/h, medium-capacity plants produce between 10 and 50 m³/h, and large-capacity plants produce over 50 m³/h. These classifications help define the scale and operational scope of desalination systems, with each category typically employing appropriate technologies and processes to match the production requirements.

In the Gaza Strip, there are over 150 desalination plants, of which around 20 are considered medium-scale, and 3 are classified as large-scale. In this study, we will focus on medium and large-scale desalination plants to analyze their performance, technologies, and operational efficiency, providing insights into their role in addressing water scarcity challenges in the region.

The investigation covered a total of 19 WDPs, including:

- **3 large-scale production WD:** Currently, Gaza has three main WDP located in the northern, central, and southern regions, with a combined capacity of approximately 36,000 cubic meters per day. These plants serve about 40% of the population and are crucial for providing safe drinking water amid ongoing scarcity.
- **16 small-scale production systems**: out of 20 Medium scale in Gaza

This means that the study covers all large-scale facilities and the majority of medium-scale ones. This comprehensive coverage ensures that the study's findings are representative and can be extended to other non-investigated plants, providing valuable insights into the performance and operational efficiency of desalination in the region.

Table 1 and Table 2 show the list of large and medium-scale WDPs. An example picture of the investigated WDPs can be found in the Annex.

In addition to desalination plants, the study also investigates wastewater treatment plants (WWTPs), which can similarly be categorized based on their production capacity. In Gaza, there are three main WWTPs (NGEST WWTP, Central Gaza, and Khan Younis) and three smaller ones (Rafah, West Gaza, and West Khan Younis) that have been operational for years. Only the smaller one in West Gaza will not be investigated. This study will cover all five plants, providing a comprehensive analysis of their performance, efficiency, and operational challenges.

Table 1, list of high-capacity WDPs

No	Name	Solar system	Station Capacity (m³/h)	Energy requirement kW	Pre-Treatment TDS, mg / Liter	Post-Treatment TDS, mg / Liter
1	CMWA/SOUTH	✔	850	4608	42000	300
2	CMWA/Deir Al Balah	✔	250	1024	42000	150
3	CMWA/Gaza	▯	420	1800	NO INFO	NO INFO

Table 2, list of medium capacity WDPs

No	Name	Solar system	Station Capacity (m^3/h)	Energy requirement kW	Pre-Treatment TDS, mg / Liter	Post-Treatment TDS, mg / Liter
1	Yaseen Gaza (ETA)	✔	50	100	12000	70
2	Yaseen Rafah (ETA)	✔	40	90	2000	70
3	Yaseen North Gaza (ETA)	✔	35	80	7000	70
4	ALSAADA DP	✔	25	45	3000	130
5	Alsaada	✔	20	50	1800	80
6	AL asdeqa station	✔	12	60	6000	130
7	Alsaada 2	✔	12	50	1800	80
8	Abusalim	✔	12	50	3000	60
9	Alhadeqa	✔	10	60	NO INFO	NO INFO
10	Almasara	✔	10	50	NO INFO	NO INFO
11	Alqaraj	✔	8	35	NO INFO	NO INFO
12	j32	□	45	150	12700	300
13	Al Forqan St.	□	40	70	2700	200
14	Taj Al Wakar	□	15	25	3000	80
15	Al-Sahaba Water	□	20	60	1000	70
16	AlRawda	□	20	45	1000	20

Table 3, a list of WWTPs investigates

	Name	**Total Power requirement (kW)**	**Station Capacity (m^3/h)**	**Type of treatment**
1	NGEST WWTP	1500	1450	Secondary treatment
2	Rafah WWTP	370	625	Primary treatment
3	Western WWTP	250	800	Primary treatment
4	Khan Younis WWTP	2400	1100	Tertiary treatment
5	Central Gaza WWTP	3500	2500	Secondary treatment

6.2 Energy Industry Standards consumption and verification of data

The energy consumption was normalized from kW to kW/m^3 to verify the collected by Comparing Against Industry Standards or meaningful analysis, comparisons, and decision-making. The energy consumption of reverse osmosis (RO) WDP for brackish water and seawater varies based on capacity (low, medium, or high), feedwater salinity, and system design. Here is an approximate breakdown:

Table 4

Plant Type	Capacity	Energy Consumption (kWh/m^3)
Brackish Water	**Small (1–10 m^3/h)**	2.5–4
	Medium (10–50 m^3/day)	1.5–3
	Large (>50 m^3/day)	1–2.5
Seawater	**Small (1–10 m^3/h)**	6–8
	Medium (10–50 m^3/day)	4–6
	Large (>50 m^3/day)	3–4.5

Obviously, brackish water desalination is significantly less energy-intensive than seawater due to:

- **Lower salinity**: Requires less pressure to overcome osmotic resistance.
- **Higher recovery rates**: Produces more water per unit of feedwater.

Energy consumption in WDP is primarily affected by factors such as feedwater salinity, recovery rate, operating pressure, system design, and maintenance practices. Higher salinity and lower recovery rates require more energy to overcome higher osmotic pressure. The efficiency of membranes, the inclusion of energy recovery devices (ERDs), and the use of high-efficiency pumps can significantly reduce energy demand. Larger plants benefit from economies of scale, and utilizing advanced technologies. Proper pretreatment and regular cleaning prevent fouling and scaling, maintaining optimal energy efficiency. Additionally, the age and maintenance of equipment also play a role in ensuring that systems operate efficiently over time.

The collected data indicate that energy consumption for medium-scale WDP operating on brackish water ranges between 2 and 6 kWh/m^3 as shown in Figure 1, significantly exceeding energy standards in some cases. While operator errors in data collection, estimated at 10–30%, may contribute to discrepancies, other critical factors must be considered. These plants rely on outdated systems without energy recovery and traditional pumps, resulting in inefficiencies. Additionally, challenges such as inadequate maintenance, financial constraints, and restrictions on importing essential materials imposed by Israel further exacerbate the situation. Frequent energy supply disruptions, as detailed in later sections, also play a significant role in the high energy consumption rates.

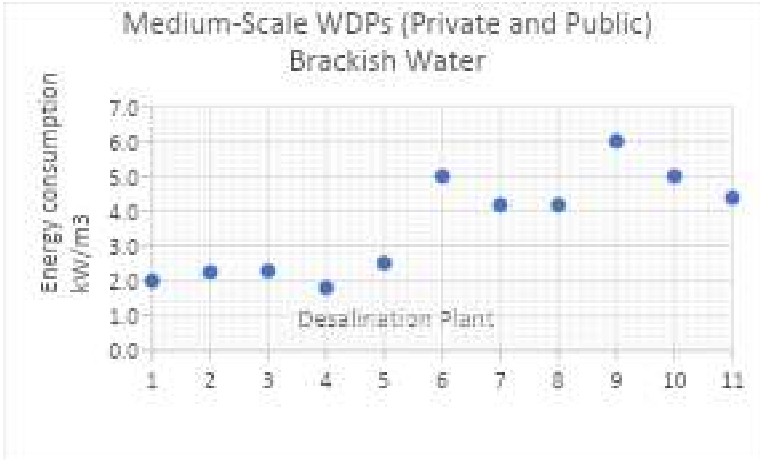

Figure 1,

For large-scale WDP (public) operating on saltwater, energy efficiencies in the three main plants range between 4 and 5.5 kWh/m³ (Figure 2), which aligns more closely with energy standards, albeit on the higher side. This improved efficiency is attributed to the use of advanced systems, economies of scale, high-efficiency pumps, and full energy recovery. However, some factors affecting medium-scale plants, such as maintenance challenges, financial constraints, and occasional disruptions in energy supply, also apply to these plants, contributing to slightly higher energy consumption.

