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Energy Production Potential of Afghanistan: Balancing Renewable and Non-Renewable Energy for National Electrification and Energy Independence

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ABSTRACT

The world is transitioning towards renewable energy sources to decarbonize the energy supply and meet the growing global energy demand. In 2023, the global investment in renewable energy reached $1.8 trillion. The progress towards renewable energy in Afghanistan is unclear, and its potential is not clearly identified when compared to non-renewable energy sources. Additionally, the country relies heavily on imported electricity, leading to numerous negative trade-offs in its energy policies and infrastructure. Therefore, this review aims to analyze Afghanistan's energy sector, encompassing demand, access, production, and development, as well as its renewable energy resources, performance, and sustainable impact on the nation. Findings show that Afghanistan has also made progress in small-scale solar projects, as the share of solar energy reached 9.64% in 2022. However, the per capita access to electricity is only 100 kWh, the lowest in the world, and only 20 percent of electricity comes from domestic resources, which are dominated by hydropower. Afghanistan's renewable energy resource potential, including solar, hydro, wind, geothermal, and biomass power, exceeds 300,000 MW. This potential not only meets domestic electricity demand but also could be exported to neighboring countries. Among all these resources, solar energy is the most efficient and cost-effective. Afghanistan is accelerating its renewable energy transition, and the country's authorities must put a strong focus on solar energy, hydropower, and natural gas power sources for a sustainable future and energy security, rather than coal-fired power sources. The information gathered will help policymakers focus on domestic renewable energy to enhance Afghanistan's energy independence, reduce its dependence on imports, and decrease carbon emissions.

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INTRODUCTION

In late 2023, at COP28, 125 countries worldwide committed to tripling their renewable energy capacity by 2030 (Coleman, 2024). Since over 80% of all global emissions are related to energy (Chilvers et al., 2024). Most nations quickly switch from using non-renewable energy sources to renewable ones in their energy systems. Global investment in the power grid has

reached historic levels (White & Ding, 2024). In 2023, renewable energy sources accounted for 30% of global electricity production, primarily due to ten years of steady and remarkable development in solar and wind power (Motyka et al., 2024) (Fig. 1). The share of solar within the global energy mix reached 5.5% (Lempriere, 2024). Together, wind and solar accounted for 13% of global electricity supplies in 2023, up from 3% a decade earlier (Evans & Viisainen 2024). The pursuit of renewable energy aims to both decarbonize the energy supply and meet the world's growing energy demand (Li et al., 2020). Together, solar and wind power have prevented more than four gigatons of CO_2 emissions between 2015 and 2023 (Lempriere, 2024). Renewable energy technologies possess the capacity to revolutionize energy systems, encompassing solar, wind, biomass, and hydropower (Zaheb et al., 2024).

According to UN estimates, by 2030, LDCs will need to achieve a 350% annual growth in power generation to catch up with developed countries in terms of electricity access (FP Analytics, 2023). Afghanistan, as an LDC, possesses enormous renewable energy resources, but its per capita electricity consumption is one of the lowest in the world (Rostami et al., 2024). Renewable energy is considered the best way to provide electricity for the majority of Afghanistan's residents and promote economic development (Hamad et al., 2024) (Rostami et al., 2024). Afghanistan has a wealth of possibilities for renewable energy sources, including solar, wind, geothermal, and hydropower. In addition to meeting its own energy needs, Afghanistan has the capacity to export excess energy to other countries in South Asia (Khan, 2024).

Afghanistan, rather than being an exporting country, relies on energy transition from neighbouring countries. Afghanistan is heavily dependent on imported electricity, with imported energy accounting for approximately 80% of the nation's consumption (Danish et al., 2017; Akhundzadah, 2024). Importing electricity from neighbouring countries has many drawbacks for the country's energy supply and development. Afghanistan's domestic energy development will not occur; importing electricity is not sustainable or reliable because it could be cut off at any time, and it is reliant on seasonal fluctuations. In the winter season, when electricity demand is higher, this affects heating and industry. In addition, the impact of climate change may make the electricity supply more totter and defective. The price of electricity and affordability are other challenges that the Afghan people face.

Keeping the above points in mind, we undertake this review to examine the current state of Afghanistan's energy sector, including demand, access, production, and development. It also examines Afghanistan's renewable energy resources, their performance, and prioritization.

