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Clean Energy Usage in Times of Conflict (Syria as an example)

Streszczenie
Zapotrzebowanie na energię i związane z nią usługi rośnie z dnia na dzień, aby nadążyć za rozwojem społecznym i gospodarczym oraz poprawą warunków życia i zdrowia ludzi poprzez wykorzystanie zielonej energii. Podczas gdy świat dąży do zaspokojenia rosnących potrzeb energetycznych za pomocą odnawialnych źródeł energii, Syryjczycy coraz częściej sięgają po energię słoneczną, aby zaspokoić podstawowe potrzeby energetyczne w wyniku załamania się krajowej sieci energetycznej. Ta tendencja korzystania z odnawialnych źródeł energii w Syrii rozpoczęła się wraz z początkiem wojny w 2011 roku, gdy wprowadzono sankcje gospodarcze i zniszczono wiele elektrowni. Brak paliwa, prądu i nieosiągalne ceny gazu doprowadziły do nowych wynalazków oraz sposobów inwestowania w odnawialne źródła energii, aby uniknąć życia w ciemnym i zimnym świecie. Artykuł pokazuje, w jaki sposób w warunkach wojennych wykorzystanie energii słonecznej może zmniejszyć część trudności i umożliwić obywatelom prowadzenie normalnego życia. Studium przypadku koncentruje się na mieście Homs, analizując wyzwania i możliwości związane z pozyskiwaniem energii słonecznej oraz jej potencjał w poprawie warunków życia na obszarach dotkniętych wojną.

Abstract
The demand for energy and associated services is increasing daily to keep pace with social and economic development as well as to improve people's well-being and health by the usage of green energy. While the world is racing to secure the increasing energy needs through renewable energy, Syrians have increasingly turned to solar power to meet basic electricity needs due to the collapse of the national grid.
The trend towards benefiting from renewable energy sources began in Syria to escape the fuel scarcity that the Syrian state faced with the beginning of the war in 2011 as the economic sanctions on the Syrian government were set and many of the power stations were sabotaged.
Lack of fuel, electricity and the unbearable prices of gas because of the sanctions have led to new inventions and new ways to invest in regenerative energies sources in some ways to avoid living in a dark and cold world.
This article aims to show how in wartime conditions, the use of solar energy can reduce some of the challenges. And allow citizens to pursue a normal life. Also, the study highlights the challenges and opportunities of solar energy adoption in Homs, demonstrating its potential to improve living conditions in war-torn areas.

Słowa kluczowe: energia słoneczna; wojna w Syrii; odnawialne źródła energii w czasie wojny; energia słoneczna w Syrii
Keywords: Solar energy; Syrian war; renewable energy during war; solar energy in Syria

1. INTRODUCTION

The global transition towards renewable energy sources is an imperative driven by the dual challenges of climate change and the depletion of fossil fuels. This shift is crucial for sustaining social and economic development while improving public health and well-being. As nations strive to meet increasing energy demands through solar, wind, and other renewable technologies, the context of this transition varies dramatically between stable and conflict-affected regions.

In stable environments, the adoption of clean energy is a matter of policy, technology, and economic planning. In contrast, in regions experiencing armed conflict, the energy crisis is immediate and severe, forcing populations to seek alternative solutions for survival. The Syrian conflict, which began in 2011, presents a stark example of such a scenario. The war has led to the catastrophic destruction of national infrastructure, including the power grid, resulting in widespread and prolonged blackouts. Economic sanctions and fuel scarcity have further exacerbated the situation, leaving millions without reliable access to electricity for basic needs such as lighting, heating, and refrigeration (UNDP, 2020). In response to this crisis, Syrian citizens, communities, and to a lesser extent, the government, have increasingly turned to solar energy. This pragmatic adoption offers a unique, real-world case study of renewable energy deployment under extreme duress. While existing literature has extensively explored renewable energy in stable settings, research on its feasibility, challenges, and impact within active conflict zones like Syria remains limited (Barau et al., 2020).

This article aims to fill this research gap by examining the role of solar energy in mitigating the energy crisis in war-torn Syria, with a specific focus on the city of Homs. The study investigates the practical solutions that have emerged, the significant obstacles faced – particularly in an urban housing context with a high proportion of informal settlements – and the potential

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for these solutions to contribute to sustainable energy strategies in post-conflict reconstruction.

The structure of the article is as follows: after this introduction, Section 2 outlines the methodological approach. Section 3 provides background on the energy situation in Syria before and after 2011. Section 4 presents a detailed case study of Homs, analyzing housing types, challenges, and proposed solutions for solar energy integration. Section 5 discusses the findings in the context of broader literature, and Section 6 concludes with recommendations for future reconstruction and policy.

2. METHODOLOGY

This study employs a mixed-methods approach to analyze the adoption and challenges of solar energy in the city of Homs, Syria, during the ongoing conflict. This methodology was selected to triangulate findings, thereby enhancing the validity and depth of the analysis by combining qualitative insights with quantitative data (Krepl et al., 2020). The research integrates primary data collected through field observations with secondary data from institutional reports and academic literature.

2.1. Primary Data Collection: Primary data was gathered to capture ground-level realities and lived experiences that are absent from formal reports.