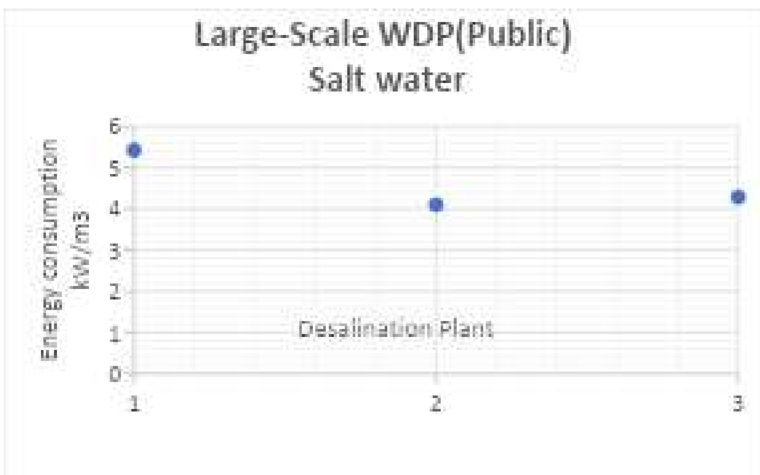

Figure 2

The energy consumption of wastewater treatment plants (WWTPs) is more complex than water desalination plants (WDPs) due to varying influent quality, multiple treatment stages, and energy-intensive sludge handling. Additionally, nutrient removal, aeration, and seasonal or diurnal variations further complicate energy use. The integration of advanced technologies and the potential for energy recovery adds another layer of complexity to WWTP energy management. Typical values are:

- **Primary Treatment:** 0.1–0.3 kWh/m³

- **Secondary Treatment (e.g., activated sludge):** 0.3–0.8 kWh/m³
- **Tertiary Treatment (e.g., advanced nutrient removal or filtration):** 0.8–1.5 kWh/m³
- **Sludge Treatment:** 0.1–0.4 kWh/m³ *(Including thickening, dewatering, and stabilization processes like anaerobic digestion.)*

Khan Younis WWTP is the only plant with tertiary treatment, so its total energy consumption should range between 1.3 and 3 kW/m³. The other plants should have energy consumption between 0.5 and 1.5 kW/m³. As shown in the figure, Khan Younis consumption is around 2.2 kW/m³, which is on the high end of the expected range. While this is not necessarily incorrect, it depends on the operational method and remains within expectations. The rest seems to be within the expected range. Overall, we can have confidence in the data regarding both production rates and energy consumption.

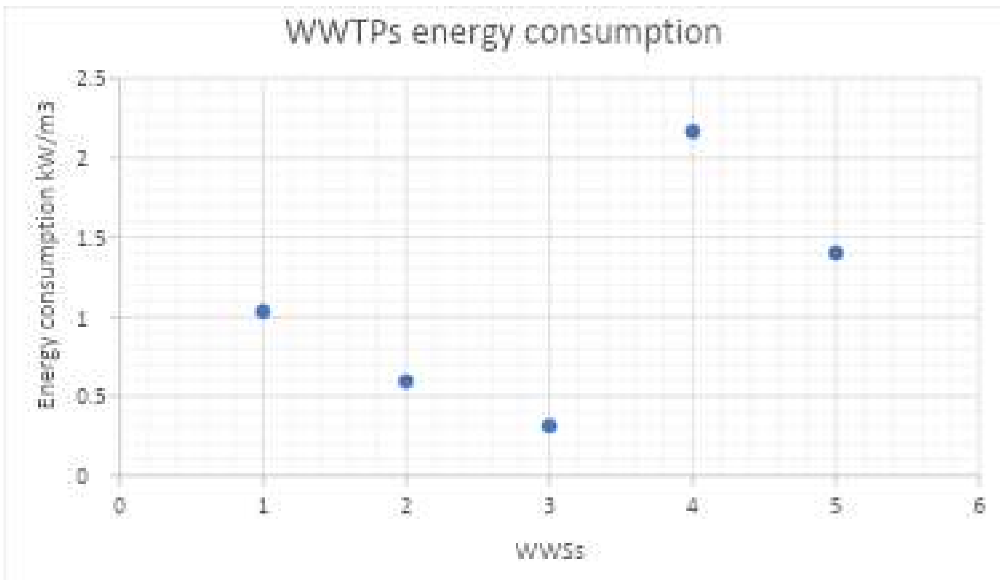

Figure 3, WWTPs energy consumption (kW/m³)

7. Pre-war status of Solar Panels in WDPs

Before the outbreak of the recent war, Gaza faced significant challenges regarding its electricity supply, which were characterized by massive electricity shortages. The frequent power cuts in Gaza severely impacted the water situation and desalination efforts, reducing the operation of WDP, limiting access to clean drinking water, and worsening reliance on unsafe water sources.

The reliance on solar energy was increasingly recognized as a viable solution to power desalination and water purification systems, particularly given the frequent electricity shortages caused by the ongoing blockade and military actions. The collected data show clearly the 3 types of energy sources Grid, Solar energy (PV Cells), and Genset (Diesel generators). These sources are used separately or combined with each other as shown in the figure below. The data in Figure show clearly that 20% of the plants use only a grid, which means that the plant is only functioning when power is on reducing the working hours quite a lot (power cuts can last up to 18 hours per day before the war). The 45% use a system with a combination of the solar system and grid (either on-grid or off-grid solar systems). 15% using a combination grid, genset, and solar system. This means the usage of solar energy is 70% of the power used as one of the sources for producing water. In terms of numbers, 12 out of 17 medium scale have a solar system installed. 2 out of 3 large-scale stations have PV cells installed

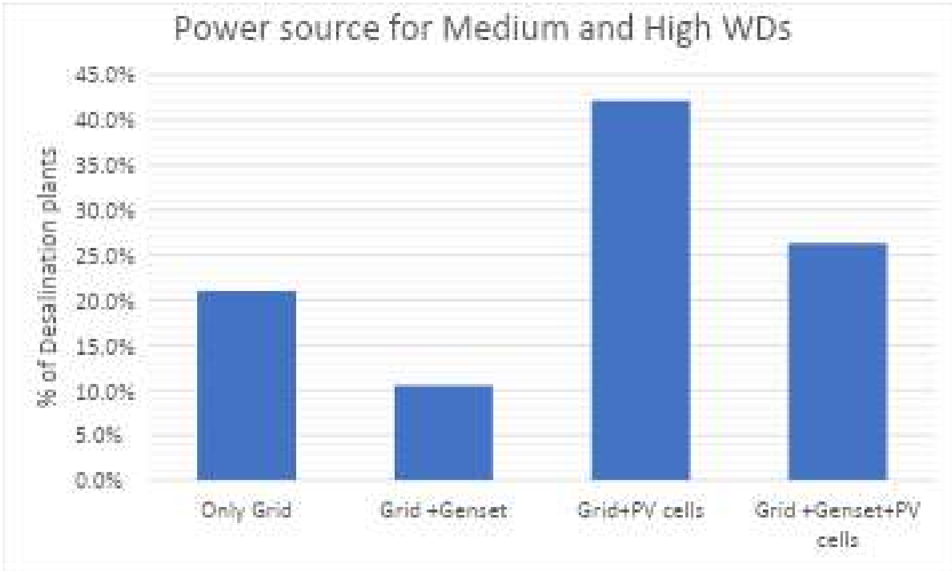

Figure 4, Power source for Medium and High WDs

For the WWTPS, in addition to Genset, Grid, and solar, there is a Combined Heat and power generator that uses methane to produce electricity and uses the heat in the generator to enhance the production of menthane in the digester. For the WWTPs, in addition to power sources such as gensets, grid electricity, and solar energy, some facilities use combined heat and power (CHP) generators. These systems utilize methane produced during anaerobic digestion to generate electricity while capturing the waste heat from the generator. This heat is then used to enhance methane production in the digester, improving overall energy efficiency and sustainability. Table 5 highlights the various power supplies utilized at different WWTPs. Notably, solar energy is employed at all the WWTPs, demonstrating a commitment to integrating renewable energy sources alongside traditional options such as grid electricity, gen-sets, and combined heat and power (CHP) systems.

Table 5, power supply source for WWTPs in the Gaza Strip

	Name	Power supply source
1	NGEST WWTP	GenSet / Grid / Solar
2	Rafah WWTP	CHP / Grid / Solar
3	Western WWTP	Grid / Solar
4	Khan Younis WWTP	GenSet / Grid / Solar
5	Central Gaza WWTP	CHP / Grid / Solar

Based on the well-established assumption that solar energy operation hours average 10 hours per day throughout the year, this estimate accounts for solar exposure during both winter and summer in the Gaza Strip (with 10 hours per day including both peak and non-peak solar hours). The efficiency of the PV cells was assumed to be 50% of their rated power, averaged over all hours, accounting for variations in sunlight intensity, angle, and other losses such as dust and heat. According to interviews with relevant station personnel, it was concluded that large-scale plants operate 24/7, while medium-sized plants operate for 8 hours per day. These assumptions and findings were used to calculate the contribution of solar energy to the total energy consumption (kWh/kWh), as illustrated in Figure 4 & Figure 5

The results show that the average contribution for large scale plants to be around 7% (ranging between no contribution on one plant to 10% contribution). As for medium-scale plants, the contribution is much higher ranging between 23% to almost 100, averaging around 55%.