The main objectives of this review are:

- To assess Afghanistan's current energy sector status, demand, and development, as well as its renewable energy potential and the feasibility of non-renewable electricity production.

- To evaluate the role of renewable energy in sustainable development and rural electrification, and to assess the potential impacts of electricity imports from neighbouring countries.

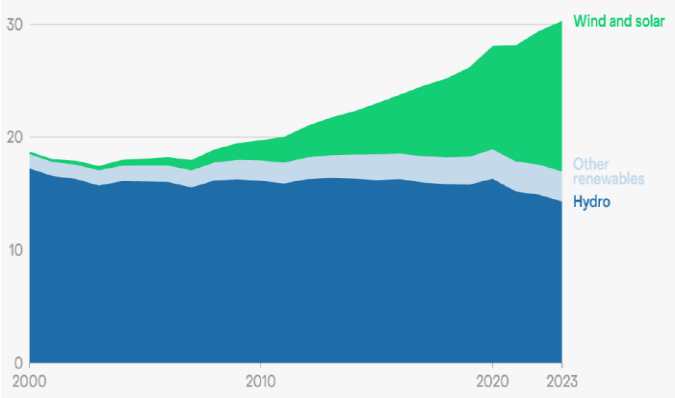

Figure 1. Renewables reached 30% of global electricity. https://ember-energy.org/latest-insights/global-electricity-review-2024/.

MATERIALS AND METHOD

This review searched online peer-reviewed journal articles, books, chapters, and technical reports from national institutions, government authorities, international foundations, non-governmental organizations (NGOs), magazines, newspapers, and media related to the topic. The search utilized Google, Elsevier ScienceDirect, Google Scholar, Science Online, Web of Science, and the Afghan government's printed and electronic resources.

The relevant existing literature and publications were selected based on the study's objectives, published up to 2024. To ensure the relevance and quality of the existing literature, precise inclusion and exclusion criteria were employed. Recent publications that directly addressed the topics covered in the review were included, while non-English publications and those that did not directly address the topics were excluded. Studies focused on various research topics, including Afghanistan's energy resources, renewable energy, electricity, hydropower, wind, solar energy, sustainable development goals, coal, natural gas, and climate change. The literature search was done from December 15, 2023, to October 30, 2024. At the first stage, 418 documents were retrieved, of which 104 were selected for inclusion based on their relevance to the research topic, and 314 were excluded as irrelevant or outside the aims and scope of this review.

This review presented evidence and information using figures and maps collected from recognized sources for most of the components studied, and finally, a conclusion was drawn. The transparent methodology and honest incorporation of research papers, as well as the selection of literature from other reputable publications, support the scientific validity of our findings on the most critical issue and key to sustainable development in Afghanistan.

FINDINGS

The following sections provide a detailed explanation of Afghanistan's current status, potential, electrification, domestic electricity generation and imports, Afghanistan's dependency on neighboring countries' electricity, renewable energy production, and sustainable development. The discussion and conclusion sections follow.

Afghanistan's Energy Status

Afghanistan's per capita electricity consumption is among the lowest in the world, at only 100 kWh per person per year (World Bank, 2021). However, about 97% of households have access to electricity in some form; access to a reliable power grid is very low (Akhundzadah, 2024). Afghanistan has made significant progress in terms of access to electricity over the last two decades. In 2001, less than 5% of the country's population had access to electricity; by 2021, this had increased to 38% (Najafizada 2021). International aid agencies and other organizations provide technical and financial support for improved electricity infrastructure (Fahimi and Stepputat, 2023), resulting in a 139% increase in Afghanistan's electricity supply between 2001 and 2009 (Rostami et al., 2024).

Accessibility is unevenly distributed, with a more notable disparity in urban areas (Ludin et al., 2024; Fahimi and Stepputat, 2023). The domestic power transmission network is limited nationally, with only a small portion (Aminjonov, 2017). The urban-rural disparity in electricity access is significant, with 70-75% of urban areas having access, compared to only 15% in rural areas. People in rural areas often depend on diesel generators and solar panels as sources of electricity (Ludin et al., 2024). Rural households use kerosene, candles, and gas for lighting (Fahimi & Stepputat, 2023). Research findings indicate that many rural residents are unable to access grid connection and self-generation due to high costs, as many Afghan firms prefer small-scale hydropower generation (Burns, 2011).

