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Resilient Urban Development in Sudan: Integrating Socioeconomic and Technological Factors for Sustainable Energy in Omdurman City, Sudan

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Abstract

This study evaluates the integration of photovoltaic (PV) systems in Omdurman, specifically focusing on Omdurman Althawra, to enhance urban design and architectural planning for domestic use. By analyzing data from blocks 10 and 18, the research incorporates the experiences of residents to identify effective strategies for implementing building-integrated photovoltaics (BIPV). The methodology includes a comprehensive historical and geographical analysis to understand existing services and infrastructure, as well as the roles of various stakeholders, including authorities, communities, and homeowners in the development of PV systems. The findings highlight the challenges of providing essential services in a rapidly urbanizing environment while addressing energy demands through renewable solutions. The study emphasizes the importance of public policy and regional planning in fostering sustainable energy practices that meet the needs of Omdurman's population. By documenting daily observations and opinions from residents, this research aligns technological, social, legal, and economic factors with environmental considerations to propose a framework for future energy-efficient urban development in Omdurman. Ultimately, the study aims to inform decision-making processes regarding health, renewable energy, and low-energy building designs that leverage rooftop PV systems as a clean energy solution for urban planning in developing regions like Khartoum state.

Keywords: *Design Rooftop, PV Systems, Omdurman, Sustainable Energy, Khartoum.*

Introduction

Pollution, acid rain, global warming, and other problems are all signs that the environment is getting worse because of the limited quantity of traditional energy sources. So, it is very important to get clean, long-lasting energy from sources that can be used again and again. One of the most hopeful types of clean energy is solar energy. because it is easy to get, there is a lot of it, and it could be profitable (1, 2) Either BIPV modules or standards have a big effect on how well photovoltaic modules and building-integrated solar systems work. The solar panels are custom made to meet particular needs, ensuring that they get the most sunshine while reducing clouds that aren't wanted. A lot of convincing study has been done on the problems of quality and number in a certain place. One of the best things about photovoltaics is that it doesn't need a regional power center to provide power, distribute power, or move energy between systems. (1). Photovoltaic (PV) energy is one of the renewable energy technologies that is becoming more and more common in buildings of the future. This trend is anticipated to continue as grid-connected power systems continue to gain popularity. We might reduce our need on non-renewable electricity sources by using this sustainable energy source (2). Sometimes, technical limitations, such as a limited height for the collector, make the simple method, which just requires one cell at the ideal angle of inclination, unworkable. Taking into account the energy collected and the financial consequences, the offered approach is ideal for using collectors inside a certain sector (3) revealed that solar photovoltaic technology might provide large-scale electricity safely for houses and the environment (1) For net-zero energy buildings, all buildings will use energy-efficient design and renewable energy technology. Indeed, the building will safeguard and generate enough energy to establish a new generation of cost-effective structures with zero net yearly non-renewable energy requirement. Photovoltaics changed building design. But this technology is still young and its application to architecture is new. A module is made of several solar modules linked and encased in different materials. BIPV systems rely on photovoltaic modules (4, 5). Modules are wired and led together to form a

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solar system. Solar cells generate unregulated direct current DC power by producing the photovoltaic effect when exposed to direct or diffuse light. DC may be utilized with a battery system or synced to an inverter, which turns electricity into ampere current. Electricity from the grid may be consumed in the building or exported to a public body via a grid connection. The photovoltaic system was installed to reduce strain in the building due to its energy needs (6, 7).

An Analysis of the Potential Opportunities for the Development of the Renewable Power Industry in Sudan

Sudan has a unique chance to boost its renewable power sector, a worldwide trend. Sudan may lead the world in renewable power. The US government will boost renewable energy in three years. Renewable power production will reach 10% by 2022 and 25% by 2025. Over the next decade, the US will spend $150 billion in a "clean energy research and development fund" to support solar, wind, biofuel, and other clean and alternative energy projects. By 2025, German policymakers want renewable energy employment to outweigh car jobs. The EU will invest 30 billion euros in renewable electricity and employ 350000 workers. The British government will grant us $100 billion to erect 7,000 wind turbines, employing 160000. The Japanese government will produce 20 times more solar electricity and 40% more eco-friendly cars. The Korean government will build 2 million energy-saving greenhouses and promote domestic solar, geothermal, wind, and bioenergy. Future investors will favor renewables. Within five years of 2020, renewable power or related firms will generate $500 billion, while mergers and acquisitions will amount over $100 billion.(6). Within the 10 service and production five hundred index industry sectors, the energy business has averaged 13% annual returns over 50 years. About 70% of Sudan's energy comes from coal. The secondary energy source is electric power, 80% of which is thermal. With 50% foreign oil dependency, an oil deficit threatens energy security. Sudan's fast economic growth and conventional energy usage are increasingly at odds. Solar, wind, biomass, nuclear, geothermal, hydrogen, and ocean energy, along with traditional energy, will diversify Sudan's energy production and consumption framework, promoting systematic and sustainable economic growth. Thermal and hydroelectric generating dominated the energy structure in 2020, with renewable energy sources hardly present. Table 1 Multiple renewable power sources are developing rapidly, offering great promise. The structure will vary significantly during decades of building.

Table 1. Percentage of Renewable Energy in Sudan's Energy Composition in 2020

Energy type	Installed capacity	Share (%)	Power Generation		Share (%)
Thermal power	60285	76.59	27793		82.30
Hydropower generation	17200	21.85	5852		17.33
Wind power generation	1215	1.54	120		0.36
Solar power	14	0.02	7		0.02
Total	78714	100	33772		100

By the end of 2020, renewable energy constituted over 9% of Sudan's total energy production from 2010 to 2020. During this period, global solar cell output rose by a factor of 4.37, whereas Sudan's production increased by only 0.5 times, positioning it as the smallest producer of solar cells globally. Sudan has not achieved significant progress in the development and utilization of wind energy, resulting in a low ranking of its wind power generation capacity globally (7). The government of Sudan has come to the realization that the development and utilization of renewable power sources is of strategic relevance for Sudan's future, and that this is a key position for the country (8). The renewable energy law of Sudan was implemented in 2019. Subsequently, the Sudanese government has implemented a series of administrative regulations and rules to actively encourage the growth of renewable energy. Sudan is required to allocate 3 billion USD in energy investments from 2020 to 2030, with 1 billion USD allocated to renewable energy, energy conservation, and environmental preservation, according to pertinent projections. The development of Sudan's renewable power industry will have an excessively optimistic prospect if the government and private forces collaborate. Sudan possesses substantial potential and development advantages in the global renewable power development trend.

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Sudan's Renewable Power Development Micro Foundation

At the micro level, firms must be encouraged, a renewable power technology and cost base established, the renewable power industry chain integrated, regional characteristics formed, and regional growth and national balance promoted. Similar firms' initiative and active expansion and agglomeration drive renewable power industry development. Understand the renewable power trend to grow renewable power companies. State-owned and commercial companies support renewable power industry growth. One of Sudan's richest wind energy regions and the first to generate wind power is Nyala. Relevant companies invested earlier in development and operation. Wind energy reserves in Nyala total 872 million kilowatts. These advantages will keep companies investing in building. Wind energy is abundant in Hebei. Kassala's wind power resources are promising, thus more than a dozen companies signed a 3 million KW wind power development agreement with a 0.5 billion USD investment. (7). The development of renewable power enterprises is also influenced by their ability to master renewable power technologies, establish a technical foundation for the development and utilization of renewable power, and assume the lead in the global market. Sudan is not averse to renewable power technology in certain renewable power sectors, with the exception of its global industrial leadership. The photoelectric conversion efficacy of monocrystalline silicon chips is approximately 10%, polycrystalline silicon chips are approximately 12%, and thin-film cell amorphous silicon is approximately 5% in terms of solar energy utilization. A Sudanese technology company's thin-film battery has a rated conversion efficacy of 4%, which is a high value in the context of thin-film batteries. Sudan is also experiencing significant growth in the development of hydrogen energy. Hydrogen production technology has evolved into a multi-channel method that encompasses chemistry, biology, electrolysis, photolysis, and chemical heat treatment since the late 1990s. Fuel cells are a critical technology for the utilization of hydrogen energy and are an ideal hydrogen energy conversion device. Sudan became one of the world's minor hydrogen producers in 2020, with an annual output of nearly three million tons. Sudan's hydrogen energy development technology has the potential to reduce the hydrogenation time of buses that utilize hydrogen fuel cells from over 10 hours to 15 minutes, thereby facilitating the realization of green development. The transfer of automotive energy and market entry have been significantly influenced by this technology (9).