- Field Visits and Informal Interviews: As a native of Homs, the author conducted field research during multiple visits to the city after relocating to Poland in 2015. This unique position allowed for access and trust-building that would be difficult for an external researcher. Through informal interviews and discussions with local residents, engineers, and small business owners, qualitative data was collected on the practical challenges, adaptive strategies, and socio-economic impacts of solar energy adoption. All participants provided verbal informed consent, and their identities have been anonymized to protect their privacy.
- Photographic Documentation: The author captured all photographs included in this study during field visits. This visual documentation provides critical evidence of the state of solar energy infrastructure, housing conditions, and informal solutions, offering a transparent record of the situation on the ground.

2.2. Secondary Data Collection: To contextualize the primary findings within the broader Syrian energy crisis and validate observed trends, a review of secondary sources was conducted.

- Institutional Reports: Key documents from the United Nations Development Program (UNDP), the Economic and Social Commission for Western Asia (ESCWA), and the Syrian Ministry of Electricity were analyzed (UNDP, 2020; ESCWA, 2019; Syrian Ministry of Electricity, 2018). These reports provided macro-level data on infrastructure damage, energy production statistics, and official renewable energy strategies.
- Academic Literature: Scholarly articles and books on renewable energy in post-conflict and developing contexts were reviewed to situate this case study within existing theoretical frameworks and identify comparable challenges (Barau et al., 2020; Besner et al., 2023).

2.3. Case Study Analysis: Homs: The city of Homs was selected as a focal case study due to its representative status as one of the most heavily damaged urban centers in Syria and its emerging, citizen-led adoption of solar energy. Data on housing types (formal and informal), energy consumption patterns, and solar panel installations were analyzed to assess feasibility and spatial challenges. The author's personal familiarity with the city enabled a nuanced understanding of the local context, supported by urban profile data (UN-Habitat, 2021).

2.4. Limitations: The study acknowledges certain limitations. The security situation in Syria restricted the scope for systematic, large-scale fieldwork or randomized sampling. Consequently, the findings are primarily illustrative and based on purposive sampling. While the primary data offers invaluable qualitative depth, some quantitative analyses rely on secondary sources and remote consultations to supplement the field observations.

3. BACKGROUND: ENERGY SITUATION IN SYRIA BEFORE AND AFTER 2011

This section outlines the evolution of Syria's energy sector, contrasting the pre-war potential with the post-2011 reality of crisis and adaptive responses. This historical context is essential for understanding the urgency and nature of the shift towards solar energy.

3.1. Pre-2011: Nascent Interest and Limited Action

Before the conflict, the Syrian government's engagement with renewable energy was characterized by theoretical interest rather than substantial implementation. While studies and conferences were conducted, tangible progress was limited. The most significant legislative step was the enactment of Electricity Law No. 32 in 2010, which included provisions to encourage private investment in renewable energy (UNEP, 2010). At the household level, the adoption of solar water heating systems was growing, driven by private companies and a desire to reduce electricity and diesel costs (Al Tawfeer Company, 2009). Concurrently, academic interest was rising, with engineering students frequently focusing their graduation projects on solar and wind energy, recognizing the country's potential, particularly in areas like the Homs Gap.

Ill. 1. Rooftops of destroyed and abandoned residential buildings in the old city of Homs, with broken and rusted water heating solar devices that were in use before the war. Homs, Syria, 2014. (Photograph taken by the author from the roof of their grandparents' residential building)

3.2. Post-2011: Collapse and Crisis

The outbreak of war in 2011 led to a catastrophic deterioration of the energy sector. Widespread infrastructure destruction and economic sanctions crippled the national grid. Electricity production plummeted from over 7,000 megawatts (pre-war need) to approximately 3,000 megawatts, while access to the grid fell from covering 98% of the population to just 30% (ESCWA, 2019; Syrian Ministry of Electricity, 2018). The

economic collapse, marked by a 98% devaluation of the Syrian Pound against the US dollar, made fuel prohibitively expensive and scarce (UNDP, 2020).

3.3. Individual and Governmental Adaptive Responses

Faced with prolonged blackouts, Syrians were forced to develop immediate, grassroots solutions.

Concurrently, the Syrian government, recognizing the scale of the crisis, initiated several projects, often in partnership with international bodies. A significant step was the launch of a solar street lighting project in 2017 by the Ministry of Local Administration and Environment in collaboration with the United Nations Development Programme (UNDP) (UNDP, 2020). This initiative aimed to address the complete blackout that had engulfed Syrian cities for years. According to ministerial reports, a total of 5,136 solar lighting devices were installed across the governorates of Damascus, Aleppo, Lattakia, Tartous, Hama, and Homs (Ministry of Local Administration and Environment, 2018). While this number was modest, it represented a critical shift in policy towards decentralized renewable energy solutions. Ill. 2 below shows an example of this implementation in Homs.

Furthermore, to circumvent challenges related to importing materials under economic sanctions, a joint public-private sector

Ill. 2. Lighting streets using solar power in Homs, Syria, 2018. (Note the water heating solar system on the roof of the building). Source: The author.