Worldwide, the direct use of renewable energy accounts for around 1%. When considering electricity generated from renewable sources and supplied via the grid, estimates suggest that approximately 10% to 20% of desalinated water is produced using this indirect method. This includes contributions from solar, wind, and other renewable technologies. The above information shows that the use of renewable energy in water desalination exceeded the global average in the Gaza Strip before the war, both directly and indirectly.

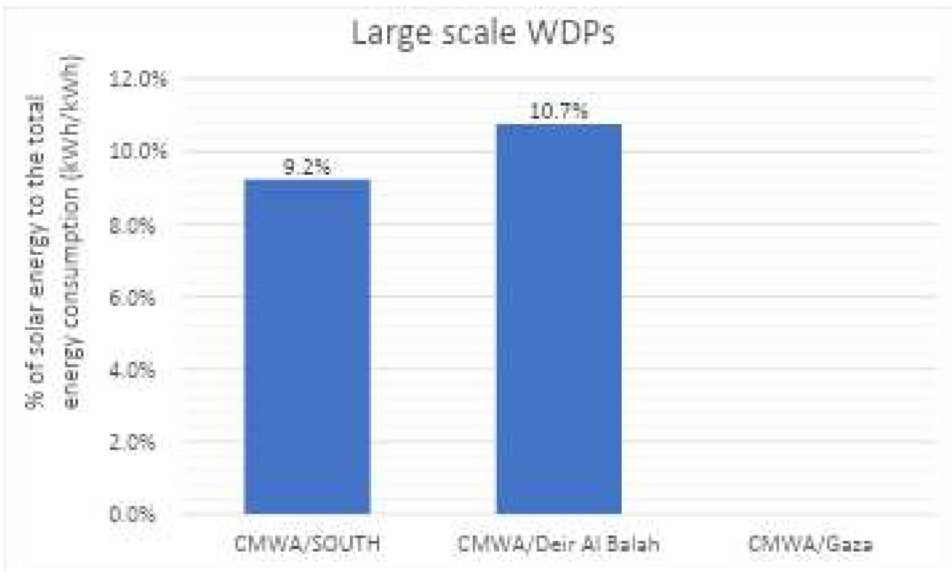

Figure 5, % of solar energy to the total energy consumption (kWh/kWh for large scale WDPs

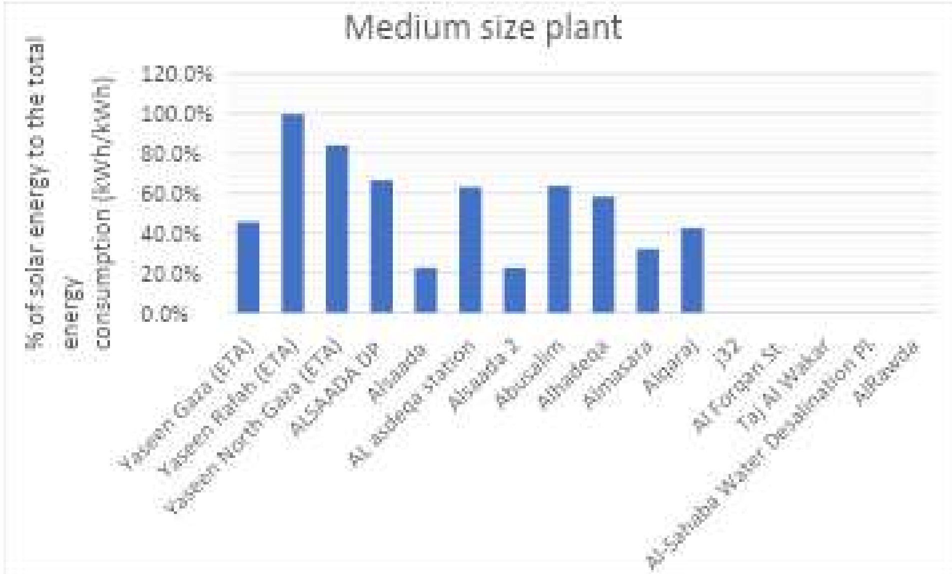

Figure 6, Figure 5, % of solar energy to the total energy consumption (kWh/kWh for medium scale WDPs

In Gaza, renewable energy (primarily PV and CHP) accounts for a substantial portion of energy use in WWTPs. At around 25% for solar alone, as shown in Figure 7, Gaza’s reliance on renewables is relatively high compared to many regions, reflecting the necessity to mitigate grid shortages and utilize abundant solar resources. Additionally, a couple of WWTPs utilize combined heat and power (CHP) systems increasing the contribution of renewable energy to up to 40%. Globally, WWTPs with access to biogas often achieve a higher overall renewable energy contribution due to such integrated systems.

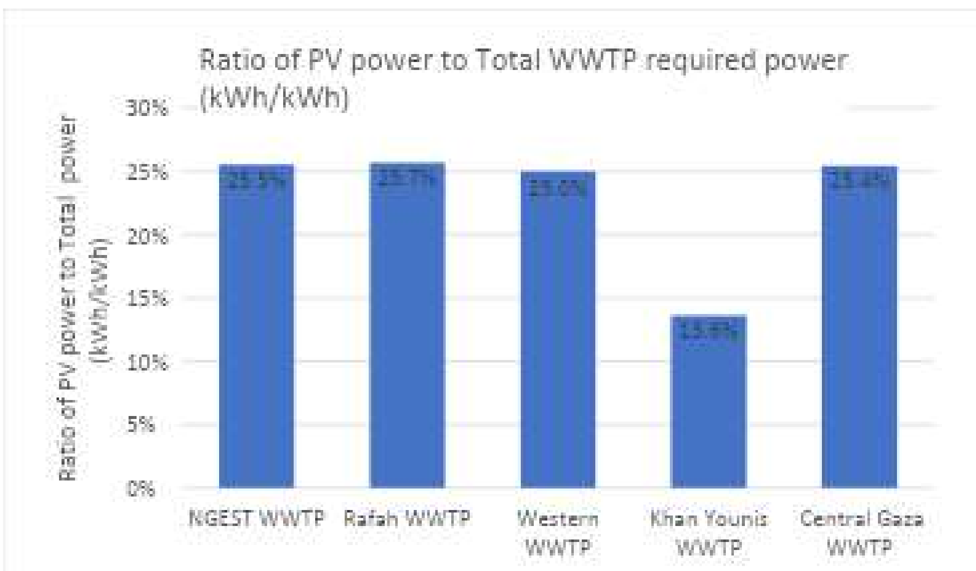

Figure 7, Ratio of PV power output to total WWTP required power (kWh/kWh)

The total rated power from installed PV cells in Gaza's WWTPs is approximately 7.1 MW. The distribution of PV systems across the WWTPs is illustrated in the figure below, highlighting the significant role solar energy plays in meeting the energy demands of these facilitie**s.**

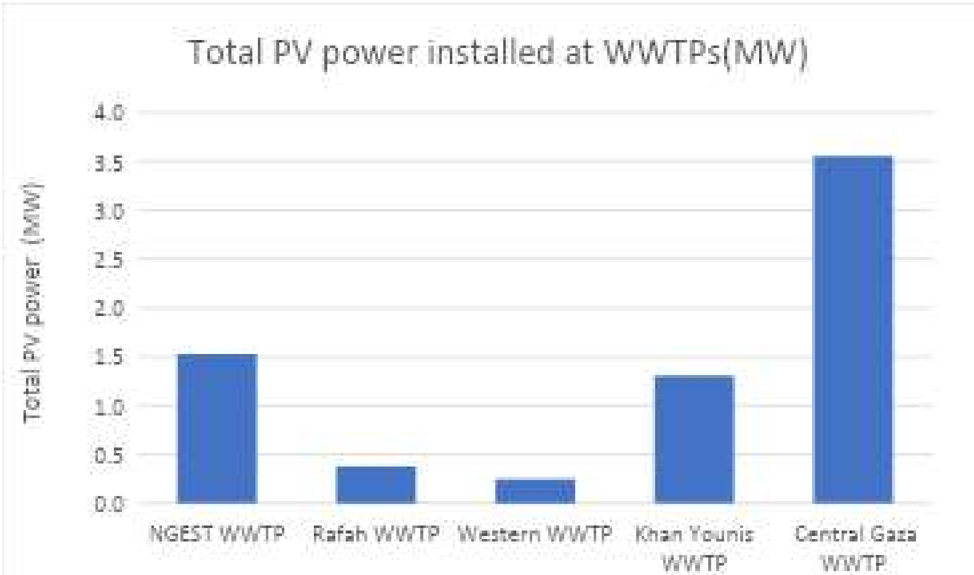

Figure 8, Total PV power installed at WWTPs(MW)

7.1 Application of PV systems

The main components of PV systems are

1. Solar Panels (Photovoltaic Modules): Convert sunlight into direct current (DC) electricity using semiconductor materials like silicon.
2. Inverter: Converts DC electricity produced by solar panels into alternating current (AC) electricity, which is used by most household appliances or fed into the grid.
3. Charge Controller: Regulates the voltage and current coming from the solar panels to prevent overcharging of batteries (in case of batteries).
4. Batteries (Mainly for Off-grid or Hybrid Systems): Store excess energy produced during the day for use at night or during cloudy periods.
5. Mounting System: Secures the solar panels to the roof or ground and adjusts the angle to maximize exposure to sunlight.
6. Wiring and Electrical Connections: Transmit electricity between the components (solar panels, inverter, batteries, etc.)

