Empowering Gaza through solar energy: A scalable humanitarian framework for electricity and water security

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Abstract

This paper presents a framework for providing rapid humanitarian relief of Gaza's critical electricity and water crises through solar energy deployment. With a population density exceeding 6,000 inhabitants per km² and approximately 90% of electricity infrastructure damaged post-2023, Gaza faces severe shortages affecting 2.2 million people. The study demonstrates that Gaza's abundant solar irradiation offers a viable solution through scalable photovoltaic microgrids.

A phased implementation strategy is proposed, beginning with mobile emergency systems and progressing to community-scale microgrids serving approximately 100 households each. These systems integrate solar generation (70-80 kWp per microgrid), battery storage, and solar-powered desalination to address both electricity and water needs simultaneously. The framework employs demand-side management through "electric springs" technology, using water desalination as a flexible load to optimize battery utilization. Preliminary estimates indicate that basic electricity and water needs could be met for a pre-war population through a feasible investment. This decentralized

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approach offers enhanced resilience, local maintenance capacity, and potential integration with future centralized infrastructure, while providing immediate humanitarian relief.
The modular nature of available microgrid technology makes it highly scalable, enabling the development of urban environments with elevated living standards once the emergency has passed.
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Keywords

Solar microgrids, Humanitarian infrastructure, Renewable energy communities

Gaza's humanitarian crisis: Infrastructure as a battleground

The Gaza Strip represents one of the most extreme cases of humanitarian distress in the contemporary world. Years of blockade, recurrent military operations, and structural underinvestment have progressively eroded basic infrastructures. Electricity and water systems—cornerstones of public health, economic activity, and human dignity—are no longer able to meet even minimal needs. The crisis is not

episodic but systemic, deeply embedded in Gaza's demographic pressure and geopolitical isolation.
With a pre-war estimated population of 2.2 million people living in an area of only 365 km², Gaza's population density exceeded 6,000 inhabitants per square kilometre, ranking among the highest worldwide. Such density magnifies the consequences of infrastructure failure: when electricity stops, hospitals, water pumps, sewage treatment plants, and communication systems collapse simultaneously.

Figure 1 - Urban overview of Gaza strip (2025)

Table 1 - Demographic and energy context of the Gaza strip (2025)

Indicator	**Value**
Population (2025 estimate)	≈ 2.2 million
Area	365 km²
Population density	≈ 6,000 inhabitants/km²
Electricity access	< 45% of daily needs met
Daily power outages	12–20 hours/day
Average household consumption (2025)	≈ 50 kWh/month

The electricity system: Chronic deficit and war-induced collapse

Gaza's electricity system has long operated under chronic deficit. Prior to the latest conflict escalation, electricity supply relied on imports from Israel (approximately 120 MW) and Egypt (around 30 MW), supplemented by a local power plant nominally rated at 60 MW but rarely operating at full capacity. In the pre-war period 12-15 MW photovoltaic capacity was also available. Even in times of relative stability, demand consistently exceeded supply.

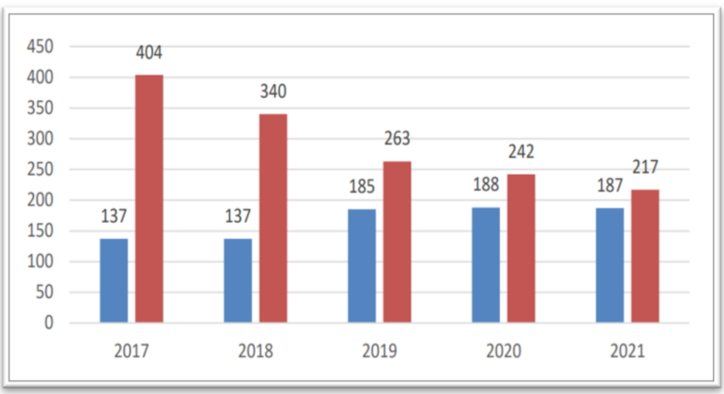

Figure 2 - Average daily electricity supply (blue) versus estimated demand gap (red) in Gaza (GEDCO data, 2017–2021).

