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THE INFLUENCE OF ROOFTOP SOLAR POWER PANELS OF RESIDENTIAL HOUSES IN KABUL CITY ON THE POWER GRID OF AFGHANISTAN

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Abstract
This paper explores the potential impact of residential rooftop solar photovoltaic (PV) installations in residential houses in Kabul on Afghanistan's power grid, amid significant energy challenges. Afghanistan's energy generation is constrained, heavily reliant on fossil fuels and imported electricity, with approximately 78% of its power sourced from neighboring countries. As rapid population growth and sectoral advancements intensify energy demands, existing sources fall short, leading to frequent blackouts and economic vulnerabilities. To address this deficit and promote energy sustainability, this study argues that decentralized rooftop solar PV systems offer a viable solution by generating power near consumption points, thus enhancing grid stability, reducing dependency on imports, and expanding access. Afghanistan's high solar irradiance and extensive rooftop space present an ideal environment for PV deployment, though economic, technical, and regulatory barriers must be addressed to achieve widespread adoption. Drawing from successful implementations in Pakistan, Nepal and India, provides policy recommendations tailored to Afghanistan's context, highlighting the importance of advancements in grid management—such as energy storage and smart technologies—to support intermittent solar energy. By overcoming these challenges, Afghanistan can harness rooftop solar to secure a sustainable, resilient energy future, reducing dependence on foreign energy and enhancing national energy security.

Keywords: Rooftop solar, power grid, energy decentralization, Afghanistan, renewable energy, grid resilience, sustainability, solar photovoltaic (PV).

Introduction

Afghanistan's electricity sector is marked by a complex set of challenges, deeply impacting the country's economic and social development. With approximately 78% of its electricity imported from neighboring countries—primarily Uzbekistan, Iran, and Tajikistan—Afghanistan is highly vulnerable to price fluctuations and geopolitical tensions that frequently disrupt supply chains and escalate costs (Asian Development Bank, 2022). The nation's domestic generation capacity remains insufficient to meet the demands of a growing population, resulting in frequent blackouts, particularly in urban centers like Kabul, and severe constraints on rural electrification. The disparity in energy access is stark, while nearly 89% of urban households have access to electricity, only about 10% of rural areas are electrified, exacerbating socio-economic divides and limiting development opportunities (World Bank, 2021).

In this context, rooftop solar photovoltaic (PV) systems offer a viable and sustainable alternative to traditional energy sources. These systems empower households by enabling them to generate their own electricity, reducing dependency on the centralized grid and lowering the demand for imported power. Afghanistan's high solar irradiance, ranging from 5.5 to 6.5 kWh/m²/day, makes rooftop solar particularly effective in supporting local electricity needs during peak sunlight hours (IRENA, 2021). By decentralizing energy production, rooftop solar installations alleviate grid strain, reduce

transmission losses, and decrease the likelihood of blackouts—benefits especially critical in a heavily burdened urban environment like Kabul.

The integration of rooftop solar into Kabul's residential sector could transform Afghanistan's energy landscape by offering enhanced grid stability, economic savings, and environmental benefits. Decentralized solar power generation minimizes long-distance transmission losses, improving system efficiency and making renewable energy more accessible. Additionally, as Afghanistan grapples with the financial strain of electricity imports, widespread adoption of rooftop solar has the potential to offset a significant portion of this dependency, thus reducing the national electricity bill and strengthening energy security.

However, while rooftop solar presents a promising solution, challenges remain. The intermittent nature of solar power requires advancements in grid management, such as energy storage, smart inverters, and net metering policies, to ensure reliability and seamless integration (National Renewable Energy Laboratory, 2021). Dealing with these technical and legal obstacles is important in order to unlock the complete potential of rooftop solar power and help Afghanistan reach a sustainable, self-sufficient energy future. This article investigates the possibility of using solar panels on rooftops in Kabul. It assesses how this could help to distribute power generation, maintain the stability of the grid, and encourage energy independence in a country that is working towards making its electricity sector more resilient.

1. Goals and methodology

This research seeks to assess the possible effect of rooftop solar PV systems on Kabul's energy situation, concentrating on how these systems can improve energy availability, decrease reliance on imported power, and support environmental sustainability.