PV systems can be categorized based on different factors, however, in this study we are more interested in the connection type or mode of operation. Based on this criterion, PV systems can indeed be categorized as:

1. Off-Grid PV Systems:

These systems operate independently of the utility grid and rely solely on solar power, often coupled with battery storage to provide energy during periods of low or no sunlight.

2. On-Grid PV Systems:

These systems are connected to the utility grid and rely entirely on the grid for backup when solar energy generation is insufficient. They do not include any alternative energy source like a genset or another renewable energy system.

3. Hybrid PV Systems:

Hybrid PV systems are designed to integrate photovoltaic (PV) cells with another energy source, such as a diesel generator or other renewable energy systems (e.g., wind turbines), to ensure a reliable and stable power supply. These systems are especially valuable in areas where there are a lot of power cuts or no grid and applications with variable energy demands and critical startup requirements, such as **WDP**. Hybrid systems are particularly beneficial in areas with inconsistent sunlight or where energy demand exceeds solar generation capacity.

Figure 9

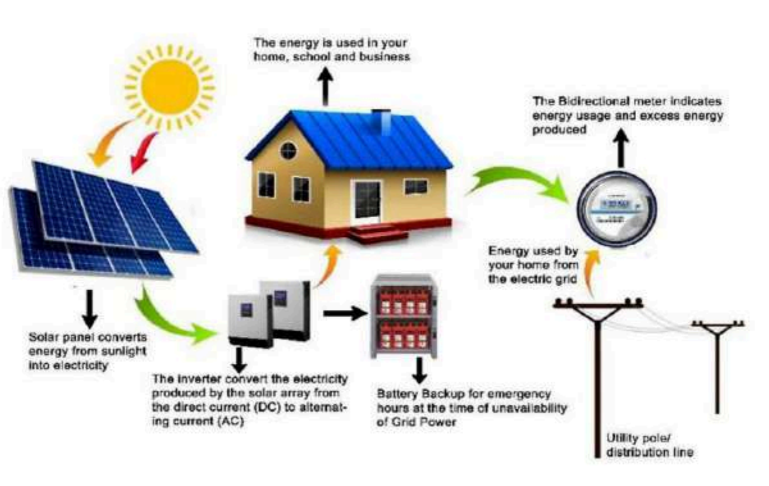

Figure 10

7.2 Investigation of Installed PV Systems

The following observations were made during the investigation of PV systems installed in WDP:

1. Inverter Types and Operation:
    a. The majority of systems (11 out of 13) use on-grid inverters; however, due to frequent power cuts, they primarily operate as off-grid systems.
    b. The only exceptions are the two large-scale desalination plants, which are supplied with electricity 24/7 through a dedicated line.
    c. Manual control is used in all systems to switch between the PV system and other power sources.
    d. Only one system is equipped with a hybrid inverter, allowing it to use PV cells in conjunction with a diesel generator.
2. Storage Devices:
    a. All medium scale WDPs include storage devices to address the intermittent power supply.
    b. Most storage devices are AGM batteries, either 12V or 2V. In a few plants, lithium batteries are used. The use of lithium batteries has increased significantly over the past two years.
    c. In Gaza's WWTPs, no energy storage devices, such as batteries, were found, as the facilities are connected to a 24/7 grid line. This continuous grid connection eliminates the need for energy storage systems, ensuring a reliable and uninterrupted power supply for wastewater treatment operations.
3. Washing systems: These washing systems are of paramount importance to maintain the cleanliness and efficiency of critical equipment, prevent clogging and buildup, and ensure the overall operational reliability of the treatment process. Regular washing helps prolong the lifespan of components and minimizes disruptions in wastewater treatment operations.
    a. In WDPs, only 40% are equipped with washing systems, either automatic systems or electric high-pressure washer pumps (5 plants out of 13).
    b. All WWTPs in Gaza are equipped with washing systems, either automatic systems or electric high-pressure washer pumps.
4. Retrofitted Systems:
    a. Most solar systems were retrofitted, meaning the WDP were installed first, and the PV systems were added later.
    b. Only one system included an inverter pump specifically designed for operation using solar power.

8. Post-war status for WDPs and WWTPs

8.1 Status of Solar systems

As anticipated, the direct and indirect effects of the bombing in the Gaza Strip have caused extensive damage, as shown in Figure 11. Among the affected facilities:

- 7 out of 13 medium-sized WDPs suffered complete destruction of their PV capabilities.
- 2 medium-sized WDPs experienced 100% damage to their PV cells and batteries, along with partial damage to their inverters—50% and 25%, respectively.

Fortunately, large-scale WDPs have incurred minimal damage, with a maximum of 5% of their PV capacity and inverters affected. Notably, no damage was reported to their batteries, as these plants do not utilize battery storage systems.

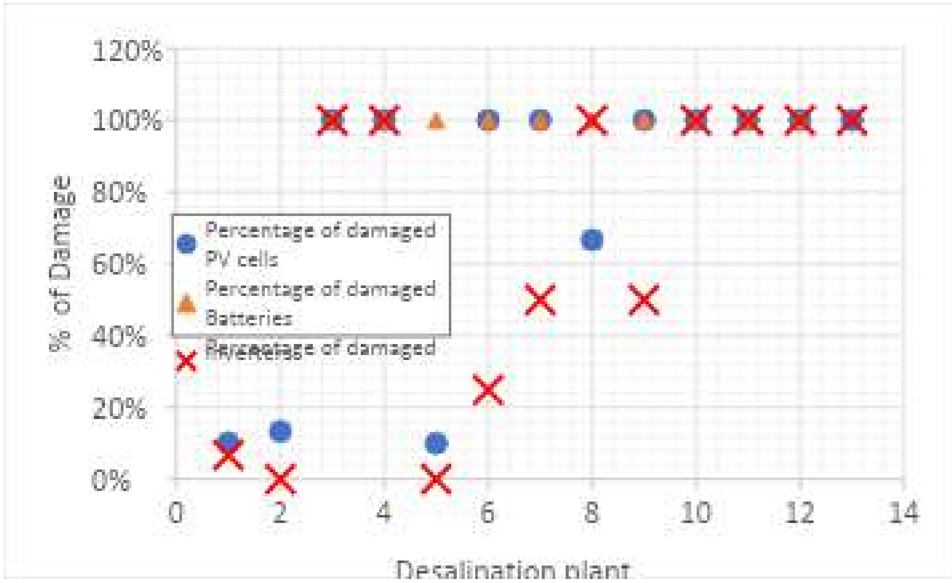

Figure 11, % of damage in solar systems main components

Figure 12 shows the cost of the PV systems for each medium-capacity desalination plant, which sustained the most significant damage. The total cost of the damage has exceeded 2 million dollars. These figures require further study to account for price fluctuations and other factors affecting costs.