Table 1: Methods used in Syrian households to compensate for the lack of electricity. Source: the author

Type of generator	**Details**	**Pros**	**Cons**
Batteries connected to LED lights	LED lights could serve any room which is connected to the main battery.	• Provides light to all connected rooms. • Affordable by all levels of society. • The internet router could be connected to the battery. • The batteries are sometimes made of used old car batteries.	• The battery needs electricity to be recharged. • LED light connected to batteries weakens in time, creating sight problems, especially for those who use LED light to study[1]. • The rechargeable batteries only serve light purposes. You cannot connect it to a TV or refrigerator. • Long wires will be installed across the rooms to connect the LED light to the battery.
Portable electrical generators	Serves one apartment only.	• Could generate enough electricity to turn on lightbulbs, television, and sometimes refrigerators. • Affordable by middle/high class level of the society.	• The high price and the scarcity of fuel. • Health issues: • connected with noise pollution, as the loud unbearable noise, those generators make leads to headaches and causes anxiety and nervous tension. • The generator's burning fuel is extremely harmful to the lungs since most families place this generator on balconies.
Bigger generators "locally known as amperes"	They are big generators, installed by local private companies or private investors in public area near residential buildings. could serve few residential buildings. People can subscribe monthly, or they can buy few amperes. This method is widely known in Aleppo and the northern parts of Syria.	These generators could provide stable electricity to the whole house. The owner of the generator is the one responsible for providing the fuel, not by the families. Affordable by middle/high-class level of the society.	Because of the scarcity of fuel, the price of the monthly bill could be very high. Health problems: Those generators are located among the residential buildings and could cause health problems: • connected with noise pollution, as the loud unbearable noise, those generators make leads to headaches and causes anxiety and nervous tension. • The generator's burning fuel is extremely harmful to the lungs since the generators are located among the residential buildings. Environmental pollution, since these generators consume too much fuel and release toxic fuels in the air.
Solar power	Despite most of the Syrian buildings were not designed to host solar energy devices, which take up large horizontal areas depending on the size of the panels (one house needs 13 square meters of space to place the panels). Also, the roofs usually are used to put water tanks, satellites, and chimneys. The usage of solar panels has spread widely.	People would pay once for the solar devices and have free electricity and hot water, and they do not have to pay for fuel, gas, or even suffer the scarcity of them. It is much healthier to have solar system than having fuel generators since there isn't noise and gas pollution, and it's much better than having a rechargeable battery connected with LED light.	The high cost of buying and installing these solar systems. Which makes it limited to wealthy people in Syria. Installing solar power system doesn't mean you will have electricity all days of the year; in case of rainy or cloudy days the solar power system cannot work in its full capacity. Installing solar power system should be accompanied with power bank batteries, so the electricity would be stored during the day to be used during the night. And again, the cost of these batteries is high.

plant was established to produce photovoltaic panels in the Damascus countryside, with the Ministry of Electricity owning a one-third share (Syrian Ministry of Electricity, 2018). This Kiswa plant was promoted as the first factory dedicated to electricity production from solar energy. Additionally, a private-sector initiative in western Homs installed two wind turbines, each with a capacity of 2.5 megawatts—enough to power approximately 6,000 homes. However, this contribution remains insufficient for a city like Homs, which requires an estimated 200 megawatts, underscoring the immense gap between isolated projects and actual urban demand (Syrian Ministry of Electricity, 2018).

In July 2020, the Ministry of Electricity granted thirteen licenses for renewable energy generation projects in several governorates, with an expected combined output of 1.5 megawatts of solar energy and 7 megawatts of wind energy (Syrian Ministry of Electricity, 2018). The government's official strategy targets a renewable energy contribution of no less than 5% of the total primary energy by 2030, equivalent to 1,500 megawatts from photovoltaics and 900 megawatts from wind turbines (Syrian Ministry of Electricity, 2018). Despite these plans, the tangible contribution of renewables to the national grid remained minimal, at around 1% (13 MW) as of 2017 (ESCWA, 2019), highlighting the significant challenges of implementation amidst ongoing conflict and economic collapse.

3.4. Syria's Renewable Energy Potential: Key Facts

Despite the modest implementation, Syria possesses significant natural advantages for renewable energy generation. The country's geographical position offers substantial potential for both solar and wind power, a fact acknowledged by national authorities (SANA, 2021).

Syria is situated between latitudes 32.3° and 37° north, benefiting from high solar irradiation. The average solar radiation is approximately 1,825 kWh/m² annually, with sunshine duration ranging between 2,800 and 3,270 hours per year and only 38-45 cloudy days annually (National Energy Research Center, as cited in SANA, 2021). Furthermore, the theoretical wind potential, particularly through areas like the Homs Gap, is estimated to be nearly 80,000 MW (National Energy Research Center, as cited in SANA, 2021). Official statements highlight that Syria has an area of about 56,000 square kilometers suitable for solar energy generation, where solar brightness intensity reaches up to 5 kilowatts per square meter for over 312 days per year, and a similar area with high wind energy potential (SANA, 2021).