By using a comparison analysis, it examines reports and case studies from organizations that are following this pathway. The approach includes recognizing the financial, practical, and legal obstacles that hinder the use of rooftop solar panels in Kabul, Afghanistan. This is a potential solution to tackle the urgent energy problems in the area.

It contributes to environmental protection and reduces the country's reliance on fossil fuels. Offering a stable and predictable source of energy, it also decreases dependence on hydropower. Moreover, by enabling decentralized generation, rooftop solar installations can be distributed widely, bringing electricity to remote areas where grid connections are difficult. Also, the growth of the rooftop solar sector can generate jobs, stimulate local economies, and attract foreign investment, promoting overall economic prosperity and resilience.

2. Current State of Energy in Afghanistan

Afghanistan's energy landscape is defined by a mix of hydropower, fossil fuels, and increasingly solar energy. As recent data indicate, less than 50% of the population has reliable access to electricity, with major cities seeing greater connectivity than rural areas, which remain largely underserved. Efforts to bridge this gap include the Central Asia-South Asia power project (CASA-1000), which is expected to enhance cross-border energy transmission and generate an additional 600 MW through hydroelectric plants. Afghanistan currently imports approximately 720 MW of electricity from neighboring countries, including Iran, Tajikistan, Turkmenistan, and Uzbekistan. This imported power costs Afghanistan $250-$280 million annually (CASA-1000 Project, 2022). With increasing demand projected to reach 7,000 MW soon, Afghanistan's National Development Strategy has prioritized alternative energy sources, particularly wind and solar, as crucial for sustainable growth. However, Afghanistan's power grid remains constrained by limited generation capacity, reliance on hydropower (which fluctuates with seasonal water levels), outdated infrastructure that results in high transmission losses, and ongoing security concerns that impact power plants and transmission lines (Ministry of Energy and Water, Afghanistan, 2020).

1. Economic and Technical Benefits of Rooftop Solar PV Systems

Decentralized energy solutions like rooftop solar PV systems are widely recognized for their potential to improve energy security and grid stability, particularly in energy-constrained countries. According to the International Renewable Energy Agency (IRENA, 2019), solar PV systems, especially at the residential level, contribute to emission reductions, enhance energy independence, and strengthen local grids by generating power closer to consumption points, thus reducing transmission and distribution losses. In regions with similar energy landscapes, such as Pakistan, Nepal and India, rooftop solar has been shown to lower peak demand, boost grid resilience, and promote energy independence (Asian Development Bank, 2022). Given that Afghanistan imports around 78% of its electricity, adopting rooftop solar could reduce dependency on imported power and the associated costs, as well as provide economic benefits through job creation in installation and maintenance (GIZ, 2016). Although initial installation costs remain high, economic models suggest that incentives such as subsidies, net metering, or tax rebates could improve the feasibility of rooftop solar adoption, especially given the declining global costs of PV technology (World Bank, 2022).

3. Potential Benefits of Rooftop Solar PV in Kabul

Afghanistan's high solar irradiance, estimated between 5.5 to 6.5 kWh/m²/day, makes rooftop solar PV an ideal energy solution, particularly for urban centers like Kabul. Kabul alone has approximately 18 million square meters of rooftop space suitable for PV installation, indicating a vast potential for solar generation at the local level (Afghanistan Renewable Energy Union, 2020).

4. Environmental Impact and Sustainability of Rooftop Solar PV

The environmental benefits of rooftop solar PV are significant in a country like Afghanistan, where reducing reliance on fossil fuels aligns with broader climate commitments under the Paris Agreement. The Renewable Energy Policy (RER2032) forecasts that Afghanistan could reach 1.5 GW of on-grid and off-grid solar capacity by 2032, with rooftop PV comprising a substantial share. This shift is projected to reduce residential sector emissions by up to 30%, which is especially relevant for urban areas like Kabul, where pollution levels are high (UNEP, 2021). Additionally, solar energy is a water-efficient power source, a critical advantage in Afghanistan's water-scarce environment. Comparative analyses suggest that rooftop solar can mitigate air pollution in urban areas by up to 20% and provide energy independence, reducing vulnerability to geopolitical tensions and fossil fuel price volatility (IRENA, 2021; Asian Development Bank, 2017).