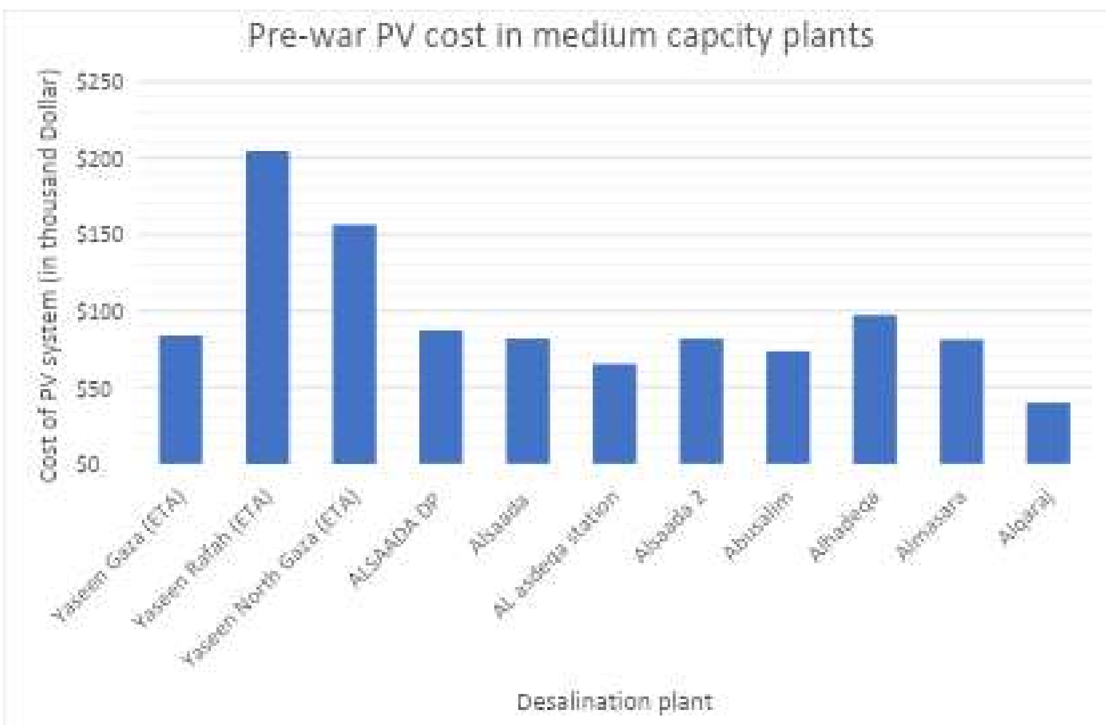

Figure 12, Cost of damaged PV systems

With regards, to WWTPs, *Table 6* below shows the level of damage sustained by the solar systems, which, unfortunately, indicates the complete destruction of the entire PV systems. Figure 12, shows the cost of the damaged PV cell system at different locations. The cost of damaged PV cells will exceed 10 million dollars

Table 6, details the damage to PV systems in WWTPs due to the war in Gaza

	NGEST	**Rafah WWTP**	**Western WWTP**	**Khan Younis WWTP**	**Gaza** central **WWTP**
% Damaged PVs	100%	100%	100%	100%	100%
% Damaged PV Combiner Box	100%	100%	60%	100%	100%
% Damaged PV Mounting Structure	100%	100%	100%	100%	100%
% Damaged PV washing system	100%	100%	100%	100%	100%
% Damaged Batteries	No Batteries	No Batteries	100%	No Batteries	No Batteries
% Damaged Inverters	100%	100%	100%	100%	100%
% Damaged Inverter AC Panel	100%	100%	100%	100%	100%
% Damaged Air Condition	100%	100%	100%	100%	100%
% Damaged Battery Inverters	100%	100%	100%	100%	100%
% Damaged Battery Combiner Box	100%	100%	100%	100%	100%
% Damaged Ducting, wiring, etc.	100%	100%	100%	100%	100%

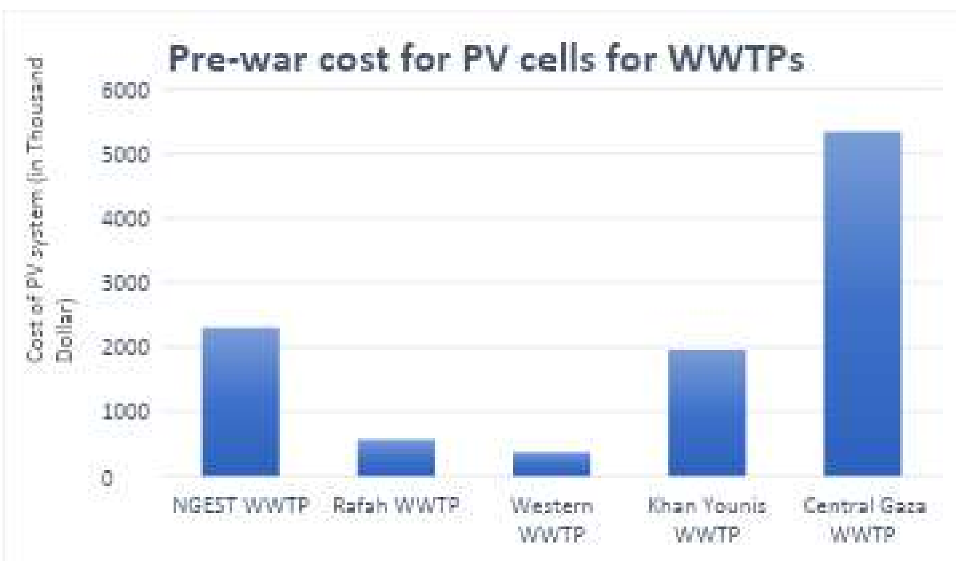

Figure 13, Pre-war cost for PV cells for WWTPs

8.2 Status of WDPs and WWTPs

Table 7 provides an overview of the medium-scale Water Desalination Plants (WDPs) and their condition following the war. The data reveals extensive damage to the water desalination plants (WDPs), with seven out of sixteen stations suffering 100% damage and becoming completely non-functional. Additionally, three stations sustained 60%-70% damage and are only partially functional, while two stations, **Abusalim** and **AlRawda**, remain fully operational with damage levels of 10% and 0%, respectively.

Table 7, % of damage of medium scale WDP during the war and working status

WDPs name	water source	% Damage of the Station During the War (0-100%)	status
Yaseen Gaza (ETA)	Well	70%	Not working
Yaseen Rafah (ETA)	Well	100%	Not working
Yaseen North Gaza (ETA)	Well	100%	Not working
ALSAADA DP	Well	100%	Partially Working
Alsaada	Well	100%	Working
AL asdeqa station	Well	60%	Partially Working
Alsaada 2	Well	100%	Not Working
Abusalim	Well	10%	Partially Working
Alhadeqa	Well	100%	Not Working
Almasara	Well	100%	Not Working
Alqaraj	Municipal	100%	Partially Working
j32	Well	10%	Not Working
Al Forqan St.	Well	60%	Working
Taj Al Wakar	Well	70%	Working
Al-Sahaba Water Desalination Plant	Well	30%	Working
AlRawda	Well	0%	Working

Table 8 shows that The CMWA (Coastal Municipal Water Authority) stations have sustained varying levels of damage during the war. The CMWA/SOUTH station experienced minimal damage (10%) and remains functional. The CMWA/Deir Al Balah station suffered moderate damage (30%) but is still operational. The CMWA/Gaza station's damage level is still unclear, but it is currently non-functional.

Overall, 75% of the medium and large water desalination plants (WDPs) are either non-functional or partially working, significantly reducing the region's capacity to provide clean water. This poses a serious challenge to meeting the population's water needs and maintaining public health. Immediate interventions are required to repair and restore the damaged facilities to mitigate the humanitarian crisis and ensure a reliable supply of potable water.

Table 8, % of damage of large scale WDP during the war and working status

Name	water source	% Damage of the Station During the War (0-100%)	status
CMWA/SOUTH	Beach Wells	10%	Working
CMWA/Deir Al Balah	Beach Wells	30%	Working
CMWA/Gaza	Beach Wells	Still unclear	Not Working

Table 9 show the extent of damage, functionality and impact. The wastewater treatment plants (WWTPs) have sustained significant damage, with three plants—Western WWTP, Khan Younis WWTP, and Central Gaza WWTP—reporting 100% damage and complete non-functionality. The Rafah WWTP sustained 35% damage, resulting in a dramatic reduction in capacity from 20,000 m³/day to just 144 m³/day, with untreated wastewater being dumped into the sea. The damage level for NGEST WWTP and Sheikh Ejleen is still unclear, but both are currently non-functional.

In terms of functionality and impact, all six WWTPs are not working effectively, with most being completely non-functional since October 8, 2023. Only the Rafah WWTP retains limited functionality, although its drastically reduced capacity poses significant environmental and health risks due to untreated wastewater discharge into the sea. The plants utilizing primary, secondary, and tertiary treatment processes have all been impacted, indicating widespread and indiscriminate damage across all levels of treatment technology.