Cost, together with market and technology, determines whether renewable power like solar and wind can be utilized widely and replace oil and coal. Innovation, scalability, and intense management can lower raw material costs and enable market-based renewable power. Solar power generation is expensive due to photovoltaic cell costs and low photoelectric conversion efficiency. The international fiscal crisis has lowered silicon material prices, but they still cost three dollars per kilowatt hour. Technology and lower raw material prices should lower solar power generation costs again. Solar energy use depends on solar power producing cost. If reduced below 1 USD per kilowatt hour, it can be pushed in economically developed countries and energy-scarce regions. Most countries and regions can promote it with government subsidies and preferential policies if it is decreased to 0.5 dollars. Japan aims to lower photovoltaic power generation costs to 1.5 dollars per kilowatt hour in 2018, 0.93 in 2020, and 0.47 in 2030. Sudan's photovoltaic power market is cost-driven. Silicon cells have dominated photovoltaic power generation for years, but thin-film cells are cheaper and will grow rapidly (10), a positive trend. To boost solar photovoltaic power generation, the government can also offer preferential tariffs. Several parties seek to lower the electricity price to less than $1 per kilowatt hour. United States development is high. The first national solar company's solar photovoltaic power generation in Nevada's desert is 0.75 dollars per kilowatt hour, while the state's thermal power generation is 0.09 dollars, which is parity on the Internet. It costs more to generate wind electricity than solar power. The 2020 cost per kilowatt hour was 0.6-0.8 dollars, the lowest among renewable power sources. Wind power can become cheaper as technology improves and equipment prices drop. Wind farms in remote western areas and high transmission costs are another issue with wind power in Sudan (10). Regional formation bases and development settings vary by technology, cost, and other factors. Although renewable power use in many Sudanese regions is low and development is slow, regions can nevertheless plan renewable power building as a regional characteristic sector. In addition to using renewable power in the province, the equipment and facilities manufacturing sector can be created according to the regional industrial historical environment to create a unique renewable power manufacturing base. Motor sets, wind turbine blades, towers, speed-up gear boxes,

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frequency converters, and other equipment components and parts can be built alongside wind turbine equipment manufacturing firms. (11).

To create a national renewable power industry framework, appropriate equipment manufacturing, components supporting, technological research and development, and service institutions will be integrated into the industrial chain. Each part can be placed elsewhere. Currently, any region with the conditions, advantages, and initiative can develop first. Investment pull is one way the renewable power industry promotes regional economic and social development. Encourage central and local state-owned and private firms to invest in renewable electricity, create output value, encourage employment, and raise taxes. Energy supply follows. Renewable energy can help develop numerous businesses, especially by solving remote power consumption and increasing rural electrification. It will boost rural and urban production and living conditions.

Potential of Renewable Energy

The enhanced accessibility of dependable and effective energy services fosters innovative development options (12). This study analyzes the potential of integrated systems in the stationary and portable power market, focusing on the pressing need for cleaner energy technologies. This approach analyzes expected trends in future energy consumption and their resulting environmental effects, such as acid rain, ozone layer depletion, and global warming. This theme explores issues pertaining to renewable energy, environmental concerns, and sustainable development from both contemporary and prospective viewpoints. It is concluded that renewable and environmentally friendly energy should be encouraged, promoted, implemented, and demonstrated through full-scale plants, especially in remote rural areas (13). Buildings represent approximately 40% of global annual energy consumption. A significant portion of this energy is employed for lighting, heating, cooling, and air conditioning applications. The increasing awareness of the environmental impacts of CO2, NOx, and CFC emissions has led to a resurgence of interest in sustainable heating and cooling technologies (14). As part of the 1997 Montreal Protocol, countries agreed to get rid of refrigerant chemicals that could damage the ozone layer in the stratosphere. Cutting down on energy use is important to keep world energy reserves from running out and to protect the environment. (15). Reducing building energy consumption can be achieved by designing structures that utilize energy more efficiently for heating, lighting, cooling, ventilation, and hot water supply. Passive measures, especially natural or hybrid ventilation as opposed to air-conditioning, can significantly decrease primary energy consumption. Exploiting renewable energy in buildings and agricultural greenhouses can significantly reduce dependency on fossil fuels.(16). Therefore, promoting innovative renewable applications and reinforcing the renewable energy technologies market will contribute to the conservation of the ecosystem through the reduction of emissions on both local and global scales. This will also aid in the improvement of environmental conditions.(7)

Integration and Multicultural Diversity

Cultural variety must be considered in Omdurman and Khartoum urban development. Past planning practices have caused geographical and socio-cultural differences. Future urban planning must celebrate multiculturalism through inclusive neighborhoods and mixed-use developments, promote regional integration to address unequal urban growth, implement transparent resource allocation mechanisms, and encourage effective governance and public participation in planning. Plan thoroughly, A comprehensive approach is needed to address Omdurman's urban issues. The study covers spatial planning, land use, housing, urban services, and local economic growth. Fair and sustainable solutions that meet every resident's basic requirements and reduce poverty over time are the goal.In conclusion, Omdurman's urban planning must balance infrastructural development, economic growth, and social cohesion while preserving the city's uniqueness and meeting the requirements of its growing population. Urbanization is a global trend that worries many places [1]. Urbanization is the process of more people living in cities. This is usually caused by rural-to-urban migration or population increase. However, urban categorization norms vary per nation, hence urban center definitions vary [2]. Unplanned urbanization is a major issue, especially in developing countries where data, including geographical information, is scarce. Conflicts, political and factional instability, internal displacements and migration, population expansion, and economic possibilities

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drive urban development. This may also be attributed to a poor system for tracking local urban movements and trends [1]. Urban planning requires trustworthy, precise data. Without satellite images, obtaining such data is difficult [1]. Remote sensing, the extraction of information about an item on Earth without physical touch [3, 4], is a potent technique for land surface change detection. Thus, urban growth affects remote sensing and GIS [5]–[7]. Remote sensing has been used to map cities and simulate urban expansion and land use change [8]. Remote sensing data is geographically consistent, covers large regions, has great spatial resolution, and has high temporal frequency [9]. It also provides accurate historical time series [8]. There are many satellite-based methods for mapping urban land use and cover [10]. However, selecting an efficient change detection approach might be difficult [11]. Due to its capacity to combine data from diverse sources, GIS is useful for urban planning and management. Remote sensing and GIS can gather and interpret spatial information from satellite and aerial photographs to track urban expansion [12]. Landsat change maps help study population increase and urban expansion [12].This research aims to detect and analyze Omdurman City's urban expansion from 1987 to 2000 and 2013. Remote sensing and GIS will process three Landsat TM, ETM, and OLI imageries to identify, quantify, and analyze land use and cover changes. The main city in Sudan, Omdurman, is on the western bank of the Nile, across from Khartoum. The research region is 15.39 N, 32.29 E (Fig. 1). Omdurman has 2,395,159 residents, according to the 2008 census. Flat land descends westward toward the White Nile and River Nile in the study area. It is 350–510 m above sea level (Fig. 2). The lower portions of the White Nile, the River Nile, and several local ephemeral stream systems flow from northwest and west to southeast and east (Fig. 2). The area has little vegetation, although periodic drainage and riverbanks may increase it. Omdurman has a semi-arid climate with heavy rainfall only in July and August. The city of Omdurman is among the warmest worldwide. Summer peak temperatures may exceed 53°C. The average monthly temperature is 37.1°C, with half the year seeing 38°C highs. Cretaceous Omdurman Formation rests above Precambrian basement rocks in the studied area. These include gneisses, marbles, foliated batholithic granites, and sheared acid dykes. The geological formation includes basic and acidic Tertiary volcanic rocks and Quaternary deposits.