5. Challenges to Implementation of Rooftop Solar PV

Despite its clear advantages, the large-scale adoption of rooftop solar PV in Kabul faces numerous challenges. High initial costs, limited financing options, and a shortage of policy for installation and maintenance remain significant barriers. Additionally, Afghanistan lacks a supportive regulatory framework that includes policies for net metering, grid interconnection, and financial incentives, all of which are essential for encouraging residential solar investment (Enabling PV Afghanistan Report, 2017). Technical challenges related to integrating distributed solar PV into the grid are also notable; Afghanistan's grid is not currently optimized to handle intermittent renewable sources, necessitating modern grid management tools such as battery storage and smart inverters to mitigate issues such as voltage fluctuations and reverse power flow (NREL, 2021).

6. Technical Influence of Rooftop Solar Power of residential houses on Afghanistan's Power Grid

The deployment of rooftop solar PV could substantially improve grid reliability by alleviating strain during peak hours, as evidenced in studies conducted in other high-solar-potential region like Kabul (Asian Development Bank, 2022). However, for effective integration, Afghanistan's grid

infrastructure requires upgrades, including microgrids and battery storage to address the intermittency of solar power. Lessons from India demonstrate that battery storage can effectively mitigate solar variability, ensuring stable power availability in rural regions (IRENA, 2022). Though costly, these grid improvements are essential for the long-term sustainability and reliability of solar PV integration.

7. Lessons from Global Comparisons

Countries with geographic and economic conditions similar to Afghanistan, such as India, Nepal and Pakistan, illustrate how supportive policies can drive successful adoption of rooftop solar PV. Measures such as net metering, feed-in tariffs, and subsidies have encouraged high residential solar uptake, leading to reduced urban energy demand and enhanced grid reliability (Asian Development Bank, 2022). These experiences underscore the importance of a supportive policy environment in overcoming financial and technical barriers, suggesting that with appropriate regulatory frameworks, Afghanistan could achieve significant progress in energy independence and sustainability. (https://www.scribd.com/document/620306244/Report-Enabling-Pv-Afg).

8. Conclusion

The integration of rooftop solar PV systems into Kabul's residential sector presents a promising pathway for Afghanistan to enhance energy resilience, reduce dependency on imported power, and contribute to environmental sustainability. With high solar irradiance and ample rooftop space, Afghanistan has an opportunity to address its energy challenges by decentralizing electricity generation, thus alleviating grid strain, minimizing transmission losses, and mitigating the economic burden of imported electricity. The experiences of neighboring countries, such as Pakistan, India, and Nepal, underscore the potential of rooftop solar to strengthen local grids, improve energy access, and reduce greenhouse gas emissions.

However, for rooftop solar PV to reach its full potential in Afghanistan, significant economic, technical, and regulatory challenges must be addressed. The high initial cost of solar installations, limited financing options, and the absence of supportive policies, such as net metering and subsidies, remain substantial barriers to widespread adoption. Additionally, the intermittency of solar energy requires advancements in grid management, including energy storage and smart technologies, to ensure stable and reliable power supply.

This study suggests that Afghanistan's path to sustainable energy independence is achievable but requires coordinated policy reforms, investment in grid infrastructure, and incentives to encourage residential solar adoption. By learning from successful regional examples, Afghanistan can create a framework that supports renewable energy growth, ultimately fostering a more resilient and self-sufficient electricity sector. Embracing rooftop solar in Kabul and beyond could lead to substantial economic, social, and environmental benefits, helping Afghanistan transition toward a sustainable energy future that aligns with global climate goals and improves the quality of life for its citizens.

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РЕЗЮМЕ
ВЛИЯНИЕ СОЛНЕЧНЫХ ЭНЕРГЕТИЧЕСКИХ ПАНЕЛЕЙ НА КРЫШАХ ЖИЛЫХ ДОМОВ В ГОРОДЕ КАБУЛЕ НА ЭЛЕКТРОСЕТЬ АФГАНИСТАНА