Electricity demand is projected to increase in all sectors, ranging from lighting, heating, industry, buildings, and transport. The cheap electrical energy is also vital for industries, the exploitation of mineral resources, and integration into international markets (Safi, 2024). In recent years, electricity demand has increased significantly; the gross annual consumption in 2000 was 570 GWh, which increased to 4,960 GWh by 2015 and 6,710 GWh by 2022, respectively (Fig. 2).

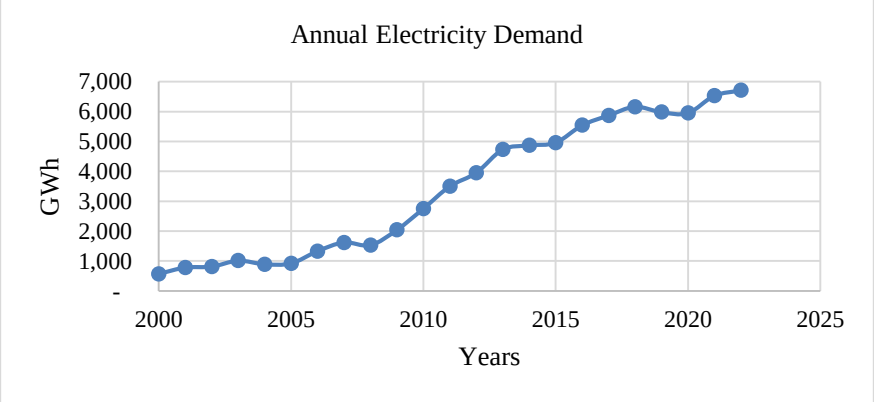

Figure 2. *Annual electricity demand in Afghanistan (2000-2022) (EMBER, 2024)*

The energy demand grew at an impressive rate of 8.7% per year over the past twenty years. Continuous growth in demand for electricity means that Afghanistan will be five times more electric than the current rate (Ershad, 2017).

Afghanistan's annual electricity demand is 1,600 MW in 2022, with only 300 MW from domestic sources (Aminjonov, 2017). Imports from Uzbekistan and Tajikistan account for 78% of consumption, despite the potential for renewable energy (Putz, 2022); however, the country has significant potential for renewable energy resources (Danish et al., 2017). The Afghan government plans to build new infrastructure. It seeks donor funds for hydropower projects, with a total capacity of 7,473.5 MW by 2023, including the Afghan-India Friendship Dam, which was constructed in 2016 (Aminjonov, 2017; Ershad, 2017). According to Afghanistan's Republican Government Power Master Plan (2012–2032), total power consumption is expected to increase from 3,500 MW to 4,300 MW by 2032, based on the country's economic development status. The president's office had a target even higher than this, aiming for 5,000–6,000 MW by 2032 (Aminjonov, 2017).

Domestic Electricity Generation

Afghanistan's domestic power production is hydro-dominated. Hydroelectricity is expected to comprise 74.7 percent of Afghanistan's electricity in 2022 (Fig. 3). However, Afghanistan's water and hydropower resources are closely tied to transboundary issues. Hydropower generation accounts for only 1.17% of the total generation capacity, far less than the available potential (Rahimzoda, 2024).

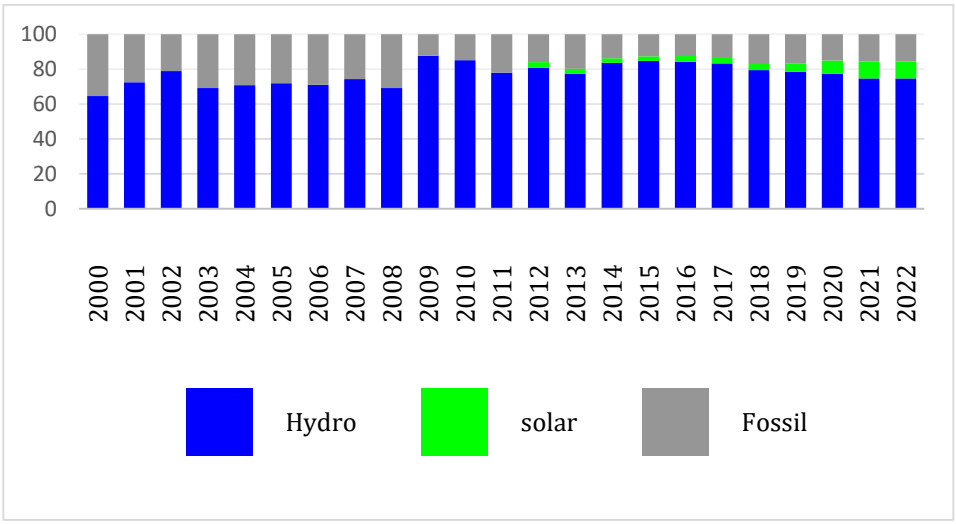

Figure 3. *Afghanistan's shares of the electricity sources (2002-2022) (EMBER, 2024)*