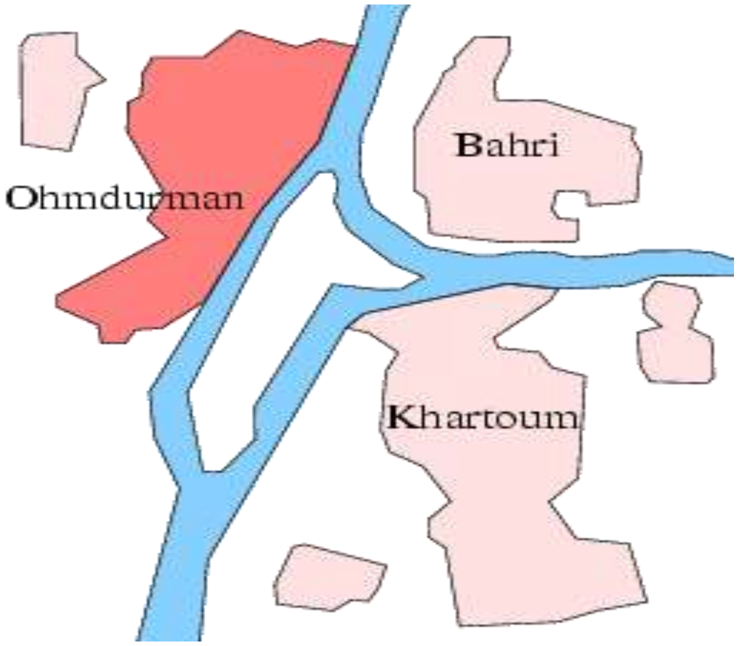

Fig. 1. Location Map of the Study Area

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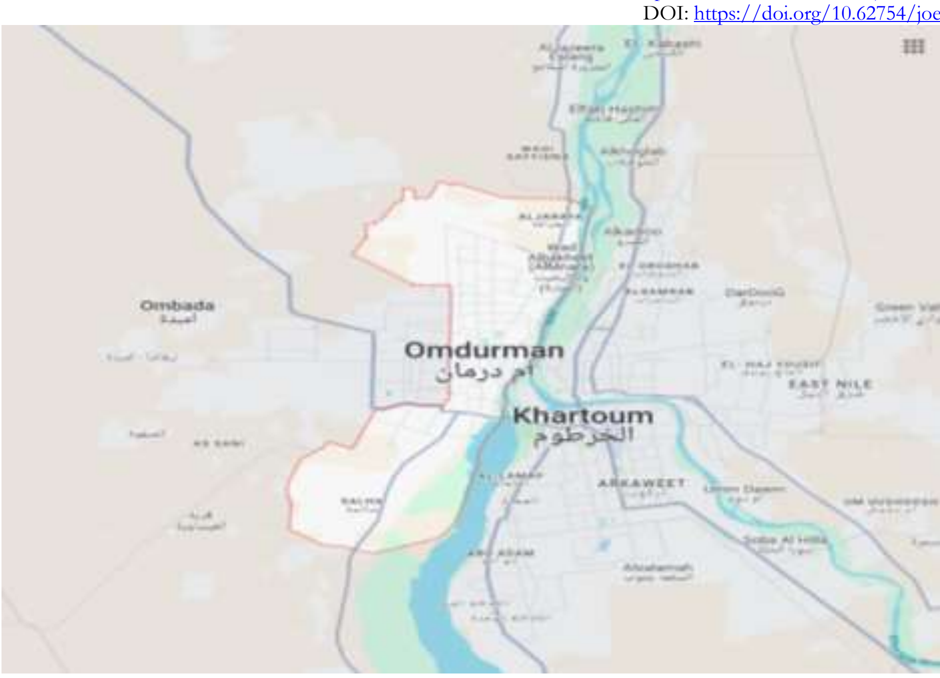

Fig. 2. Digital Elevation Model and Drainage System of Omdurman Area

Essentials and Procedures

Additionally Argument for PV System Insulation in Domestic Applications

This article showcases a photovoltaic (PV) system design that is designed to blend in with the architecture of the building. Photovoltaics (PV) may have a nuanced or considerable impact on the architectural design of the structure. sloping roof of a residential building P.V. Both architecturally and technically, the researchers put their photovoltaic system into operation. Considering the project's historical significance, this alternative was chosen as the best choice. Because of the nature of this design, contemporary high-tech materials are not suitable. A completely new and modern architecture was chosen by the Khartoum community in order to address the issues of service requirements and support. (2017). photovoltaic (PC) The architectural portrayal in a particular location is influenced by the urban design system that is in existence there. Due to the fact that the photovoltaic system is an essential part of the building envelope, it is considered to be an important architectural aspect. In order to dominate the roofs and improve the neighborhood's aesthetic appeal, solar systems are being used. Despite its rarity, the blue PV roof is a stunning addition to the PV environment, which is characterized by a combination of water and the heavens. a glass corridor that may be considered cliched is transformed into an important feature that adds to the overall beauty of the building (18). Those who are in charge of carrying out the research define The photovoltaic system encourages the development of creative building projects. The incorporation of photovoltaic modules, particularly when combined with passive solar design principles, encourages the development of new designs and architectural breakthroughs in Khartoum. This, in turn, increases the possibility for future research in the home sector of the area.

Systems Applications in Omdurman

In Omdurman, Sudan, the integration of sustainable practices is crucial for enhancing quality of life and tackling environmental challenges. Key initiatives involve the implementation of rainwater harvesting and purification systems to improve water security, the promotion of recycling and composting for efficient waste management, and the establishment of biogas systems to convert organic waste into renewable energy for cooking. Promoting community gardens can enhance local food security, while investments in solar collectors and wind generators will support sustainable electrical demand fulfillment. Furthermore, the implementation of solar thermal systems for space and water heating, the development of integrated control

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systems to optimize resource utilization, and the adoption of energy-efficient construction practices using local materials will significantly improve sustainability. Collectively, these initiatives have the potential to enhance resilience and foster a more sustainable future for Omdurman.

Urban Regeneration Proposals and Urban Expansion and Challenges

In recent years, Omdurman, the biggest neighborhood in Khartoum, Sudan, has encountered several difficulties related to urban development. The city's quick development and expansion have created possibilities as well as issues that need for careful urban rehabilitation plans. Due to significant urbanization and population increase, Omdurman now requires careful planning to handle its growing population. The metropolis is home to around three million people and has an area of roughly 320 km². There are severe infrastructural limitations as a consequence of this fast urbanization, especially in the areas of water distribution and supply. The Omdurman Water Supply and Optimization Scheme has been one of the city's most important urban planning projects. About two-thirds of the population was impacted by the severe drinking water deficit, which this initiative attempted to remedy. Comprehensive urban redevelopment plans have been demanded after the 2018 Omdurman Market fire. Creating a Form-Based Code (FBC) to encourage vernacular design and control building elements is one suggested tactic, as is splitting existing commercial property into smaller parcels to allow additional enterprises. establishing pedestrian-friendly zones and enhancing traffic control, converting public squares into lively areas for socioeconomic activity and giving street merchants access to designated areas.

Historical & Geographical Background

Geomorphological Challenges

For Khartoum and Omdurman, dust storms pose a serious geomorphological danger, a problem that many desert urban areas face. The megacity's susceptibility to haboobs, or severe dust storms, has been known for many decades, and there have been continuous reports of dust issues occurring (21). As urbanization has increased, impermeable surfaces have become more common, which has made the city's heat island effect worse. As a result, dust storms and heat waves have become more frequent throughout the dry season. Additionally, overuse of local silty soils increases wind erosion, which increases the frequency and intensity of haboobs (22). During the rainy season, street flooding occurs more often as a result of the concentration of rainfall in a few intense storms, especially where impermeable surfaces are present. Floods are one of the biggest risks to the metropolitan area since the city's drainage infrastructure is unable to handle erratic rainfall. Flooding occurs often in the area, highlighting how vulnerable unmanaged urban areas are (23) (24). While the Blue Nile flood partially restricts its flow, raising its level, the Jebel Aulia dam lessens the worst effects of White Nile flooding (Figure 4). The banks are lower than those of the more carved Blue Nile near the confluence east of the White Nile. The White Nile enters when the Nile floods (Figure 4). As Sir William Willcocks noted over a century ago, high Blue Nile levels may keep their waters from joining the Nile, resulting in floods. Due to limited penetration, local heavy rainstorms result in overland and street flooding. Wood and sediments have piled up against the pillars of the Omdurman Bridge in recent years, increasing the Blue Nile's dam effect and increasing the likelihood of flooding in the uppermost White Nile (Figure 4). Every river bridge has the same issue as a result of poor pillar maintenance. Lastly, small ephemeral watercourses such the Khor Abu Anga and Khor Shambat crossing Omdurman flood because to persistent rainfall. Refer to Figure 4.