Table 9, % of damage of medium scale WWTPs during the war and working status

	Damage level	Type of treatment	status	Notes
NGEST WWTP	Still unclear	Secondary treatment	Not working	Not working since 8th of October 2023
Rafah WWTP	35%	Primary treatment	Partially working	Dropped from 20 000 m^3/day to 14000 m^3/day which is dumped to the sea
Western WWTP	100%	Primary treatment	Not working	Not working since 8th of October 2023
Khan Younis WWTP	100%	Tertiary treatment	Not working	Not working since 8th of October 2023
Central Gaza WWTP	100%	Secondary treatment	Not working	Not working since 8th of October 2023
Sheikh Ejleen	Still unclear	Primary treatment	Not working	Not working since 8th of October 2023

The extensive damage to these critical facilities highlights a severe disruption in wastewater management, leading to potential public health hazards, environmental pollution, and a significant strain on the already fragile infrastructure. The non-functionality of tertiary and secondary treatment plants further exacerbates the problem, as these systems are essential for advanced wastewater purification.

Immediate intervention is necessary to restore at least partial functionality and prevent further environmental degradation and health crises.

9. Post war intervention,

9.1 Energy recovery:

The electricity grid in Gaza has been severely damaged during the ongoing conflict, with reports indicating that 90% of machinery and equipment has been destroyed, resulting in losses estimated at $450 million. The grid has been completely non-operational since October 11, 2023, when Gaza's sole power plant ran out of fuel and Israel cut off electricity supplies. The restoration of Gaza's electricity grid, is expected to be a lengthy process.

There is a plan for basic restoration of essential services, such as hospitals and water desalination plants, might take several months, provided international aid is mobilized quickly. However, full reconstruction of the grid is likely to take years due to the extensive damage, logistical challenges in importing necessary materials, dependence on international funding, and ongoing security risks that could disrupt repair effort.

With regards, to large scale WDPs and WWTPs, basic restoration of electric grid already started as shown in the table below

Table 10

Desalination Plant	Connection Date	Details	Current Capacity	Beneficiaries
Khan Younis Plant	2-Jul-2024	Connected to a new Israeli power line. Managed by UNICEF. Still awaiting full operational status.	Expected: 20,000 m^3/day	Will serve ~200,000 residents
Deir al-Balah Plant	26-Dec-2024	Reconnected to the Israeli grid after repairs. Fully operational.	16,000 m^3/day	Serves ~600,000 residents

Although There is no definitive timeline for connecting the third large capacity WDP (Gaza WDPs) and WWTPs to the electricity grid or restoring their full operational capacity, it is expected to follow the same trend.

Medium-capacity desalination plants are less dependent on centralized grid restoration and can serve critical needs in dispersed areas. Medium-capacity desalination plants contribute to more than 70% drinking water in Gaza strip. For that reason, addressing these plants ensures a broader reach and flexibility in providing clean water to affected populations.

The energy intervention can be divided into two categories:

9.1.1 Immediate Intervention

In the past, PV systems for water desalination plants (WDPs) were designed to rely partially on grid electricity, operating with an assumed availability of 30–50% grid supply. However, given the current destruction of the grid and its uncertain restoration timeline, immediate interventions must exclude grid electricity from the design. For medium-sized WDPs operating 16 hours daily to meet market demands, two main options are proposed:

1. **Standalone PV System**:
    - Requires a large storage system to address the variability in solar energy production (from 0 kW at night to peak output during optimal conditions) and fluctuations in water demand.
    - While it ensures self-sufficiency, this option involves significantly higher costs due to the large battery capacity needed for continuous operation.
2. **Hybrid System**:
    - Combines PV panels, a genset, and smaller battery storage, balancing renewable energy utilization with reliability.
    - The PV system supplies energy during the day, the batteries provide limited backup, and the genset fills in during extended low-solar periods or high-demand spikes.
    - This option is more cost-effective and offers operational flexibility, making it suitable for the immediate post-war recovery plans.

Given the urgency of restoring medium WDPs to operational status, the hybrid system is recommended as a practical, reliable, and scalable solution. It minimizes reliance on expensive storage systems while ensuring uninterrupted operation to meet drinking and washing water needs. The table below the main components of the hybrid system.

Table 11, Main Components of a Hybrid System for Medium-Sized WDPs

Component	Description	Key Role
Solar PV Modules	Converts sunlight into electricity.	Provides primary energy source during daylight hours.
Battery Storage System	Stores excess solar energy for use during low sunlight periods.	Ensures smooth operation and reduces reliance on the genset.
Diesel Generator (Genset)	Backup power source during low sunlight or increased demand periods.	Enhances system reliability and operational continuity.
Inverter	Converts DC electricity from PV and batteries into AC electricity for plant operations.	Powers pumps and other equipment with compatible current.
Fuel Save Controller (FSC)	Regulates energy flows between PV, batteries, and genset to minimize fuel use.	Optimizes energy management and maximizes renewable energy utilization.
Mounting Structures	Secures PV panels and batteries in place.	Ensures optimal solar energy capture and safe housing for batteries.
Control and Monitoring System	Provides real-time data and control of energy production, consumption, and system performance.	Enables efficient management, fault detection, and remote monitoring.

Electrical Distribution Components	Includes circuit breakers, switchboards, and cables.	Safely and efficiently distributes power within the system.

In addition, we have to make sure that all pumps are equipped with VFD that allows to reduce starting up current and allow for changes in flow demands as shown in the table below

Variable Frequency Drives (VFDs)	Regulates pump motor speeds based on operational needs.	Improves energy efficiency and adapts to demand variations.

9.1.1.1 Example of the proposed system

An example of a real hybrid system will be presented in this section. Looking at the energy demand from different Medium WDPs as shown in Table 2. This design will be based on 50kW demand. The key parameters for the design are as follows:

Table 12

System Operation Hours	12 hours/day
Peak System Load	50 kW
Solar Irradiation	5.5 kWh/m²/day
Genset Contribution	Limited to 80% of rated power during peak demand.

Based in the calculations included in the Annex the following system is proposed:

Table 13

Component	Specs	Purpose
Solar PV Modules	70 kW	Supplies daytime energy and charges batteries.
Diesel Generator (Genset)	70 kW	Backup power, stabilizes load during PV fluctuation.
Battery Storage System	65 kWh (Lithium-ion)	Covers 1 hour of operation and stabilizes the system.
Hybrid Inverter (most likely more parallel one)	70 kW	Manages energy flow between PV, genset, and batteries.
Fuel Save Controller	Included	Optimizes genset efficiency.

The energy distributions will be:

Table 14

Source	Energy Contribution	Percentage of Total Demand
Solar PV System	215 kWh/day	65%
Diesel Generator	385k Wh/day	35%

The genset contributes approximately 35% of the total energy used during the 12-hour operation. The remaining 65% comes from solar energy.

In summary the proposed solution involves a hybrid system combining a 50 kW diesel generator and a 70 kWp solar PV system to meet a 50 kW demand for a desalination plant. The generator operates in parallel with the PV system, providing 80% of capacity when there is no solar output and reducing its contribution to 10% as solar output increases. This ensures reliable energy supply while minimizing fuel consumption, with an estimated daily fuel use of 150 liters.

A quick calculation comparing the fuel consumption of the hybrid system with a genset-only solution shows a significant reduction in diesel usage and CO_2 emissions, with the hybrid system saving **2925 liters of fuel per month** and reducing emissions by **7779 kg of CO_2/month** (65% reduction). This accounts to **93 ton of CO_2/ year** if genset only is used.

Table 15

Scenario	Monthly Diesel Consumption (L)	CO_2 Emissions (kg CO_2/month)	Reduction Compared to Genset Only
Genset Only	4,500	11,970	N/A
Hybrid System	1,575	4,191	65% reduction
Savings	2,925 liters	7,779 kg CO_2	

Detail all of the calucation can be found in the annex below.

Benefits of Design

1. **Cost-Effective**: Uses PV as the primary source, reducing fuel costs significantly.
2. **Reliable**: Genset ensures continuous operation during low solar availability.
3. **Scalable**: Modular PV and battery systems allow future expansion if energy demand increases.

9.1.1.2 Cost of the system

Table below show the cost estimation for such asystem, the cost is based on current prices with 10% error margin.