These illustrations present a stark contrast to the current reality where renewable energy's contribution was about 1% in 2017 (ESCWA, 2019). This gap between immense theoretical potential and minimal practical application underscores a critical opportunity for post-conflict energy strategy, moving beyond stopgap solutions towards a sustainable foundation based on the country's innate resources.

However, solar and wind energy are not economically feasible and is not currently qualified to support cities, and they will not be able to cancel the electric rationing in Syria to fulfill the needs of inhabitants. However, the individual use of green energy will be extremely useful in operating some electrical devices such as television, refrigerator and lighting which could improve the living conditions of Syria.

In this study, the author is going to highlight how a heavily damaged city could benefit from green energy.

4. CASE STUDY: SOLAR ENERGY ADOPTION IN HOMS

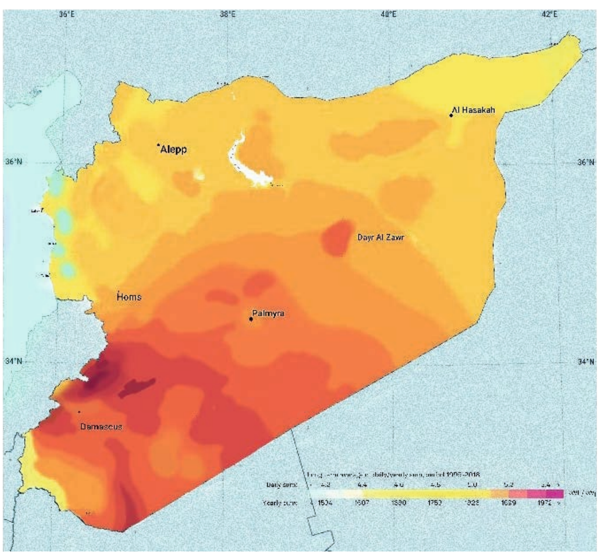
This section presents a detailed analysis of the city of Homs as a case study, focusing on the intersection of urban morphology, housing typologies, and the practical challenges of integrating solar energy solutions in a post-conflict setting. Homs, the third--largest city in Syria, serves as a critical example due to the extensive damage it sustained and its representative urban fabric.

4.1. Urban Context and Wartime Damage

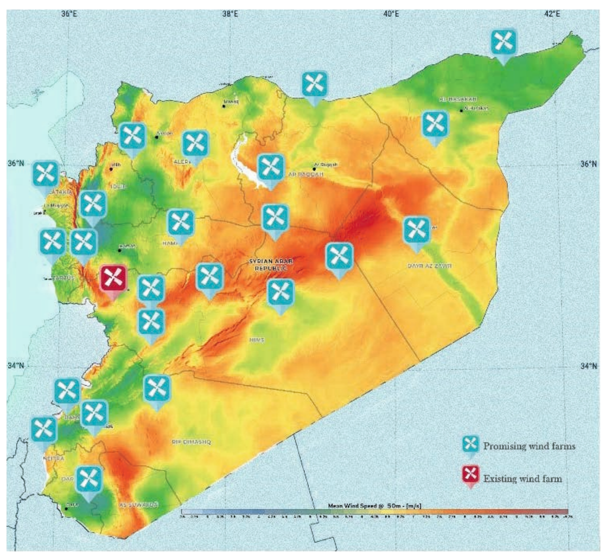
Homs is a city located in the heart of Syria, on the banks of the Orontes River, and lies on an important road and rail network that links the country's main towns and cities. It hosts significant industrial centers, including the country's largest oil refinery. Homs is the third largest city after Damascus and Aleppo and serves as the capital of Homs Governorate, with a population of 775,404 according to the 2017 census (Central Bureau of Statistics, Syria, 2010).

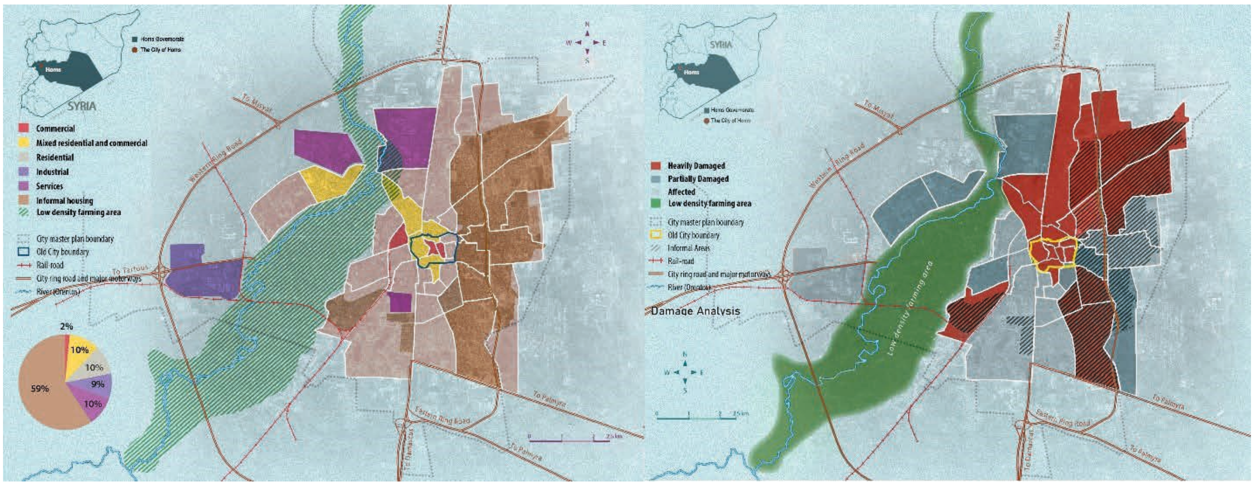
As with all Syrian cities, Homs is ancient, dating back to the first millennium BC. Its general plan features an old town in the