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В данной статье рассматривается потенциальное влияние солнечных фотоэлектрических (ФЭ) установок на крышах жилых домов в Кабуле на электросеть Афганистана на фоне существенных энергетических проблем. Генерация энергии в Афганистане ограничена, сильно зависит от ископаемого топлива и импортируемой электроэнергии, при этом около 78% ее электроэнергии поступает из соседних стран. Поскольку быстрый рост населения и секторальные достижения усиливают спрос на энергию, существующих источников становится недостаточно, что приводит к частым отключениям электроэнергии и экономической уязвимости. Для устранения этого дефицита и содействия энергетической устойчивости в этом исследовании утверждается, что децентрализованные солнечные фотоэлектрические системы на крышах предлагают жизнеспособное решение, генерируя электроэнергию вблизи точек потребления, тем самым повышая стабильность сети, снижая зависимость от импорта и расширяя доступ. Высокая солнечная радиация Афганистана и обширное пространство на крыше представляют собой идеальную среду для развертывания фотоэлектрических систем, хотя для достижения широкого внедрения необходимо устранить экономические, технические и нормативные барьеры. Опираясь на успешные внедрения в Пакистане, Непале и Индии, предоставляет рекомендации по политике, адаптированные к контексту Афганистана, подчеркивая важность достижений в управлении сетями, таких как хранение энергии и интеллектуальные технологии, для поддержки прерывистой солнечной энергии. Преодолевая эти проблемы, Афганистан может использовать солнечные батареи на крышах для обеспечения устойчивого, устойчивого энергетического будущего, снижая зависимость от иностранной энергии и повышая национальную энергетическую безопасность.
Ключевые слова: солнечные батареи на крышах, электросеть, децентрализация энергии, Афганистан, возобновляемые источники энергии, устойчивость сети, устойчивость, солнечные фотоэлементы (PV).

ТҮЙІНДЕМЕ
ЖАЛҒАСТЫРУ ҚАБУЛ ҚАЛАСЫНДАҒЫ ТҰРҒЫН ҮЙ ҮЙЛЕРІНІҢ ТАМЫРЛАРЫНДАҒЫ КҮН ЭНЕРГИЯСЫ ПАНАЛДАРЫНЫҢ АУҒАНСТАННЫҢ ЭЛЕКТР ЖЕЛІГІНЕ ӘСЕРІ

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Бұл мақала маңызды энергетикалық қиындықтар аясында Кабулдағы тұрғын үй төбесіндегі күн фотоэлектрлі қондырғыларының Ауғанстанның электр желісіне ықтимал әсерін қарастырады. Ауғанстанның энергия өндіруі шектеулі, ол қазба отындары мен импорттық электр энергиясына қатты тәуелді, оның электр қуатының шамамен 78% көрші елдерден келеді. Халықтың жылдам өсуі және салалық прогресс энергияға сұранысты арттыратындықтан, қолданыстағы көздер жеткіліксіз болып, электр қуатының жиі үзілуіне және экономикалық осалдыққа әкеледі. Осы тапшылықты жою және энергияның тұрақтылығын арттыру үшін бұл зерттеу орталықтандырылмаған шатырдың күн сәулесінің PV жүйелері тұтыну нүктелеріне жақын электр энергиясын өндіру арқылы өміршең шешім ұсынады, осылайша желі тұрақтылығын арттырады, импортқа тәуелділікті азайтады және қолжетімділікті кеңейтеді. Ауғанстанның жоғары күн радиациясы және шатырдың кең кеңістігі фотоэлектрлік жүйелерді орналастыру үшін тамаша ортаны қамтамасыз етеді, дегенмен кеңінен қолданысқа жету үшін экономикалық, техникалық және нормативтік кедергілерді шешу қажет. Пәкістандағы, Непалдағы және Үндістандағы сәтті енгізулерге негізделе отырып, ауған контекстіне бейімделген саясат бойынша ұсыныстар береді, үзіліссіз күн энергиясын қолдау үшін энергияны сақтау және смарт технологиялар сияқты желіні басқарудағы жетістіктердің маңыздылығын көрсетеді. Осы қиындықтарды жеңе отырып, Ауғанстан тұрақты, тұрақты энергетикалық болашаққа қол жеткізу, сыртқы энергияға тәуелділікті азайту және ұлттық энергетикалық қауіпсіздікті арттыру үшін шатырдағы күн батареяларын пайдалана алады.

Түйінді сөздер: Күннің шатыры, Электр желісі, Энергияны орталықсыздандыру, Ауғанстан, Жаңартылатын энергия, Тордың тұрақтылығы, Тұрақтылық, Күн фотоэлектрлері (PV).