Table 16

Component	Specifications	Cost/Unit (USD)	Total Cost (USD)
PV Modules (kW)	70 kW (including 30% margin)	$700/kW	$49,000
Lithium Batteries (kWh)	50 kWh storage (1 hour)	$700/kWh	$35,000
Hybrid Inverter (kW)	70 kW	$350/kW	$24,500
Diesel Genset (kW)	70 kW	$200/kW	$28,000
Fuel Saver Module (unit)	Integrated	$5000/unit	$5,000
Mounting Structures kW	For PV & Batteries	$200/kW	$21,000
Wiring & Accessories	Junction boxes, cables, etc.	Lump Sum	$10,000
Installation & Labor	PV, Genset, and integration	Lump Sum	$10,000
sum			**$182,500**

9.1.2 Long-Term Intervention

Grid-Integrated Renewable Systems

- The designed PV systems to function independently in off-grid conditions while ensuring compatibility with the grid once it is restored.
- Incorporate advanced energy management systems to maximize solar energy usage and minimize genset reliance.

9.2 Infrastructure Repair and Rehabilitation

9.2.1 Key Interventions for WDPs

Immediate Interventions (0–3 Months)

- Focus on restoring functionality to high-damage medium-scale WDPs by repairing critical infrastructure such as RO membranes, pumps, and pre-treatment systems.
- Deploy temporary mobile desalination units to ensure water supply during the recovery period.

Medium-Term Interventions (3–12 Months)

- Fully rehabilitate medium-scale WDPs to at least 80% capacity, addressing both structural and operational challenges.
- Upgrade partially damaged plants with advanced filtration and pre-treatment systems to improve water quality and reduce maintenance needs.

Long-Term Interventions (12+ Months)

- Expand the capacity of high-demand medium and large-scale plants through modular upgrades.
- **Construct New Solar-Optimized Facilities**: Develop new medium desalination facilities designed for high energy efficiency and powered primarily by solar energy. These facilities should incorporate advanced energy recovery devices and modular systems to accommodate growing demand.

9.2.2 Key Interventions for WWTPs

Damage Assessment: Conduct a rapid and detailed assessment of NGEST WWTP and partially operational facilities to clarify the extent of damage and prioritize repairs.

Immediate Repairs: Focus on the Rafah WWTP, as it is the only partially operational plant, ensuring it can handle increased loads to mitigate untreated wastewater discharge.

Long-Term Rehabilitation: Allocate resources to restore functionality to tertiary and secondary treatment plants (Khan Younis, Central Gaza) to address wastewater management and environmental risks comprehensively.

10. Conclusion

The recovery and rehabilitation of water desalination plants (WDPs) and wastewater treatment plants (WWTPs) in Gaza are critical to ensuring sustainable access to clean water and effective wastewater management. Medium-sized WDPs, which account for a significant portion of drinking water production, should be prioritized in interventions due to their essential role in meeting the population's immediate water needs, the level of damage they sustained, and the relative ease of access to electricity in large plants.

Immediate actions include restoring energy supply through hybrid systems, repairing critical infrastructure, and deploying mobile desalination units to maintain water quality during the recovery period. In the long term, integrating renewable energy systems, implementing advanced monitoring technologies, and scaling capacity will enhance operational reliability and resilience.

These interventions require careful prioritization, focusing resources on high-damage medium-scale facilities and leveraging international support to overcome logistical challenges. By addressing energy challenges, optimizing system efficiency, and ensuring the sustainability of operations, these efforts will contribute significantly to the resilience of Gaza's water infrastructure in the face of ongoing challenges.

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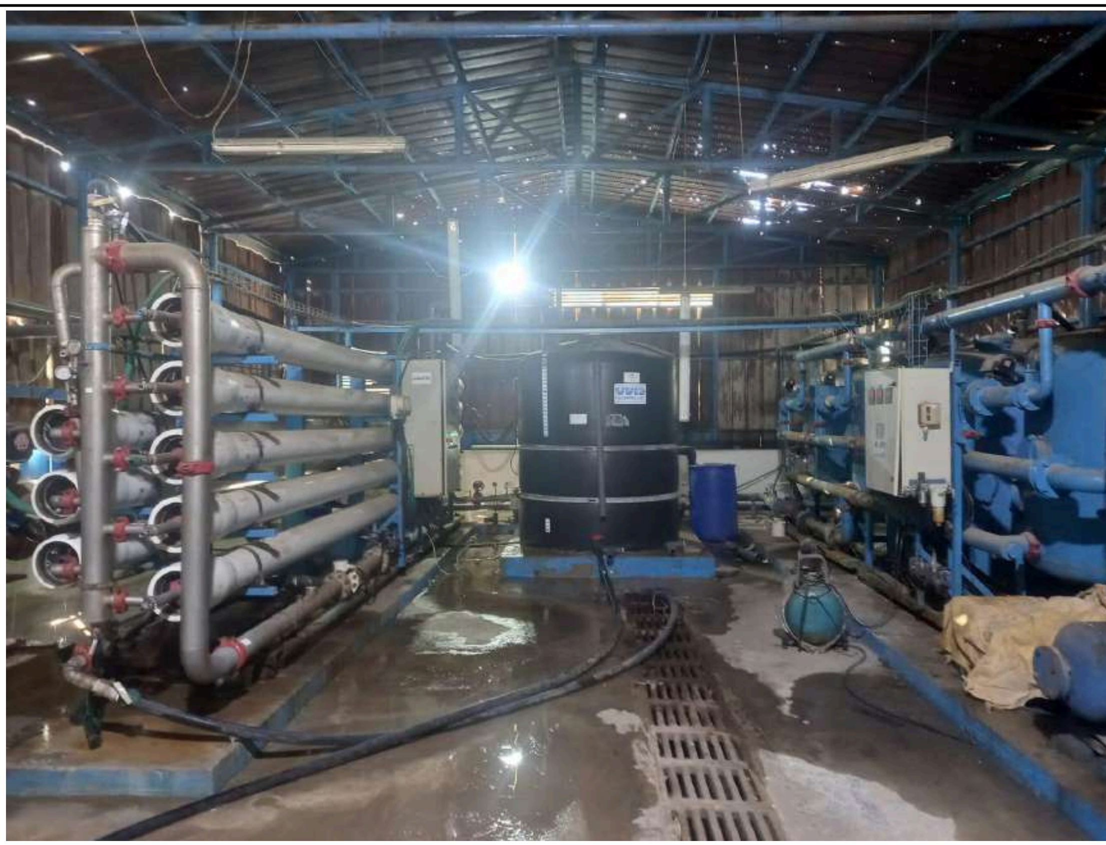
12. Annex

12.1 Picture of Desalination plans WDPS

Alnusairat station


High Pressure Pump
مضخة ضغط عالى


Filter Unit
2
artridge Filter Unit
وحدة الفلاتر
1




unicef

Asaada WDPS


محطة سعده
لتحلية المياه
أبو عبد الله سعده 0597399609 0599920201

AL asdeqa station2

خان يونس


Note cam lite
Note : محطة تحلية عيا
Date : 14/04/2024 10:58 AM
Latitude : 31.33972638°
Longitude : 34.29676705°


Note cam lite
Note : تحلية السعادة
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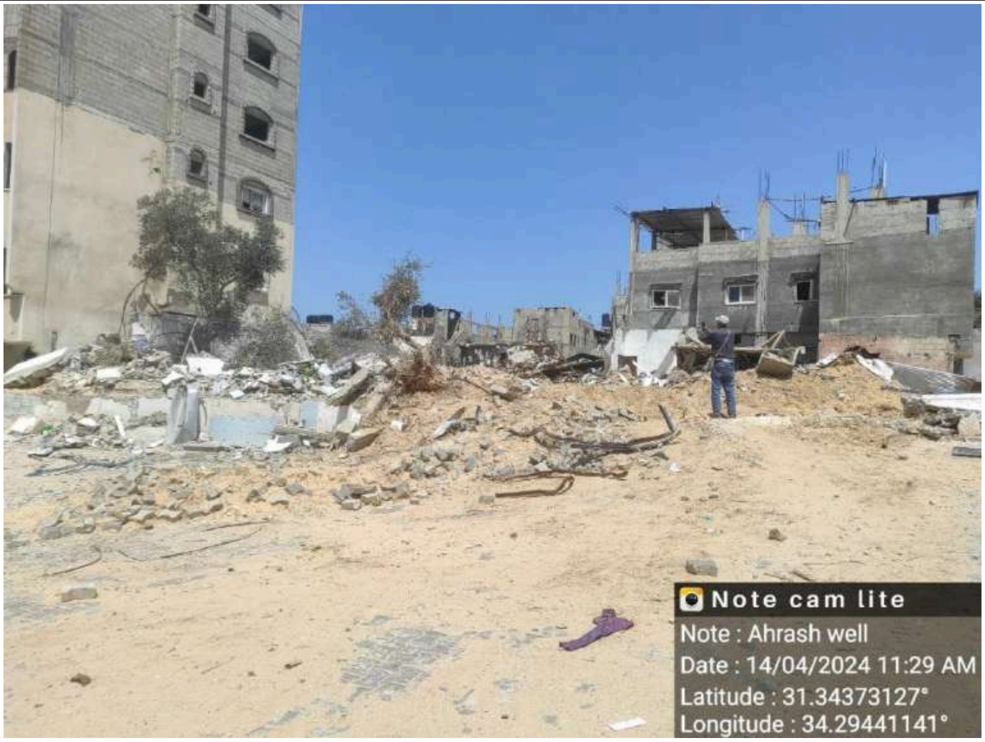
Latitude : 31.34631976°
Longitude : 34.29649409°