Ill. 3. Photovoltaic Power Potential in Syria. Source: the author, based on: World Bank Group, accessed on: 20.07.2021



Ill. 4. Mean wind speed in Syria and the Promising wind farms in Syria. Source: the author, based on map on: globalwindatlas.info, accessed on: 20.07.2021





Ill. 5. Building analysis before and after the war. Source: the author based on UN-Habitat, Homs Regional City Profile

city center surrounded by newer districts. The city's population began to increase rapidly starting from the second half of the 1970s. This growth was not accompanied by adequate planning measures to direct development and accommodate the resulting population and service needs. This led to increased population density in residential neighborhoods and a significant expansion of informal housing areas (Qandilqi, 2010).

The idea of planned residential suburbs, whose construction began in the late 1970s, failed to keep pace with population growth due to significant delays in their completion and because the number of housing units was insufficient for the actual need. The approximate area of these informal neighborhoods is about 2,227 hectares, constituting about 50% of the area of the city of Homs and housing about 42% of the total population of Homs Governorate (UN-Habitat, 2021). The majority of these areas are illegal neighborhoods, extending over agricultural land or through squatting on state-owned or private lands. These areas, generally termed informal settlements or informal housing, are characterized by variations in building heights and high population densities (UN-Habitat, 2021). Besides these informal housing districts, the city consists of modern residential districts, commercial districts, mixed contemporary residential and commercial areas, industrial districts, and service districts. Ill. 5 provides a functional analysis of the city's structure.

In this study the author will focus only on the residential districts. Homs is one of the most damaged cities from the war, with a total destruction of over 58% of its neighborhoods. Out of a total of 36 neighborhoods, 26 are either totally or partially nonfunctional, with only 10 neighborhoods functioning normally. Before the war started in 2011, Homs had 178,000 housing units. Seventy-one percent (71%) were multi-story apartment buildings, 16% were courtyard houses (located in the old town and traditional neighborhoods), and 13% were single-family houses (row housing and villas). By the end of 2013, 96,700 housing units were no longer in use or had been abandoned (UN-Habitat, 2015). Ill. 5 illustrates the stark before-and-after analysis of the city's districts.

4.2. Housing Typologies and Energy Needs

The residential fabric of Homs reflects both planned developments and extensive informal expansion, which together shape the feasibility of solar energy adoption. Before 2011, the city contained approximately 178,000 housing units, of which 71% were multi-story apartment buildings, 16% were traditional courtyard houses, and 13% were single-family homes including villas and row houses (UN-Habitat, 2015). Since the outbreak of conflict, nearly 96,700 units have become uninhabitable, with informal housing expanding rapidly to absorb displaced populations. Today, more than half of the residential stock in Homs (55.1%) consists of informal settlements (Quindici, 2017; UN-Habitat, 2021).

Energy demand varies across housing types but averages around 5 kWh per household per day, covering essential needs such as refrigeration, lighting, and communication devices. Meeting this demand typically requires ten solar panels per household, each with a daily output of approximately 500 Wh under Syrian

Ill. 6. Analysis of the heights of the buildings in Homs. And an example of residential housing in each district. Source: the author

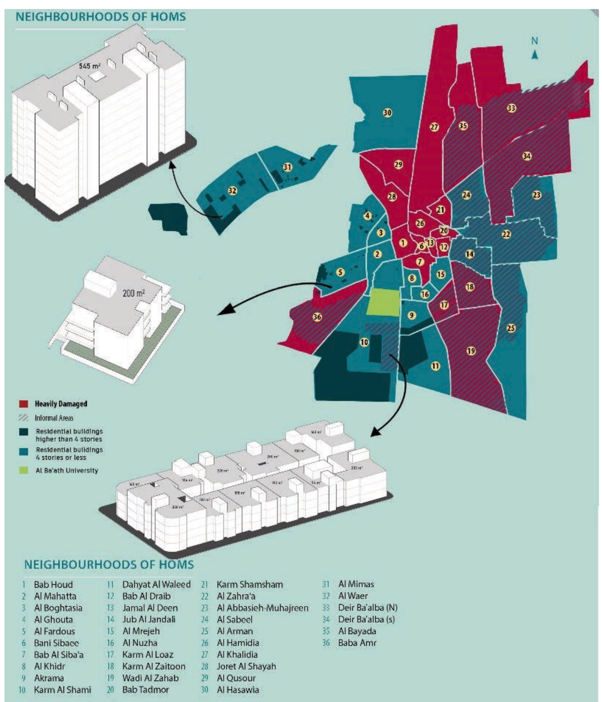


Table 2. House types and their sustainability for solar power, source: the author