In Figure 2, the persistent demand gap in the pre-war period highlights the structural inadequacy of the centralized electricity provision. Drawing on data from GEDCO (the local utility), it can be observed that the fuel entry ban worsened the electricity crisis in Gaza, in 2017 supply-demand gap can be estimated at ~ 75%, GEDCO supplied only 4 hours/day of electricity whereas the Energy demand

exceeds 540 MW (peak at night). It can also be observed that the demand and, consequently, the demand gap reduced in the period 2017-2021 but it can be likely due to an economy which deteriorated and a steadily increase of the utilization on Renewable Energy Resources (RES) during years.
Following October 2023, the situation deteriorated dramatically. According to UNDP estimates, approximately 90% of Gaza's electricity grid infrastructure has been damaged (2025). Fuel import restrictions further reduced the operational capacity of the Gaza Power Plant to less than eight hours per week, while supply through Egyptian lines was intermittently suspended.

Water insecurity and the energy–water nexus

Water scarcity in Gaza is inseparable from the electricity crisis. Water extraction, pumping, treatment, and desalination are all energy-intensive processes. Without reliable electricity, water systems fail, leading to widespread contamination and public health risks.
Gaza's water supply has been unstable for decades, with ongoing strain affecting water quality, reliability, and acceptability.

- In 2022, 76% of Gaza's water supply came from groundwater and surface water sources.
- That same year, Gaza produced only 9.6 million m^3 of desalinated water, with plans for significant increases through new central desalination plants.
- Only 4% of Gaza's population had access to safe, clean drinking water even before October 7, 2023.
- Average daily water consumption in 2022 was 85.7 liters per capita in Palestine, 86.4 l/c/d in the West Bank and 84.6 l/c/d in Gaza.

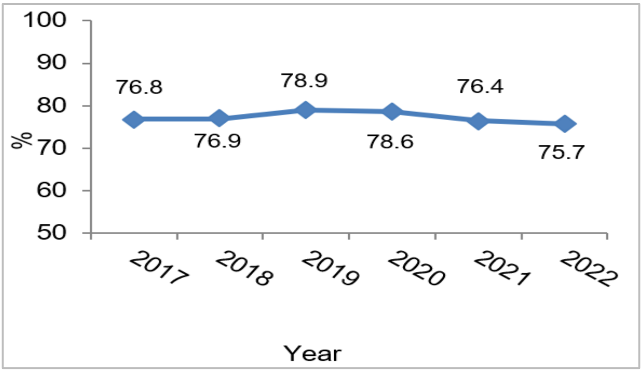

Figure 3 - Composition of Gaza's water supply prior to the conflict (2022). Groundwater and surface water percentage.

Even before the 2023 conflict, only 4% of Gaza's population had access to safely managed drinking water. Groundwater and surface water dominate, despite severe overexploitation and contamination.
Post-war assessments indicate that up to 95% of available water is now unfit for human consumption, while approximately 70% of water infrastructure has been damaged or destroyed.

Solar energy potential in Gaza

Despite widespread destruction, Gaza retains a critical natural resource: abundant solar energy. Average solar irradiation is approximately 5.5 kWh/m²/day, making photovoltaic (PV) generation a technically sound and geographically appropriate solution. The Specific Photovoltaic Power Output is 1833 kWh/kWp (Figure 4).

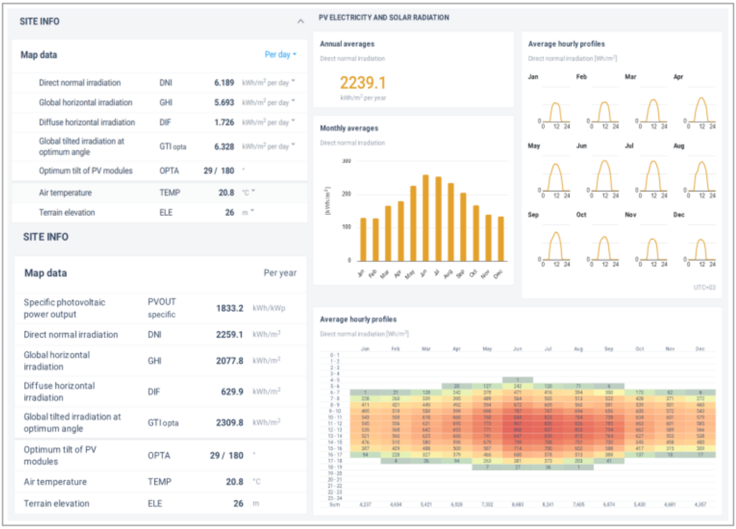

Figure 4 - Site photovoltaic electricity production and solar irradiation (source: https://globalsolaratlas.info)

The great availability of solar energy makes it possible to imagine widespread exploitation of photovoltaic energy, which integrated with storage systems and truck/disseminated generation units would make it possible to generate electricity throughout the day.