Hydroelectricity generation over the last 22 years has shown an increasing trend due to new installations. Solar generation has been rising especially fast in recent years. In 2012, solar energy contributed 0.3% of the electricity and reached 9.64% by 2022. The share of solar energy (9.64%), despite its high potential, is below the global average of 13%. The electricity shortfall was met by fossil fuel power. The share of fossil fuels in Afghanistan's electricity is declining. Fossil fuels accounted for 35% of Afghanistan's electricity generation in 2000 and 30% in 2008, then dropped to nearly 15% in 2022. Solar has shown the fastest

growth rates among renewable electricity sources in Afghanistan. Solar supplied 9.64 percent of the country's electricity in 2022, up from less than one percent in 2011.

Electrification in Afghanistan

Afghanistan has the lowest rate of electrification, at 43 percent (UNIDO, ICSHP, 2016). Fragile and conflict-affected countries, including Afghanistan, experienced annual increases in access rates of 0.8 percentage points from 2010 to 2019 (International Energy Agency, 2021). The Afghan government must prioritize renewable energy investments to avoid falling behind its regional and global peers, and capitalize on the current security environment to drive infrastructure investment. (FP Analytics 2023). Encouraging private investment is essential for domestic electricity production and development, according to DABS's five-year plan. According to TOLOnews (2024), 1,000 megawatts of additional power will be added to the current generation. Over the past two years, the Ministry of Industry and Commerce (MOIC) and private institutions have signed 63 agreements worth $54.5 million across 25 provinces, which are expected to employ 641,000 people (Khan, 2024). Private investment in abundant renewable resources can drive economic development and facilitate an energy transition. The private sector is growing, providing a favorable opportunity for development in the energy sector. The Afghan government plan establishes Hisar-e-Shahi Industrial Solar Park, a solar power plant in the eastern Nangarhar province (Khan, 2024). A private company has invested $6.5 million in the Surobi district to generate 10 megawatts of solar power. Another project, a 10-megawatt solar electricity-producing plant, is in the planning phase in the Tarakhel area of Kabul City (Qooyash, 2024). A private company in Herat Province produces 300 solar panels, each with a daily electricity-generating capacity of 650 watts (Ariana News, 2024).

Additionally, a Chinese company has expressed interest in constructing three large dams on the Kunar River, with a projected electricity generation capacity of over 2,000 megawatts. The Afghan interim government's rapid construction of the Pashdan Dam on the Harirud River, with a capacity to produce 2 megawatts of electricity, is expected to be completed by the end of 2024 (Khan, 2024). Limited financial resources are a significant constraint on the development of renewable energy infrastructure, as major renewable energy projects are costly (Danish et al., 2017).

Afghanistan's Renewable and Non-renewable Potentials

Afghanistan's renewable energy resources, including solar, hydro, and wind power, offer promising opportunities for employment, economic activity, and poverty reduction, which is discussed below:

Solar Energy Potential

Solar energy is a free, sustainable, and inexhaustible source of energy, whereas fossil fuels are finite and significant contributors to emissions (Chilvers et al., 2024). Over the past decade, solar manufacturing has undergone significant expansion, making it a cost-effective and affordable option for supplementing electricity in certain countries (Hamad et al., 2024).

With current investments, solar manufacturing capacity is expected to rise from approximately 640 GW in 2022 to over 1,200 GW globally by 2050 (International Energy Agency, 2023). Solar power development is crucial for combating global warming by reducing carbon emissions (Irfan, 2023), with a 23% growth in 2023, offering a glimpse of a future clean electricity system (Motyka et al., 2020).