Housing Type	Description	Advantages for Solar Power	Challenges for Solar Power
Multi-story Apartment Buildings (71%)	4–5 story buildings with two apartments per floor. Often with ground-floor commercial shops.	• Many buildings are low-rise, increasing sunlight exposure. • Some newer designs include larger balconies or rooftop gardens, which may accommodate solar panels.	• Roof space is limited and shared among multiple apartments. • High energy demand per building requires large solar installations.
Courtyard Houses (16%)	Traditional, single or two-story homes built around a central courtyard.	• Sufficient roof space for solar panels. • Courtyards provide additional sunlight exposure.	• Limited to older neighborhoods, making modernization costly. • Historic preservation rules may restrict solar installations. • Most of these houses were severely damaged during the war.
Single-Family Homes (Villas, Row Houses) (13%)	Standalone or row houses with private gardens.	• Sufficient roof space allows for easy solar panel installation. • Houses can store excess energy using battery systems.	• High initial cost of installing solar panels per home.
Informal Housing (55.1%)	Unplanned, densely packed homes, often built with low-quality materials.		• Irregular building heights and unplanned rooftop additions reduce space. • Weak structures may not support heavy solar panels. • Many roofs are already occupied (extra rooms, water tanks, etc.). • No formal grid connections, requiring battery storage solutions.

climatic conditions. However, adverse weather and poor panel quality can reduce efficiency by up to 40%, leaving households with only 3 kWh/day — sufficient for basic lighting but inadequate for appliances with higher loads (Besner et al., 2023).

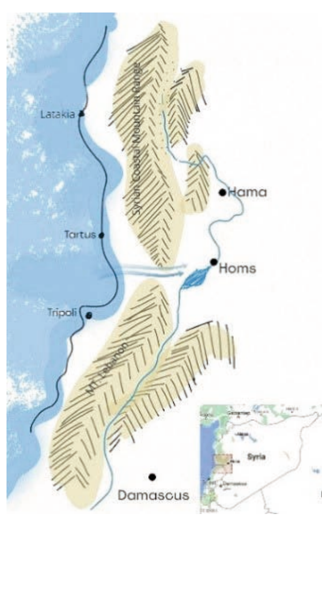
These findings reveal a sharp socio-spatial divide: while formal housing units often have the physical conditions to host solar devices, their high density limits per-apartment feasibility. Informal housing, which now houses a majority of Homs's population, presents even greater structural and economic barriers. Similar challenges have been documented in conflict-affected urban areas such as Kano, Nigeria (Barau et al., 2020) and Sana'a, Yemen (Al-Ammar et al., 2022), where solar adoption remains constrained by poverty, informal construction, and lack of technical standards.

4.3. Challenges for Green Energy in Urban Homs

The city's location near the wind corridor makes its suburbs suitable for wind farms, particularly in the Homs Gap. While two turbines were installed, supplying nearby villages, residents of Homs itself rely predominantly on solar energy. To reduce costs, many resort to buying second-hand solar panels imported from Europe (Hamdo, 2014).

Even with the increasing reliance on solar energy in Homs, multiple structural, spatial, and financial barriers continue to limit its effectiveness. Each apartment requires approximately 5 kilowatt-hours (kWh) per day to operate essential appliances such as refrigerators, lighting, and televisions. To generate this amount, about ten solar panels are necessary, each producing roughly 500 watt-hours daily depending on local climatic conditions. However, even with the installation of ten panels, the desired 5 kWh may not always be achievable. Factors such as cloudy weather, reduced panel quality, and dust accumulation can reduce efficiency to as low as 60%, leaving households with only 3 kWh per day – sufficient for lighting but inadequate for heavier appliances.

Ill. 7 Homs Gap. Source: the author



Another significant challenge is the roof space required for solar panel installation. Ten panels occupy around 25 square meters, which means that a standard residential block with eight apartments would need approximately 200 square meters of roof area, excluding the space needed for maintenance. This presents a major limitation, particularly in dense urban districts where roofs are already occupied by water tanks, satellite dishes, chimneys, and additional rooms built informally.

The financial burden is another critical obstacle. Most Syrian households purchase second-hand panels imported from Europe to reduce costs, as new panels and battery systems are prohibitively expensive under current economic conditions. Even so, the initial installation remains unaffordable for low- and middle-income families. Furthermore, the efficiency of such second-hand panels is often lower, and their lifespan shorter, compared to new equipment.

In addition, many of the buildings in Homs – especially those constructed informally – were not designed to support the additional weight of solar systems. Structural fragility, combined with the absence of regulatory standards, raises safety concerns and discourages investment in rooftop installations. This is particularly true in informal housing areas, where irregular roof heights, weak construction materials, and the lack of formal maintenance exacerbate the risks.

Finally, technical and infrastructural constraints hinder broader adoption. The absence of integrated energy storage systems means that households often experience shortages during the night or on cloudy days. Power bank batteries are essential to ensure stable supply, yet their high cost and short durability limit their widespread use. Without subsidies, technical support, or reliable supply chains, solar adoption in Homs will remain fragmented, accessible mainly to wealthier groups, and insufficient to address the city's overall energy deficit.