The distribution of generation sources throughout the territory would make it possible to create microgrids comprising small generation units, utilities and desalinators.

Land scarcity poses challenges, but Gaza’s dense urban fabric offered before the war an extensive rooftop space. Estimates indicate that if only 5% of pre-war existing rooftops could be utilized, making available over 18 km² for PV deployment—sufficient to sustain the basic needs of the pre-war population.

Several solar projects, implemented before the conflict, demonstrated the feasibility of decentralized renewable energy. In 2018, UNDP-supported installations in hospitals providing critical services and reducing the dependence on diesel generators.

Table 2. Solar photovoltaic installations in selected Gaza hospitals

Hospital	Installed PV Capacity (kWp)	Supplied Function
Beit Hanoun Hospital	20	Laboratory
Al-Aqsa Hospital	25	Laboratory
Najjar Hospital	20	Laboratory
Emirati RC Maternity Hospital	20	Laboratory

Microgrids: A scalable gradual deployment

Some short-term emergency solutions to alleviate electricity and water scarcity can be envisaged based on Solar Microgrids with "Energy Backpacks" for Refugee Camps,

Figure 5 - Some mobile photovoltaic systems to provide emergency power supply.

namely:

- Mobile microgrids, including small solar arrays that charge backpack batteries and trolley-mounted solar generators, can be quickly deployed to high-need areas such as hospitals and shelters.

- Displaced families can carry power to their tents/camps.

To produce water, it is possible to install mobile and decentralized Water Supplies Solution for War-Torn Areas such as Trolley-mounted units which can be moved to high-need zones (hospitals, shelters, near refugee camps) or away from conflict hotspots.

Furthermore, due to restrictions on importing heavy machinery and fuel into Gaza, low-tech solutions based on evaporation or small solar power units offer a practical solution allowing community-owned maintenance, implementing modular designs and employing local abilities and competencies.

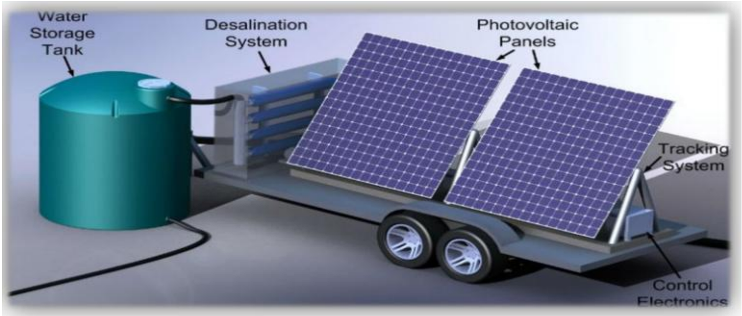

Figure 6 - Trolley-mounted solar desalination units

In the medium and long-term, a microgrid based solution can provide a gradual and scalable deployment plan of solar technology.

The application of Multiple Microgrids embedded in a distribution grid introduces the vision of a disseminated electricity production based on modular and scalable entities characterized by a high reliability, resilience and better decentralized maintenance.

In a recent project, financed by the Ministry of the University (PRIN 2022), the concept of multi-microgrid (MMG) as a structure composed by several MGs, distributed generation units, and controllable loads has been proposed for Europe as a new paradigm to develop urban clean electrification ensuring sustainability through RES, reliability through storage and flexible loads, resilience due to a modular and distributed infrastructures. It has been shown that the approach is effective when starting from scratch in urbanization, but it can also work envisioning a community of MMG embedded in an existing interconnected distribution system allowing the clean electrification of services such as illumination, heating/cooling, transportation, etc. Remote villages, small islands and humanitarian emergency areas can get effective solutions from this technology.

Beyond individual microgrids, interconnected MGs can form Renewable Energy Communities (RECs). Such configurations allow energy sharing, adaptive reconfiguration, and enhanced resilience also in the case of infrastructure damage. Each REC can support communities in need by adjusting its generation or ownership boundaries to redistribute power flows, either to compensate for lost generation or to integrate new areas. Optimal Network Reconfiguration (ONR) functions enable the system to find new topologies to reconnect loads and generation in case of faults or loss of lines and generation.

ONR goes beyond identifying reclosure paths.