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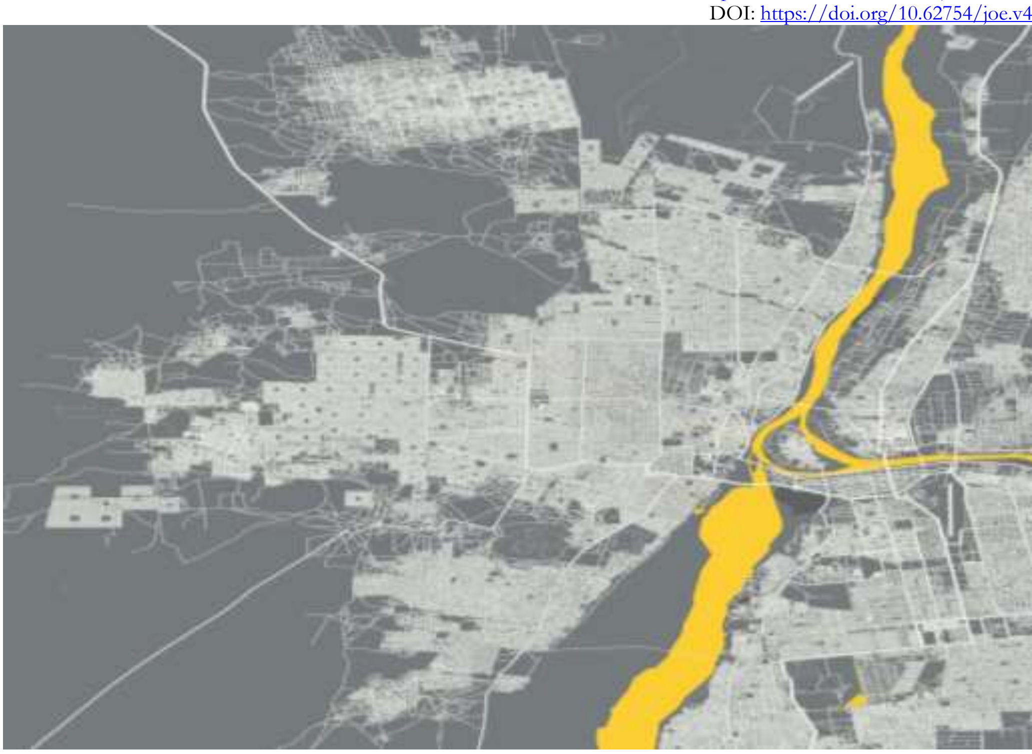

Figure 3. Following Prolonged Rainfall

Historical Planning of Omdurman

Omdurman, Sudan, on the western Nile River, has a rich history that has shaped its urban layout and growth. Once a little riverine town, Omdurman transformed in the 19th century with the rising of Muhammad Ahmad (al-Mahdī), who led a victorious insurrection against British colonial control. After his triumph in 1885, Omdurman became the Mahdist capital and grew rapidly as a political, cultural, and religious hub. The town flourished swiftly, with unplanned mud dwellings and informal settlements reflecting the need for housing and infrastructure to accommodate Mahdist newcomers. Anglo-Egyptian troops destroyed the Mahdist army at the Battle of Omdurman in 1898, establishing British rule over Sudan. Despite combat damage, Omdurman grew as a metropolitan hub. The British renovated sites, such as al-Mahdī's mausoleum, which became a symbol of national pride and culture. Omdurman became a thriving textile, livestock, and agricultural market in the 20th century. The Islamic University of Omdurman was founded in 1912, solidifying its educational and cultural position. Omdurman's urban planning has frequently been reactive, reacting to population expansion and economic needs without long-term plans. This has caused infrastructure and service issues. Recent efforts promote sustainable urban development that integrates historical context with current demands to solve these concerns. Omdurman's historical planning shows how cultural heritage and urban progress interact. Historical events, notably the Mahdist era and British colonial administration, shaped the city's growth from a tiny town to a large metropolitan hub. Omdurman's growth highlights the necessity for strategic planning that acknowledges its rich heritage while tackling modern issues.(25, 26)

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Figure 4. The Location of Omdurman City at Khartoum State

Location Study Surveying

This article focuses on the region of Omdurman Althawra, employing personal meetings with government officials and local residents, as well as direct observation of the area, its inhabitants, and the public services pertinent to this investigation. Conducting a survey, registering, and examining the services offered to the residential sectors in Omdurman Althawra, which includes its three classifications. The main aims of the survey in urban design emphasize the importance of having well-defined objectives in the chosen study area. Collection of data for future user application. Assessing public perception of the acceptance of photovoltaic (PV) technology represents a more strategic approach for executing programs designed to facilitate its adoption. This approach systematically identifies the challenges encountered by residents in the studied area regarding the provision of PV systems. The development of photovoltaic systems encompasses multiple functions performed by authorities, communities, and households within the region.

The Primary Focus of the Study is Urban and Environmental Aspects

Studying health and environmental threats because of improper usage of services and how individuals are affected by improper environmental behavior and the role of formal authorities in the occurrence of this phenomenon.

Methodology for Field Study of Research Sample

The study assessed the samples through a methodical selection of locations in Omdurman Althawra. At that point, the researcher initiated the process of selecting a sample in Omdurman Block No. 10.18. This included 723. Block 18 comprised a total of 1,280 dwellings, with 260 of those incorporating BIPV technology. The researcher identifies the community members who are the direct users of BIPV. The citizens have the authority to impact how their contributions are distributed. Although communities have shown a significant aversion to new facilities, their construction has proceeded nonetheless. The lack of engaged individuals diminishes the opportunity for discussions focused on innovative social change and holistic inclusion (27)

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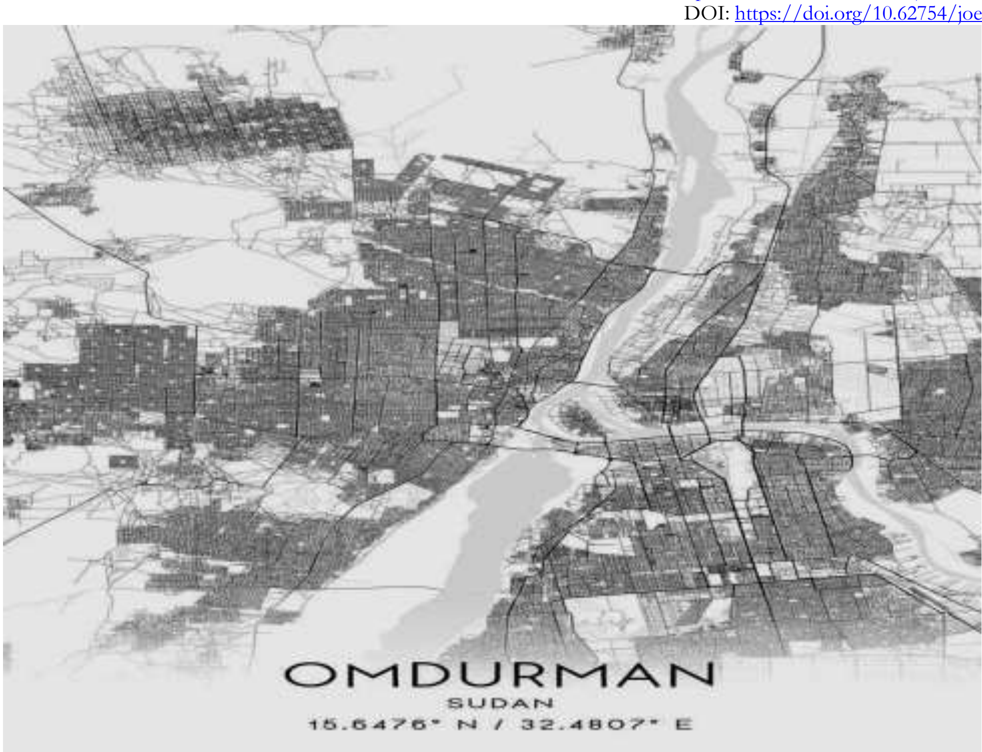

Figure 5. Planning of Block No. 18 Omdurman

Source: Ministry of planning 2021

Approach of Simple Random Sampling

The primary objectives of statistical application encompass the collection, presentation, analysis, and interpretation of data. The focus of statistical application is directed towards these objectives. The initial phase involves the collection of data. Most statistical analysis techniques rely on the assumption that the data collection process was carried out through randomization to acquire the data. As discovered by (28) The effectiveness of statistical analysis and its interpretation is compromised when the assumption of randomized controlled sampling is not upheld. Therefore, before delving into the methods of statistical analysis, it is essential to gain an understanding of sampling. Obtain a representative sample of qualified respondents along with a directory of houses (29). A random selection from the database comprised 50% of the total homes (n = 249), which corresponds to 50% of the homes utilizing BIPV. The compilation featured the name, postal address, and race of each potential responder for every homeowner. The focus in selecting a random sample lies in the methodologies of sampling and estimation within statistical analysis. The focus is on the applications of sampling, particularly in the design and execution of surveys, which involves the use of three distinct questionnaires. The sample was selected by the researcher from Omdurman Althawra Block No. 10.18. Among the 723 households in the area, 294 have adopted a BIPV system. The researcher implemented a random sampling method, systematically surveying each household, which resulted in a total of 147 participants, accounting for 50% of the study's population base.