4.4. Informal Housing: Barriers to Solar Energy Adoption

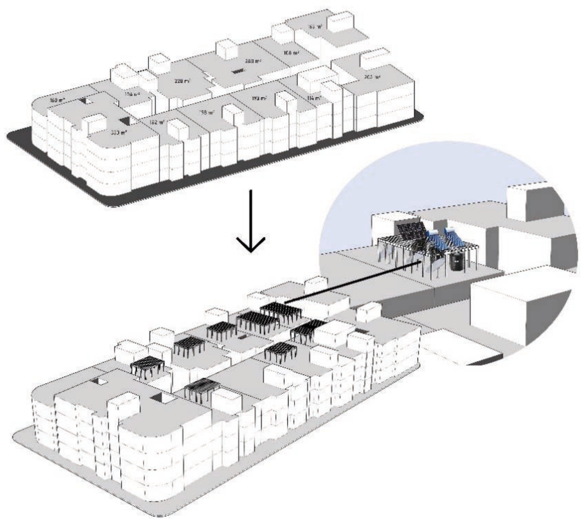
Informal housing constitutes one of the most pressing urban challenges in Homs, as in many Syrian cities. These neighborhoods emerged through unregulated construction on agricultural or state-owned land, and today they occupy nearly 55.1% of the city's total residential stock (UN-Habitat, 2021). Their rapid growth, coupled with the absence of technical, service, and health standards, has resulted in overcrowding, inadequate infrastructure, and structural vulnerabilities. Informal districts impose additional costs on municipal authorities, distort the city's urban form, and present significant challenges for future reconstruction.

From an energy perspective, the conditions of informal housing make solar adoption particularly difficult. Most structures are built with low-quality materials, without proper foundations or reinforcement. Roofs are irregular in shape and height, often occupied by makeshift rooms, water tanks, and satellite dishes. These conditions limit the available space for solar panels and, in many cases, the roofs are structurally incapable of bearing the additional weight of photovoltaic systems.

Furthermore, the lack of formal electrical grid connections in these areas forces residents to rely on standalone systems with battery storage, further increasing costs.

Despite these limitations, informal housing remains in high demand due to the unaffordable price of formal apartments.

Ill. 8. Solving the problem of small areas of roofs in the informal housing by adding a metallic structure to hold the solar panels and hide water tanks and satellite dishes under. Source: the author



Middle-class families, unable to secure housing elsewhere, often resort to purchasing units in informal districts despite their poor safety and health conditions. In the post-war context of displacement and rising poverty, the reliance on these neighborhoods is expected to grow, making their integration into energy planning unavoidable.

In this context, innovative approaches are required. Conventional rooftop solar installations are rarely feasible, but alternative solutions may offer promise. Shared rooftop systems, where a single installation supplies several households, can maximize limited space. Another strategy involves the construction of elevated metallic frameworks above rooftops to host solar panels, while water tanks and satellite dishes are stored beneath. Finally, community solar farms located in open spaces near informal neighborhoods could provide electricity to multiple households under cooperative management.

The challenge of integrating renewable energy into informal housing is not unique to Syria. Studies in other conflict-affected or rapidly urbanizing contexts highlight similar difficulties, including structural fragility, overcrowding, and lack of regulatory frameworks (Barau et al., 2020; Besner et al., 2023). Nevertheless, given the scale of informal housing in Homs, addressing this issue will be decisive for the broader success of renewable energy strategies during both wartime survival and post-conflict reconstruction.

4.5. Proposed Solutions for Informal Housing

Given the structural limitations and spatial constraints of informal housing, rooftop solar installations for individual households are often unfeasible. However, several community-based and technical solutions could increase the viability of renewable energy adoption in these areas.

- Shared Solar Installations:

One approach is to design shared rooftop systems that provide electricity to multiple families within the same building. Such collective installations optimize scarce roof space while distributing costs among several households. Small-scale micro-grids could then be established to supply energy to groups of dwellings, with fees collected cooperatively to cover maintenance and replacement costs.

- Solar Panel Platforms:

An alternative solution involves constructing metallic frameworks above rooftops to host solar panels. These elevated platforms allow dual use: solar panels can be installed on the upper surface, while existing rooftop functions such as water tanks, chimneys, or satellite dishes are accommodated underneath. This arrangement not only maximizes efficiency but also protects vulnerable equipment from weather damage (Ill. 8).

- Off-Site Solar Farms:

In areas where rooftop installations are structurally impossible, small-scale solar farms located in adjacent open spaces could serve entire informal districts. Such systems can be managed through cooperative models, in which residents contribute modest monthly payments to sustain maintenance and repairs. These farms also offer scalability, as additional panels can be installed gradually in response to demand and available funding.

Key Considerations.

For all of these solutions, several technical requirements must be addressed.

1. Structural Integrity: Buildings must be assessed to ensure they can support the added load of solar devices and water tanks.
2. Orientation: Solar frames should be angled to face south, with inclination matching local latitude to maximize efficiency.

3. Accessibility: Installations must allow for easy maintenance and avoid overcrowding of rooftops.
4. Waterproofing: Proper sealing around mounting points is essential to prevent roof leakage and subsequent structural deterioration.