Solar can play a bigger role in the global clean energy transition. Afghanistan, with 300 sunny days each year, has great potential for solar power (220,000 MW); the annual average solar insolation is 6.5 kWh/m2/day; however, in the summer it reaches 9.0 kWh/m2/day (Mainali and Silveira, 2017; Ludin et al., 2024). Solar energy accounts for over two-thirds of the country's total renewable energy potential, at 300,000 megawatts (MW) (Slimankhil et al., 2020). Afghanistan is a sunbelt country; its solar energy potential is equivalent to that of four sunbelt states in the United States (Khan, 2024). So, solar energy is considered the heart of the energy transition in Afghanistan.

Recently, Hamad studied global horizontal irradiance (GHI) and site suitability for photovoltaic (PV) power plant installations. Afghanistan's GHI for the years 2007–2021 ranges from 1910–2351 kWh/m2/year; the entire country's GHI is greater than 1900 kWh/m2/year. These levels are classified as 'very good' and'excellent' radiation levels for photovoltaic (PV) systems (Hamad et al., 2024). Most areas in the central region at higher altitudes were recognized as promising locations for solar energy projects. Only 3.5% of the area is identified as highly suitable for PV power plant installation (Fig. 4) (Hamad et al., 2024).

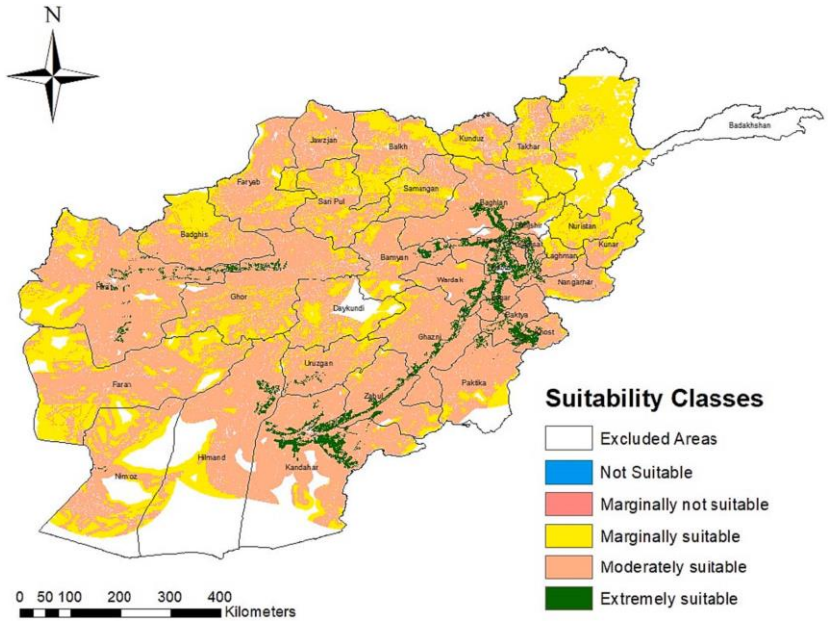

Figure 4. *Suitable sites for photovoltaic power plant installation in Afghanistan (Hamad et al., 2024)*

From the identified extremely suitable 41.256 GW of solar energy, a 6.5 kWh/m²/day density will be considered, with 12 hours of sunlight per day and 300 sunny days. This amount of energy is 11.7 times greater than the country's total demand in 2032. Despite the country's substantial solar energy potential, industrial-scale solar power plants are limited. Small-scale

rooftop panels and home solar systems are being developed in the country, providing power to various devices and benefiting schools, hospitals, health centers, and local communities. The UNDP has launched solarization initiatives in some parts of the country (UNDP, 2024).Solar power generation is expanding faster than other sources in Afghanistan. The share of solar electricity in Afghanistan reached 9.64% by 2022, up from 0.1% in 2012. According to the International Renewable Energy Agency (IRENA), Afghanistan's solar energy production increased from 30 GWh in 2012 to 80 GWh in 2022 (Fig. 5). Large-scale solar energy is crucial for addressing Afghanistan's energy challenges, reducing dependency and saving millions of dollars in electricity bill payments.