Classification of Data Types

This study employs multi-temporal Landsat imagery from route 173, row 49, collected on various dates. The Landsat data were obtained from the USGS Earth Resources Observation and Science Data Center. Table (1) details the characteristics of the satellite images along with the date of collection. All datasets have undergone orthorectification and have been registered to a consistent coordinate system, specifically UTM zone 36N utilizing the WGS 84 datum. The demographic data was obtained from the Central Bureau of Statistics, Sudan (30). [13]

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Result and Discussion

This article analyzed and evaluated the urban situation. This section may be divided by subheadings. It should provide a concise and precise description of the survey results, their interpretation as well as the most important things that can be found:

Omdurman Population Growth

The significance of possessing knowledge regarding future population trends as a resource for social and economic development planning is discussed in other contexts. In numerous developing nations, the data available for planning purposes, including a foundational statistical basis for population projections, is often either significantly inadequate or entirely absent. Regarding population estimates, the aforementioned statement holds true for Omdurman City. Nonetheless, this endeavor is deemed warranted, as census data provides insight into population growth for the census year. This serves as a foundation for estimating potential future developments of various influencing factors, ultimately leading to a preliminary projection of anticipated population growth. Among the three factors that govern population growth—productivity, humanity, and internal migration—the influence of migration emerges as the predominant force impacting the growth of the Omdurman population. Omdurman evolved from a modest village into a prominent national town when the Mahdi designated it as the national capital of Sudan in 1885. The population experienced a significant increase, expanding from 150,000 in 1885 to 3,099,711 by 2014 (Table 2). The establishment of the new capital and the religious significance of Omdurman drew a diverse array of ethnic groups and tribes from across the nation. The swift expansion of the town can be ascribed to the significant influx of rural migrants rather than to natural increase (30).

Table 2. Omdurman Population Progress 1890-2016

Year	Population	% of 2014 population
1890	150,000	4.8%
1900	150,000	4.8%
1910	43,000	1.4%
1920	50,000	1.6%
1930	104,000	3.4%
1940	116,000	3.7%
1950	125,000	4.02%
1955/56 ©	116,231	3.74%
1960	153,522	5%
1970	267,833	7.3%
1973 ©	316,499	10.2%
1980	467,260	15.1%

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1987	689,858	22.29%
1983 ©	552,163	17.8%
1990	815,180	26.3%
1993 ©	963,301	31.1%
2000	1,422,160	45.8%
2008 ©	2,219,751	71.6%
2013	2,931,917	94.59%
2014	3,099,711	100%

Sources: [16] estimated, and projected from 1955/56 census as a base, © census.

Table (2) indicates that the population of Omdurman City experienced a decline from 150,000 individuals to 43,000 between 1890 and 1900, attributable to the drought and famine that transpired during that period. The demographic consistency of Omdurman between 1900 and 1930 can be attributed to the stringent policies implemented by the colonial administration to regulate the influx of rural inhabitants. The swift increase in population in Omdurman during the years 1940 to 1960 was also noted by [14]. Since independence, the process of growth has been ongoing. The 1983 National Census (Table 2) recorded the population of Omdurman at 552,163 individuals, whereas the 1990 Capital Region Census indicated a rise in Omdurman City's population to 815,180 individuals. [15] elucidated the unique characteristics of the rural population in Omdurman as a significant manifestation of urban overflow. Furthermore, they elucidated the phenomenon of the significant population surge in the urban fringes of Omdurman as a substantial influx of migrants originating from the west. Following the 1993 census, Omdurman City experienced a significant population surge, culminating in a total exceeding two million individuals by the 2008 census. The total population experienced a notable rise, escalating from 552,161 individuals in the 1983 census to 963,301 individuals in the 1993 census, ultimately reaching 2,099,751 individuals in the 2008 census. In conclusion, it is evident that the population of Omdurman City has experienced rapid growth over the past one hundred and twenty-five years, rising from 150,000 in 1890 to 3,099,711 in 2016, primarily driven by migration displacement and natural population increase.

Land Use/Land Cover Classification

Multispectral image classification serves as a pivotal technique in remote sensing, enabling the categorization of every pixel within an image to generate thematic maps that represent the current land cover. There exist two distinct classifications employed in the processing of satellite imagery: unsupervised and supervised. Each of these approaches categorizes the pixels of an image into uniform classes to illustrate the spatial distribution of various features identified by the satellite sensor [18]. In this manner, the diverse land covers within the study area were categorized into five distinct classes: sand, water body, built-up land, vegetation, and soil. The subsets of three Landsat images pertaining to the Omdurman area were subjected to classification through unsupervised methods. This classification yields three thematic maps that illustrate the Land Use and Land Cover (LULC) for Omdurman City in the years 1987, 2000, and 2013. The total areas occupied by each land use and land cover type, along with their respective percentages for each date, are detailed in Table (4).

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Historical Urban Development

The confluence of the Blue and White Nile Rivers delineates three distinct zones, each giving rise to the establishment of three separate centers: Khartoum Town, Omdurman (or Umm-Durman), and Khartoum North. The urban characteristics of these three settlements vary significantly, shaped by their unique historical influences on town formation. Khartoum Town. The urban plan established in 1910 for the city's development marked the inaugural instance of systematic town planning in Sudan. This design illustrates a rectangular grid intersected by diagonal thoroughfares, optimally configured for military engagement in the event of civil unrest (Figure 1). The 1910 plan of Khartoum Town remains partially discernible (Main Map) and is distinguished by a synthesis of an orthogonal layout featuring multiple axes that evoke the design of the British Union Jack(32). Omdurman. The modest town of Umm-Durman commenced its evolution as an Arab-Islamic city during the Mahdist era (1885–1898). The town exhibited characteristics typical of numerous Muslim towns in west and central Africa (33); however, in spite of various efforts to manage its growth, residential areas expanded indiscriminately (Figure 1) into the desert region to the west of the Nile River (34). Khartoum North. The Baedeker's 1914 Map (Figure 1) delineates the configuration of Khartoum North, comprising two distinct orthogonal layouts; each features a central square and military edifices positioned adjacent to the river(34). At the dawn of the twentieth century, Khartoum North gradually evolved into a hub of industrial activity. During the twentieth century, four urban plans were proposed; however, none were successfully implemented. This can be attributed to various socio-economic factors: a precarious economy, inefficient governmental structures, and environmental challenges. presented the notion of the Deplaning of Khartoum to signify the rampant urban sprawl phenomenon that commenced during the second military regime (1969–1985) and culminated under the regime that ascended to power in 1989. Beyond the principal urban centers, numerous small rural villages, predominantly constructed from single-family mud-brick edifices, were scattered along the banks of the Nile.

Urban and Agricultural Land Exploitation 1989–2019

The population increase in the Khartoum-Omdurman conurbation over the past 30 years has significantly influenced urban and infrastructural development. The Main Map illustrates the progression of urbanization from 1989 to 2019. At first, the growth of the urban area took place in a northern direction along the primary Nile River, as this serves as the principal commercial pathway extending from the south to the north of the nation. The arrangement of roads fostered a corresponding arrangement of development, in which primary roads draw in retail and commercial hubs (36). A second trend of urban development in Khartoum extended both east and west into the surrounding rural areas, enveloping untouched rural communities and frequently incorporating ancient villages. The conurbation developed its elongated form and expanded significantly in length primarily due to agricultural practices (Figure 2). Multiple elements contributed to the significant utilization of the rich sediments along the banks of the Nile River and throughout Tuti Island: (i) a rising food demand fueled by the population growth of the expanding urban area, (ii) restricted possibilities for agricultural production in the dry regions encircling Khartoum and Omdurman, and (iii) the shortage of water resources(35).