In operation, it offers a complete network reconfiguration ensuring power balance satisfying security constraints. Using smaller, distributed generating units instead of large, centralized plants enhances system adaptability and resilience, allowing critical loads to be supplied by remaining operational units during outages. Furthermore, this approach can provide restoration and black start strategies for interconnected systems after a blackout, increasing the overall resilience of the system. As an example, a MG controller can be designed to allow the shift from grid-connected to islanding mode, and conversely, without requiring a centralized control structure for reconfiguration. In planning ONR enhances system reliability also during the building phase of the infrastructure making it adaptive, modifying the energy paths as the construction proceeds. Each area can be viewed as a collection of microgrids forming Renewable Energy Communities (RECs), aimed at sharing energy for mutual support. These interconnected renewable energy systems (RES) can evolve as new structures are built or existing ones are enhanced, allowing the network to adapt and grow over time.

MG technology is ready, numerous control methodologies have been presented in the literature and even technical standards and guidelines are available at this time such as IEEE 2030, a standard and a Guideline for implementing smart grids, developing functions for the Microgrid controller, etc.

In these notes, a very preliminary assessment, without any claim of accuracy, is proposed in a humanitarian energy framework to provide first aid to Gaza during the power system reconstruction. The situation is in rapid development and more reliable data are needed for a more accurate feasibility study. However, the following preliminary example is introduced just to illustrate some ideas and stimulate a discussion on that issue.

It has been assumed, as an example, that modular solar microgrids serve approximately 100 households each. Of course, better optimization can be obtained considering more accurate and updated data and analyses will be available. These systems integrate photovoltaic generation, battery storage, and demand-side management with a solar capacity of about 40-50 kWp and 400-500 kWh storage to ensure very basic needs (less than 2kWh per household, 60 kWh/month). In recent years, it should be considered that household consumption dropped from 200–300 kWh/month to 50 kWh/month according to the Palestinian Central Bureau of Statistics (PCBS), thus the assumption adopted here is about reconstituting a minimum level of quality of life ensuring very basic needs for humanitarian purposes. New updated data is necessary to improve this preliminary analysis after the military events of the last years.

Table 3. Vision of a possible first deployment of microgrids

Phase	Microgrids (100 homes each)	People Covered	% of Gaza (Population)	Total Cost
Phase 1 (Pilot)	200	~ 110,000	~ 5%	~ 40 M$
Phase 2 (Mid-scale)	800	~ 450,000	~ 20 %	~ 160 M$
Phase 3 (Wide rollout)	1900	~ 1,100,000	~ 50 %	~ 400 M$

It should be considered that total cost reflects market costs not considering difficulties due to the political and military crisis.

Nevertheless, with all the limitations of such very preliminary analysis, we can assess that not a very big amount of money is needed to provide basic needs and first help.

Of course, given the decentralized infrastructure the capacity and storage per microgrid can be gradually increased providing better comfort and supplying more advanced needs.

The infrastructure so built can successively be considered as a community of MGs embedded in an eventual interconnected power system after that the reconstruction is completed, providing more electrical services, capacity and reliability.

Finally, it should also be considered that in Europe the first mass deployment of photovoltaics is close to the end of the

20-year-old lifecycle and it can be replaced on the same surface with double the capacity possible at the time they were installed. This opens the possibility of a second life for the photovoltaic panels of the first generation which lost about 20 % of their initial efficiency but they can be still operated for years. They could be used for humanitarian purposes in the first phase of the reconstruction to supply energy to a large population in a short time, perhaps cutting costs. New regulations on the second-life of used PV plants for humanitarian purposed needs to be developed.

A synergy between photovoltaic resources and water: Solar-powered desalination and water security

Synergy can be obtained by the dual production of electricity and drinking water.

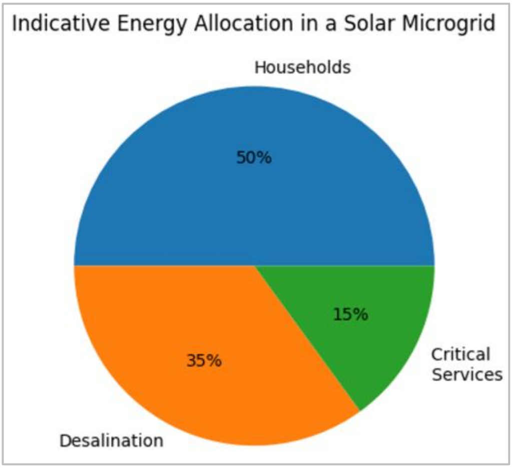

Figure 7 - Indicative allocation of electricity within a community-scale solar microgrid, balancing domestic consumption, water production, and critical services.