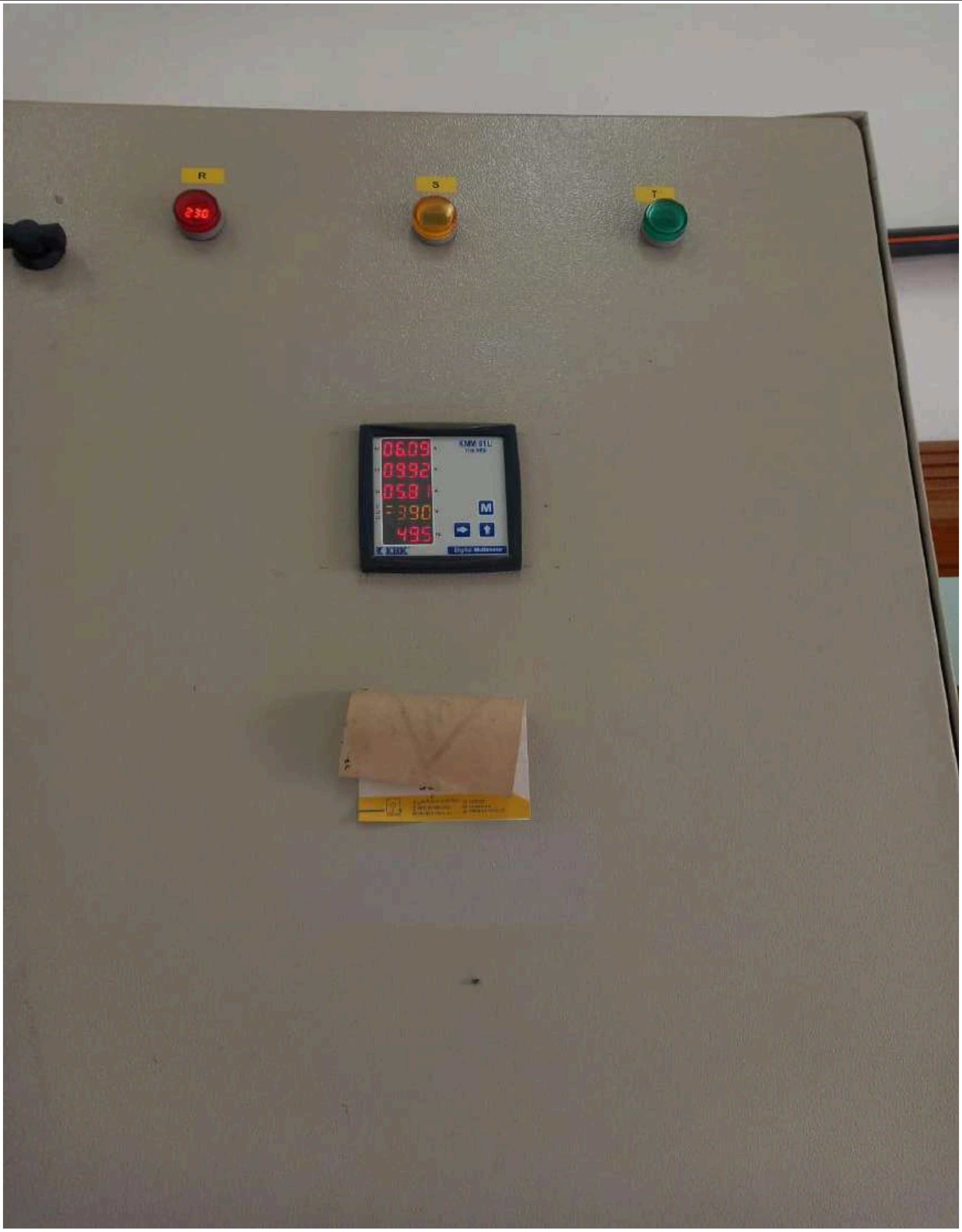


AlRawda WDPs


ireg

Abassan WDP

Donated in the memory of
Malik Ahmed Khan
and
Khan
Desalination
Water Plant in Khany
Peace and Relief
International
UK
The Gaza Strip 2019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0609
0992
058
390
495
M
Digital Multimeter


MATIX
LIGHTING
ON
OFF
UP
DOWN
POS +
NEG -

Alhadeeqa WDP


Manzoo
Eta


Eta
Eta

12.2 Hybrid system calculation

12.2.1 Hybrid system sizing

Plant Demand:

- 50 kW continuous for **12 hours/day** → **600 kWh/day**.

PV Contribution During Daytime:

- **10 solar hours/day**, with output ramping up and down based on irradiation.
- At peak, PV generates up to **60 kW** (with safety margin), and its contribution varies throughout the day.
- Average effective PV contribution = 60% of peak output.

Genset Contribution:

- Operates continuously for stability.
- Covers load during early/late hours when PV output is minimal.
- Runs at **80% of its rated capacity (56 kW)** during non-solar hours and reduces to **10% (7 kW)** during peak PV generation.

System Sizing

1. PV Array Sizing

- Solar energy required during the day (10 hours):
  Solar Contribution=50 kW×10 hours×60%=300 kWh
- Required PV capacity (adjusted for average efficiency):

$$PV\ capacity = \frac{300kW}{10\ hours \times 60\%} = 50kW$$

  Adding a 30% safety margin:

- Final PV Capacity=50 kW×1.3=**65 kW.**

2. Diesel Generator Sizing

- Genset size to handle full load with a 30% margin:
  Genset Size=50 kW×1.3=65 kW (rounded to 70 kW).

Scenario 1: Daytime Operation (10 Solar Hours)

- **Energy Demand (Plant Load):**
- 50 kW×10 hours=500 kWh.
- Battery Recharge Requirement:
- Battery capacity to recharge (1 hour backup): 65 kWh.65

Total Energy Required During the Day:

500 kWh (plant load)+65 kWh (battery recharge)=565 kWh.

PV Contribution:

- PV system capacity: 65 kW.
- Average solar efficiency: 60%.
- Total PV energy produced: 65 kW×10 hours×0.6=390 kWh.

Genset Contribution:

- Remaining energy demand: 565 kWh−390 kWh=175 kWh.

Notes on Battery Recharging

- The PV system produces enough energy to cover most of the plant load and recharge the batteries during the day.
- The genset fills in the gaps, ensuring consistent operation and minimal reliance on fuel.

Scenario 2: Nighttime Operation (2 Non-Solar Hours)

1. **Energy Demand**:

50 kW×2 hours=100 kWh.

2. **Battery Contribution**:

Battery supplies power for 1 hour: 50 kWh.

3. **Genset Contribution**:

Genset supplies power for the remaining 1 hour: 50 kWh.

12.2.2 Daily Fuel Consumption

Energy Supplied by Genset (Daytime):

175 kWh.

Energy Supplied by Genset (Nighttime):

50 kWh.

Total Energy Supplied by Genset:

175 kWh+50 kWh=225 kWh.

Fuel Consumption:

Fuel consumption rate: 0.3 liters/kWh.

Daily fuel use: 225 kWh×0.3 liters/kWh=67.5 liters/day.

Comparison with Genset-Only Solution

1. **Genset-Only Daily Fuel Use**:
    - Full load for 12 hours: 50 kW×12 hours×0.3 liters/kWh=180 liters/day.

2. **Fuel Savings**:

   180 liters/day−67.5 liters/day=112.5 liters/day.

CO2 Emissions

1. **Genset-Only Emissions**:

180 liters/day×2.64 kg/liter=475.2 kg CO_2/day.

2. **Hybrid System Emissions**:

67.5 liters/day×2.64 kg/liter=178.2 kg CO_2/day.

3. **CO2 Savings**:

475.2 kg/day−178.2 kg/day=297 kg/day.