Urban Planning of Omdurman

Omdurman, the largest city in Sudan, has experienced substantial urban development since its inception as a small fishing village. The urban planning of the city has been influenced by historical events, demographic expansion, and evolving governmental strategies. In the late 19th century, Omdurman evolved from a small village into a fortified capital during the Mahdist era. This period witnessed the construction of significant structures such as the Mahdi's tomb and the establishment of narrow, winding streets typical of traditional Islamic urban design. The British conquest in 1898 signified a transformation in urban planning methodologies. Despite the relocation of the capital to Khartoum, Omdurman retained its cultural and economic importance. The British established broader streets and new administrative structures, incorporating aspects of colonial urban planning. Following independence in 1956, Omdurman underwent significant urbanization and population increase. The population of the city rose from 150,000 in 1890 to 3,099,711 in 2014, influenced by displacement, migration, and natural growth. The rapid expansion has presented considerable challenges to urban planning initiatives. The growth of Omdurman has

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predominantly transpired without an adequate urban planning framework, especially in recent decades.The lack of regulation in development has resulted in multiple urban challenges, such as insufficient infrastructure, informal settlements, and risks to cultural heritage sites. The city's layout illustrates its historical evolution, featuring older areas defined by traditional Islamic urban patterns and newer regions exhibiting modern, grid-like structures (35). Souq Omdurman, recognized as one of Africa's largest markets, illustrates the organic development of commercial zones in the city.Current urban planning issues in Omdurman encompass:Flood vulnerability: As a desert city, Omdurman faces risks from intense convectional storms, necessitating improved flood management strategies

- Infrastructure development: The rapid population growth has strained existing infrastructure, requiring significant investments in roads, water supply, and sanitation systems.
- Cultural preservation: Balancing modernization with the preservation of historical sites and traditional urban fabric remains a key challenge
- Sustainable growth: Implementing environmentally sustainable practices in urban development is crucial for the city's long-term viability.
- Integration with Greater Khartoum: As part of the Khartoum metropolitan area, Omdurman's urban planning must consider its relationship and connectivity with neighboring cities.

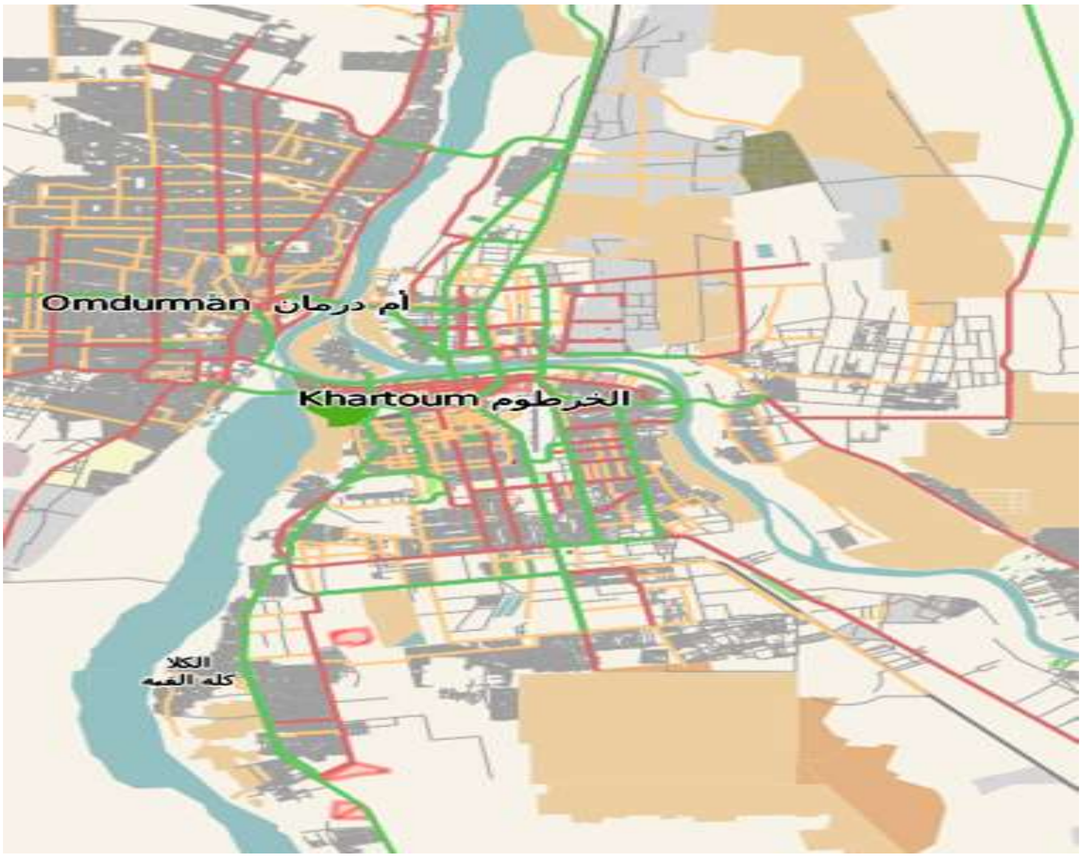

Figure 6. Omdurman City, Block No.10 The Area Which Surveyed

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Architecture Situation

Sudan's biggest city, Omdurman, has a rich history and urban development spanning centuries. Traditional Sudanese, Islamic, colonial, and modern architecture make up the city's distinctive urban fabric. Omdurman's architecture is founded on Sudanese households. These dwellings, called "bayt jalus," are rectangular or square with flat roofs made of dried clay, sun-dried mud, brick, or cow-dung plaster2. The Mahdist state capital, Omdurman, had this classic box-house architecture in the late 19th century2. Omdurman's architecture was shaped by the Mahdists (1885-1899). The Khalifa House Museum (originally Abdallahi ibn Muhammad's home), the restored tomb of Muhammad Ahmad (al-Mahdi), and Al Tabia2 fortifications are important structures from this period. These buildings demonstrate Omdurman's Islamic architectural style. The British colonial period gave Omdurman new architecture. While colonial development focused on Khartoum, Omdurman included broader avenues and administrative buildings to mix imperial urban design with traditional layouts1.Omdurman's post-independence architecture is a combination of traditional and contemporary. One of the earliest complex structures in the region with red brick façades, the 1952 Omdurman Municipality building used local materials and reinforced concrete3. In Omdurman's urban environment, religious architecture is important. Al-Nilin Mosque (Mosque of the Two Niles) is notable for its dome design and lack of pillars2. This mosque and others, along with religious leaders' tombs, are part of the city's Islamic architecture. Rapid urbanization and population increase shape Omdurman's modern architecture. Compact, multi-story concrete frame homes have appeared throughout the city, especially among higher-income residents1. This change replaces the dispersed room arrangement with a single constructed unit that houses all areas and activities. Modern Omdurman residences retain certain traditional architectural aspects. High boundary walls, which visually divide private and public spaces, remain ubiquitous. Houses' interiors generally reflect the societal demand for gender segregation1(36). Omdurman's architecture must balance modernity with cultural and historical preservation as it evolves. Initiatives to address infrastructure, sustainability, and the city's particular urban character within the Khartoum metropolitan region will likely determine its architectural future.

Local Housing Situation

Two land categories are employed for planned residential complexes. The minimal size is set by local planning legislation at According to official statistics (37), 1067 families built walls using mud (Table 3). Since first and second class regions ban mud building, the 65% result suggests that third and lower class areas use it often. In contrast, brick (28%) dominates the upper classes. Mod roofs are made of indigenous timbers, thick mud, and animal excrement for waterproofing.(38).(Baladi) and Zink (corrugated galvanized, Iran sheets) roofs make up 78% of Al- Althawra households, again indicating the predominance of third and lower classes where these materials are allowed, and the most important material used on top was (39, 40).