These solutions underline the importance of designing renewable energy strategies that are not only technologically feasible but also socially inclusive. Given the prevalence of informal housing in Homs, adopting flexible, community-oriented approaches will be critical for ensuring that solar energy contributes meaningfully to both survival during conflict and long-term post-war reconstruction.

5. DISCUSSION

The findings from Homs illustrate that solar energy has become an indispensable coping mechanism for households during conflict, particularly in the absence of a reliable national grid. Although adoption rates remain limited by cost, space, and technical constraints, the case of Homs demonstrates both the resilience of local populations and the potential role of renewable energy in crisis settings.

The analysis confirms that solar energy can partially mitigate the humanitarian consequences of war. Even when reduced in efficiency, photovoltaic systems provide households with enough electricity for lighting, communication, and refrigeration. These basic services significantly improve living conditions, especially in comparison with diesel generators, which are costly, polluting, and dependent on scarce fuel supplies.

At the same time, the challenges identified – financial barriers, insufficient roof space, and structural weaknesses in informal housing – underscore the limits of relying on individual households to implement solar solutions. Without external support, these obstacles risk deepening socio-spatial inequalities, as wealthier households are more likely to afford and benefit from renewable systems, while vulnerable groups remain excluded.

These results are consistent with findings from other conflict-affected or fragile urban contexts. Barau et al. (2020) observed similar constraints in Nigerian informal neighborhoods, where lack of technical standards and household poverty restricted solar uptake. Besner et al. (2023) highlight that decentralized renewable energy services in informal settlements often require collective solutions rather than individual installations. Such parallels suggest that the barriers documented in Homs are not unique but part of a broader pattern of renewable energy adoption under conditions of conflict, displacement, and informality.

In the Syrian case, the lessons from Homs highlight the urgent need to link short-term survival strategies with long-term reconstruction planning. If solar adoption remains ad hoc and limited to households that can afford second-hand systems, it will reinforce existing inequalities. By contrast, if municipalities, NGOs, and international partners promote cooperative solar schemes, shared platforms, and community-based solar farms, renewable energy could form the backbone of inclusive recovery.

Ultimately, the discussion reinforces the central research argument: that the wartime adoption of solar energy in Homs not only addresses immediate energy scarcity but also provides critical insights for designing sustainable energy strategies in post-conflict contexts. These insights are especially relevant for Syria's future reconstruction but also extend to other regions of the Middle East and North Africa experiencing instability and resource shortages.

6. CONCLUSION: FUTURE OF SYRIA; REBUILDING NEW SYRIA

This study has demonstrated that solar energy, despite its technical and financial limitations, has become a vital coping strategy for households in Homs during the Syrian conflict. By providing basic electricity for lighting, communication, and refrigeration, photovoltaic systems have enabled families to maintain a minimum level of daily life under conditions of prolonged blackout and infrastructure collapse.

At the same time, the findings highlight structural and socio-economic barriers that limit the broader adoption of solar technology. Roof space shortages, the fragility of informal housing, and the high costs of panels and storage batteries constrain access, leaving renewable energy solutions concentrated among wealthier households. Without coordinated strategies, this unequal distribution risks reinforcing existing urban and social disparities.

Nevertheless, the experiences of Homs also reveal important opportunities. Community-based models – such as shared rooftop systems, elevated solar platforms, and neighborhood solar farms – offer viable solutions to overcome spatial and structural limitations. Integrating these approaches into urban recovery planning could significantly expand access to clean energy, particularly in informal settlements that house the majority of the city's population.

The Syrian case provides lessons that extend beyond national borders. Similar patterns of constrained yet innovative renewable energy adoption have been observed in other conflict-affected regions, including parts of Nigeria, Yemen, and Gaza (Barau et al., 2020; Besner et al., 2023). These parallels suggest that decentralized, low-cost, and community-driven energy solutions are essential not only for survival during conflict but also for building resilience in post-war reconstruction.

For Syria, the integration of renewable energy into reconstruction strategies should be prioritized as both a short-term necessity and a long-term development goal. Policymakers, international organizations, and local communities must collaborate to establish regulatory frameworks, provide financial support, and ensure technical standards for solar energy systems. Doing so would allow renewable energy to serve not only as an emergency response to war-induced scarcity but also as a cornerstone of sustainable urban development in the country's recovery phase.

In conclusion, the case of Homs illustrates that conflict can accelerate the adoption of alternative energy pathways. While born out of necessity, this shift holds the potential to reshape Syria's post-conflict energy landscape, offering a model of resilience and adaptation for other regions in the Middle East and North Africa facing similar crises.

ENDNOTES

[1] Light from LEDs doesn't have to be unhealthy. There are some studies saying that being exposed to the blue light may disturb your circadian cycle, but you can always buy a LED with a warmer light temperature to avoid this problem, Unfortunately, some choices may not be available in a war-zoned country. Read more: Hipólito, Vladimiro, and João MP Coelho. "Blue light and eye damage: a review on the impact of digital device emissions." In Photonics, vol. 10, no. 5, p. 560. MDPI, 2023.

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