Let us consider an indicative allocation of energy needs which can be satisfied by a local solar microgrid.
Water desalination and distributed storage of water together with electrochemical storage and microgrid technology can provide a useful way to store energy (in the form of produced water) when there is an excess of RES production while ensuring flexibility and demand-response by curtailing desalinization when other critical services need to be supplied.
This approach can be useful to reduce the capacity of the electrochemical batteries (BESS -Battery Energy Storage System).
Why is this relevant?

- BESSs are quite expensive, so, their optimal sizing is crucial;
- in small islanded microgrids with limited generating capacity, regularly charging an oversized storage can be challenging,
- a frequent and regular charging/discharging of batteries can impact their lifespan
- and chemical risks and environmental concerns are connected to their final disposal.

A viable solution can be provided by Electric Springs applied to water desalination plants. In few words, a smart demand-side power management approach is assumed considering water production not as a critical load since it can be easily stored in tanks when solar power is in excess.
Critical loads may include Health care facilities, Hospitals, Data centers, Communication infrastructures whereas non critical ones may include, as said, Water desalinization, but also Induction cookers, heating systems, refrigerators, air conditioning, etc.

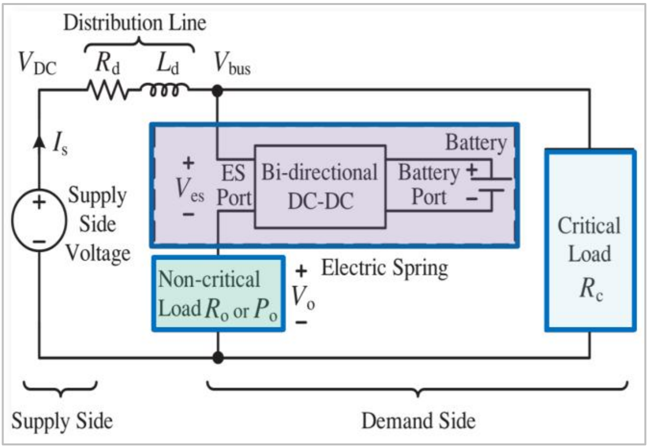

Figure 8 - Indicative scheme for an electric spring through power electronics

According to WHO guidelines, basic human needs require 7–20 liters of water per person per day, while the United Nations considers 50–100 liters essential for dignified living. Meeting even minimum requirements in Gaza necessitates large-scale desalination perhaps supported by renewable energy.

Small-scale Seawater Reverse Osmosis (SWRO) plants typically require 8–9 kWh/m³, while large-scale facilities can reduce consumption to approximately 3 kWh/m³ as demonstrated by some plants in the area, namely: Taweelah (Emirates), and Jubail 3A (Saudi Arabia the first PV powered large plant).

Solar-powered desalination plants integrated into microgrids through the electric spring approach can operate as dispatchable loads, enhancing overall system flexibility.

Let us make a very preliminary assessment. Meeting very basic water needs (20 liters/person/day) requires around 40,000 m³/day per a population as Gaza strip (pre-war).

Figure 9 - A pictorial representation of a seawater reverse osmosis desalinization plant.

Small-scale desalination plants can produce this volume using approximately 360 MWh/day. Energy demand can be met by about 70 MW peak power photovoltaic (PV) systems. 1/3 less is needed in the case of large-scale plants.
Even the first figure is possible with small and decentralized desalinization plants.
This peak power can be shared among the MGs associated to 100 households each serving about 500 persons with a basic need of 10 m^3/day of water which requires about extra 18 kWp per microgrid. Consequently, a MG with a capacity of about 70-80 kWp can provide basic electricity and water needs for about 100 households and, in emergency conditions, constitute the fundamental module for a decentralized production of both these essential goods.

Conclusions

Gaza's electricity and water crises illustrate how infrastructure has become a frontline humanitarian issue.

In these notes, an incitation to provide practical and easy-to-install solutions to provide immediate aid to critical areas under emergency conditions is proposed. Solar energy, abundant in Gaza area, offers a realistic, scalable, and resilient pathway to restore essential services.
Available microgrid technology, with its modularity, is prone to a scalability which can lead to the development of an urban environment characterized by high life standards when the emergency has got over.
Decentralized photovoltaic systems, microgrids, and solar-powered desalination cannot resolve a political conflict, but these technologies can provide rapid aid, create a cooperating community aware of energy and sustainability issues and start restoring hope.

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