Table 3. Town Planning Regulation at Al-Azhari City Block No.10

Roof material	**Wall materials**							
	Gros s	Mud	Mud brick s	Brick	Stone	Others	Total	Approx age %
Mud/earth	206	19.701	899	4.751	20	205	77.462	57%
Baladi (wood)	20	9.549	200	9.045	90	241	24.476	20%
Zink streets	30	3.442	109	20.521	43	250	14.474	11%
Comment		-	5	3.012	93	432	4.541	4%
Others	650	1.241	12	1.149	10	6.517	9.464	8%

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House Type

Omdurman's housing displays its fast urban expansion and diversified architecture. Sudan's predicted population of 51,662,147 by 2025 includes the city's population rise from 150,000 in 1890 to 3,099,711 in 2014. This growth has created a mixed housing market with traditional "Bayt Jalus" box-houses in older communities, institutional dwellings in planned neighborhoods, and contemporary multi-story buildings for higher-income people. Sudan's real estate industry is estimated to reach US$923.70 billion by 2029, expanding 8.76% yearly from 2025-2029. Omdurman has at least 40 Airbnb vacation rentals, 10 of which are family-friendly and 20 of which have WiFi, combining traditional and contemporary conveniences. Omdurman, a prominent Sudanese city with 1,849,659 residents in 2008, contributed considerably to the metropolitan agglomeration's 2005 estimate of 4,518,000. Omdurman's housing landscape balances ancient architecture with current urban growth demands due to displacement, migration, and natural rise. Table 4.

Table 4. Dwelling Typologies

Living Type	No. of households	No. of population	%of total household
One Floor	413.26	2587	**90%**
Multifloors	9.43	95	**6%**
Villa Or Flat	5.59	610	**2%**
Qottia	7.98	84	**2 %**
Others	16.02	90	**3 %**
Total	**55317**	**3014250**	**100%**

The Family Component in the Urban Environment

Family structure includes size and makeup. Omdurman Althawra and Khartoum have 853,017 homes. Family size, location, Table 5 shows the pyramid of family size from one-person homes to four-person households. After then, it steadily lowers to seven-person houses and ultimately to eight-person families.(41) Less than half of larger Khartoum families are unaware about their family type. Sudanese houses enable married daughters and sons to reside with their parents after marriage to maintain family structures. Financial issues and the option to go school or job instead of living with family may also produce composite families (42). Education in bigger Khartoum Higher education is scarce in Omdurman Althawra, however the literacy rate is high (27.3%) of the population over school age. 3% income and education information Since there are no class divisions, most people are low-income workers, employees, or small company owners. On average, salaries are above SD 50,000.(43). Development is aided by 98% of the population being homeowners. Table 3 shows that the income proportion in Khartoum was equal to (44).

Table 5. Incomes Groups

Income	population	Percentage	Income	No. of population	Percentage	Income$
High	1650.000	5%	>10000	265.000	5%	**>10000**

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Middle	3300.000	10%	300-100	795.000	15%	**3000-1000**
Low	**2.805.000**	**85%**	**0-300**	**4.240.000**	**80%**	**0-300**

Infrastructure and Facilities

The residential areas of Omdurmman Althawra have water, drainage, sewage, and electricity. Energy will be an emphasis owing to BIPV(44).

Omdurman, Sudan's largest city, has an energy issue from January 2025. The city's energy infrastructure has suffered since the Rapid Support Forces (RSF) and Sudanese Armed Forces (SAF) began fighting in April 2023. Some areas have had power shortages for almost 10 days. Drone attacks on critical energy infrastructure have worsened the issue. On January 13, 2025, drone attacks on Merowe Dam, which supplies over 40% of Sudan's electricity, damaged the energy supply. Omdurman and other significant cities have suffered greatly from this strike's electrical shortage. Because of this, several firms Despite challenges, Omdurman's energy condition is being improved.(36). Sudan's 200 MWp solar PV plant near the city is part of its renewable energy expansion. This initiative diversifies energy and reduces reliance on risky centralized power facilities. The energy crisis has impacted other vital services. Lack of energy to operate pumping stations has interrupted water supplies, impacting sanitation and increases waterborne illness risk. Many hospitals depend on backup generators that are growing harder to fuel. About 60% of Sudan's population had electricity in late 2024, with large inequalities between urban and rural locations. This proportion may have dropped more in Omdurman due to previous battles and infrastructural damage (45). owing to the economic crisis induced by the war, industrial energy usage has decreased, but household consumption has increased as more people remain home owing to safety concerns. The circumstance highlights the necessity for short-term power restoration and long-term energy infrastructure development in Omdurman and Sudan. Omdurman relies on electricity for everyday living and urban services. Traditionally, many transformers serve blocks (10, 12, 19, 15, 4) of the city's electricity distribution by the National Electricity Corporation. As of January 2025, the Sudanese Armed Forces and Rapid Support Forces are fighting, changing the scenario. Some communities have had power outages for nearly 10 days (46). Recent drone attacks on the Merowe Dam power facility, which supplied 40% of Sudan's energy, have exacerbated these delays. Many households now use kerosene (75% in certain regions), gas (15%), and charcoal for cooking and lighting. The Omdurman energy infrastructure is insecure, with suspended network lines and transformers at decreased capacity. The fighting has made it harder to maintain a continuous electrical supply, requiring many inhabitants to use diesel generators and other energy sources. Energy in the city is mostly electricity. Electricity is cheap and powers all municipal services, so people depend on it. The lighting reveals its importance. The National electricity Corporation supplies electricity to the area. Transformers with the numbers (3, 2, 2, 2, 2, 1 from 2 to 3) provide electricity to all blocks (10, 12, 19, 15, 4). (47) It can produce 433.11 kW.Many network cables with a diameter of 70 mm2/km and an average length of 55.000 mm2/km are hung and transported. 2. In places without electricity, some people use 75% kerosene for cooking and lighting and 15% gas (49). Gas, 55% of the total, is utilized for non-lighting uses like cooking. However, 35% of all blocks utilize charcoal.50, figure 5.

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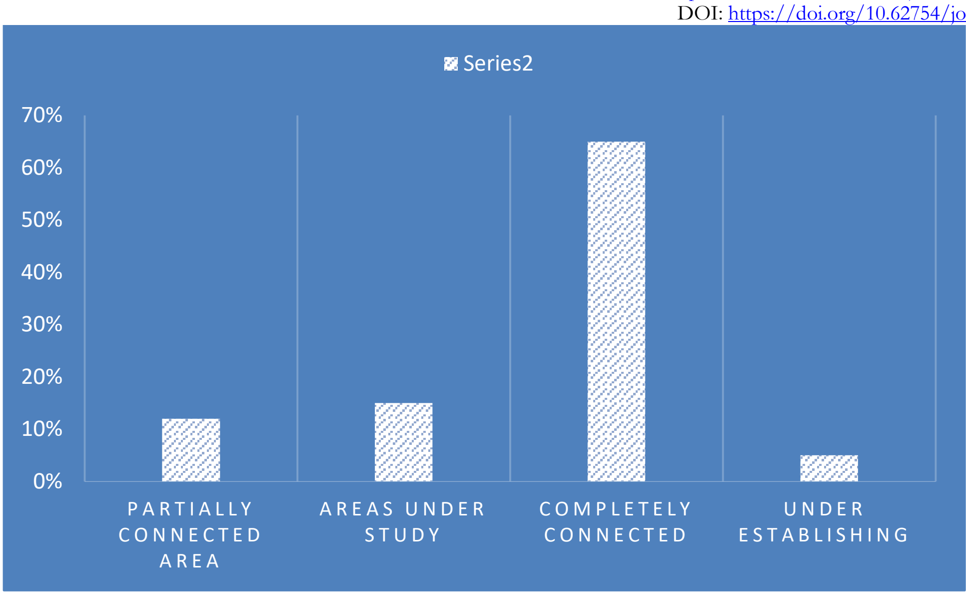

Figure 5. Electricity Networks in the City: Descriptions and Situation

The Economic Efficiency of Utilizing Electricity

The national electricity corporation policies state that blocks inhabited by up to 37% are entitled to receive electricity.

(39), The citizens are required to contribute 33% of the total cost to the national electricity corporation, which will supply electricity based on its established policies. Individuals will be responsible for covering their electricity costs based on their personal usage (51) studies.

Characteristics of Society

Finding the living areas that don't have electricity is one thing that should be thought about when stretching and giving energy to the different blocks. Putting these places into blocks and parts(39). Analysis of the population percentage and the financial capacity of individuals. Public committees must embody the citizens' demand for electricity. The electricity fees are elevated due to the political circumstances in Sudan following 2019, and they are reliant on the Ministry of Electricity for the years 2022-2023.

Effects of Technology

Over the next four years, the power network will be extended to all blocks that aren't already lit. In the city, only 13% of the blocks have electricity. Some electricity is provided in blocks 1, 2, 3, and 4, which is 13.8%of the whole. Old Omdurman (Hai Alameda and Omdurman Market) is linked to these blocks. Ten percent of the blocks with the numbers 9, 15, and 4 are already partly linked to the main power network. 7% of the blocks are made up of the numbers 11 and 16. Setting up and growing the network are still ongoing tasks. The old counters that use the delayed payment system are used to track how much is being used. The National Network does basic upkeep to fix problems that affect the whole network (46).

PV System Availability

In Sudan, households utilizing photovoltaic systems generally produce 0.25 KWh of electricity daily. The device generates approximately 30 kWh annually and has been utilized in multiple residences in Khartoum. Battery systems are utilized in most households, with an annual consumption ranging from 10 to 30 kWh as of 2006. Refer to Table 4 for the estimated power consumption of typical appliances in solar battery systems and households connected to the grid (53). The estimates are derived from standard levels of energy consumption, which are based on assumptions regarding the number of hours electricity was utilized in a

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single day (52). 52. The fundamental value that devices can leverage in a compact home BIPV system is dictated by the amount of daily energy consumption. Certain devices, including televisions, radios, cassette players, and mobile phones, as well as energy appliances associated with modest solar power systems, such as kitchen equipment, refrigerators, and irons, are unable to manage this level of electricity. This concise study demonstrates the varying energy consumption options available to families utilizing solar panels and battery systems compared to those relying on grid connections (46) Table 6.

Table 6. Electricity Consumption for Household Appliances Used in Rural Sudan

	Appliance	Power Use Wh per day	Daily Energy Use Wh per day	Used in Solar Systems
1	15-Watt Incandescent Light Bulb	5	60	Often
2	10-Watt Fluorescent Lamp	5	40	Often
3	32" Television	5	360	Some Time
4	Radio/Cassette Player	9	9	Often
5	Cellular Phone (charging)	3	6	Often
6	60-Watt Incandescent Light Bulb	3	220	Very Rare
7	Small Refrigerator	12	1200	Very Rare

*Systems for Distributing Power PV Systems Can Be Used in BIPV Homes***.**

Table 4 additionally illustrates the energy consumption associated with various types of BIPV tools. For instance, cell phones and radios consume minimal power. Conversely, televisions and lighting do. A significant distinction exists between standard light bulbs and fluorescent light bulbs. Fluorescent lights typically outperform light bulbs by a factor of three to four.One hundred A 10-watt fluorescent light bulb produces more illumination while consuming less electricity compared to a 15-watt light bulb (52). Despite this, low power consumption and low incandescent bulbs continue to be widely used in rural solar systems in Sudan since they were first introduced. The cost is roughly 25% of what is linked to fluorescent lamps (54). In 2015 and 2016, electronic data information monitoring was conducted in 40 households in Sudan, yielding comprehensive insights into energy distribution patterns for homes utilizing solar power. In larger systems exceeding 25 watts, there is an increased energy consumption for lighting, as illustrated in Figures 7 and 8. In smaller plants (<25 watts), television is more commonly observed (55) This suggests that installation can be achieved. Radios and cell phones utilize a modest amount of energy in both systems, yet the energy consumption of radios represents a more significant share in smaller systems. The findings highlight the considerable focus on connective tissue, especially concerning television. In the context of rural households in Sudan (56). In smaller systems where energy availability is constrained, a considerable amount of energy is dedicated to television usage. A modest but important share is designated for radio, which, when paired with television, represents about two-thirds of overall production. As the system size expands, the findings suggest that the quantity may show diminishing returns. The allocation of surplus energy to lighting addresses the demand for television and radio. (57) This theory is supported by data regarding the usage patterns of each device on an hourly basis. In structures with energy consumption below 25 W, televisions operate for an average of 2.1 hours daily, lighting is utilized for 1.5 hours, and

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devices are engaged for 4.8 hours. The larger systems within the group exhibit similar usage patterns for radio and TV, averaging 2.1 and 4.2 hours per day, respectively. However, they demonstrate a higher average usage of lights, at 7.6 hours per day (58). The findings significantly influence the societal relevance of harnessing solar energy for residential power supply. Radio and TV can be utilized for both small and large solar energy lighting applications, although they are predominantly associated with larger systems exceeding 25 watts. This study highlights the significant impact of purchasing power on the availability of sunlight access in Sudan's unsubsidized solar market. The low adoption of solar energy can primarily be attributed to the actions of the middle class in the country. Nonetheless, significant disparities in wages exist among middle-class families. Information: Figures 6 and 7 show that wealthy families may be more likely to use solar energy to light their houses if they can afford a bigger system in their slightly less expensive homes. The neighbors who lack the financial means for a modest solar installation.

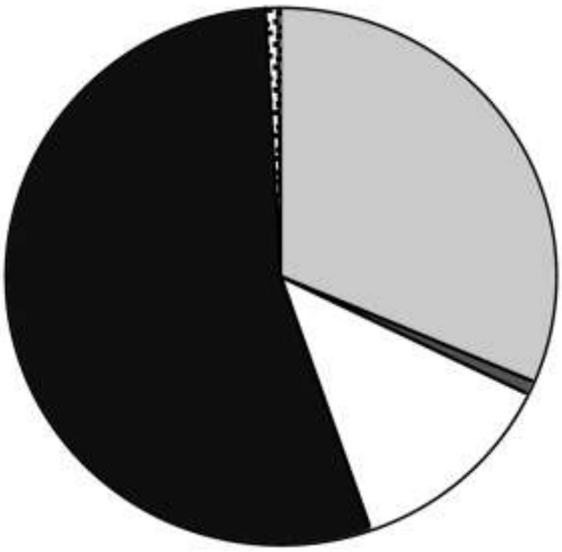

Figure 6. Mapping of Solar Systems More Than 25 Watts (See Figure 8 Below the Legend)

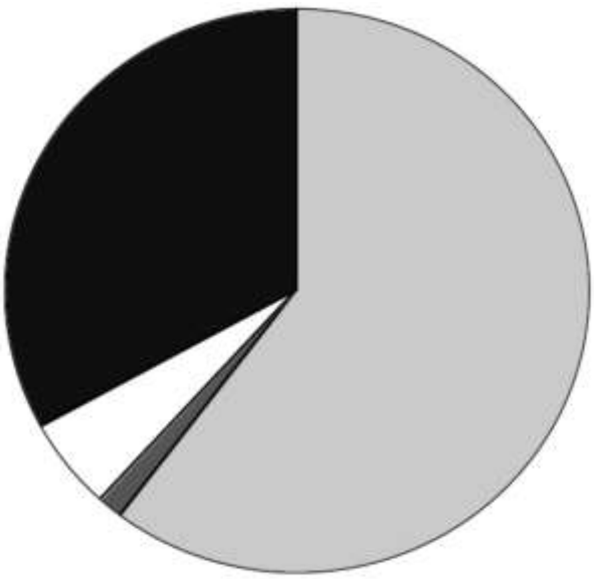

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Figure 7. Distribution of Solar Energy Use in Smaller Systems of 25 Watts107

Using local renewable energy technologies, like solar and wind systems, to provide power in places where grid infrastructure isn't present is an effective way to improve access to sustainable energy in rural Sudan. Along with building people's skills and teaching them about the benefits of green energy, it is very important to make policies that are helpful and encourage investment and public-private relationships. Adding energy options to water and food security programs can help people in rural areas make a better living generally. Promoting female equality in energy projects and working on climate protection will also make sure that clean energy solutions last and help everyone in the community. Implementing these plans will greatly improve energy access in rural Sudan, making life better for the people who live there.

Conclusions

The comprehensive study on PV system integration in Omdurman's Althwara reveals critical insights for sustainable urban energy development. By analyzing blocks 18 and 10, the research demonstrates that successful photovoltaic implementation requires a multifaceted approach encompassing urban planning, architectural design, technological innovation, and socio-economic considerations. Key findings indicate that optimal PV system integration depends on strategic factors including government policy support, architectural compatibility, environmental sustainability, and community acceptance. The study highlights that Omdurman's unique geographical and historical context necessitates a tailored approach to renewable energy deployment, with particular emphasis on designing systems that are aesthetically integrated, cost-effective, and aligned with local architectural characteristics. The research concludes that by addressing technological, social, legal, and economic challenges simultaneously, Omdurman can develop a robust framework for domestic PV system adoption, potentially serving as a model for other emerging economies seeking sustainable urban energy solutions. The proposed strategy not only addresses immediate energy needs but also positions the city to leverage renewable technologies for long-term environmental and economic resilience.

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