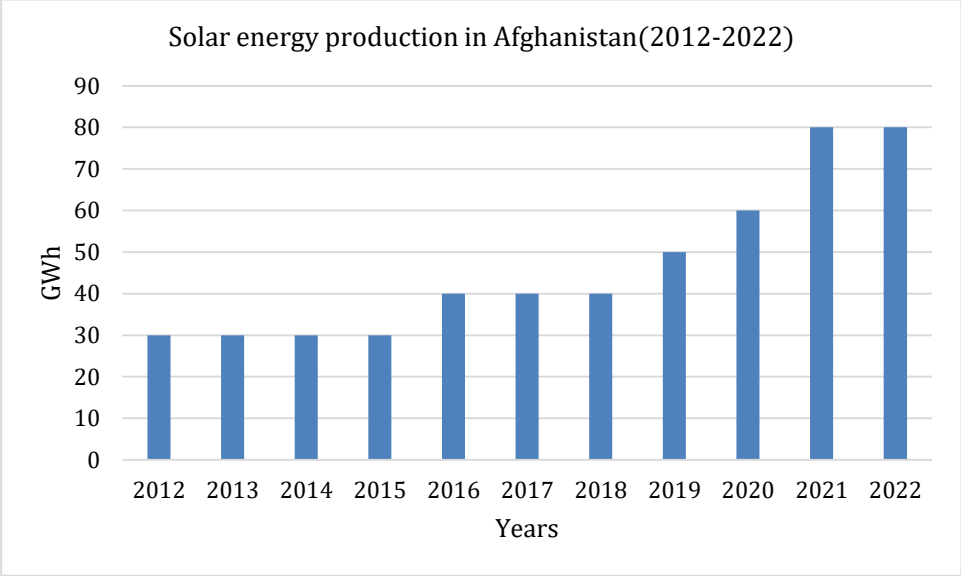

Figure 5. *Solar energy production in Afghanistan (2012-2022) (EMBER, 2024)*

Hydropower Potential

Hydropower production has been increasing globally by 2.1% annually since 2015, accounting for 16% of global electricity and 60% of global renewable energy (International Hydropower Association, 2020). Afghanistan has significant potential for hydropower, which is a crucial renewable energy source (UNIDO, ICSHP, 2016). Its total hydropower potential is estimated at 23,000 MW (Ershad, 2017; Mujeeb et al.,2024). Hydropower is the primary source of electricity generation in Afghanistan, accounting for 74.7% of the country's electricity production in 2022. Hydroelectric dams have come under focus due to their low environmental impact (Danish et al., 2017).

The previous government's primary strategic goal was the development of hydropower projects for energy self-sufficiency; however, the full potential of hydroelectric energy has not been fully utilized (Aminjonov, 2017). The total hydropower production reached 300 MW from 13 medium and small dams. Hydropower accounts for 31 percent of Afghanistan's total installed hydropower capacity (UNIDO, ICSHP, 2016). The Salma and Kamal Khan dams were constructed during the Islamic Republic government, each with an electricity production potential of 42 MW and 9 MW (Safi 2023). The Kamal Khan dam was built on the lower

Helmand River in Chahar Burjak District, Nimruz Province, where river flows are low and affect the level of electricity production. Compared to the hydropower potential, the planned construction of the Salma and Kamal Khan projects is insufficient. There are 13 hydropower projects constructed prior to the war that need renovations and reconstruction. The conflict and civil war destroyed built infrastructure and terminated the development of hydropower projects (Danish et al., 2017). Hydropower construction is significant to the country for economic development, improving livelihoods, industrialization, and poverty reduction (Nagheeby and Warner, 2018; Danish et al., 2017). In 2015, Chinese experts surveyed the Kunar River and reported an estimated installed capacity of 1,500 MW (Kabul Times, 2016).

The Amu Darya and Kabul River basins account for 94.7% of Afghanistan's total hydropower capacity (Slimankhil et al., 2020). The Amu Darya and Kabul River basins can provide 20,137 MW and 1,941 MW of hydropower energy, respectively, totaling 22,078 MW. The Kabul River is shared with Pakistan, and the Amu Darya Basin is shared with the Central Asian countries of Uzbekistan, Turkmenistan, and Tajikistan. The Afghan government does not have any water-sharing treaties with neighboring countries in these river basins.

Small hydropower can contribute to rural electrification in Afghanistan, particularly in remote regions. Small-scale hydropower plants are an efficient way to harness the energy potential of smaller watercourses and river systems. Small hydropower projects with lower initial expenditure would improve living conditions, rural economics, and alleviate poverty (Gassner et al., 2017). GIZ's assistance in 2011 led to the construction of six small hydropower plants in Afghanistan, which provided electricity to approximately 63,000 people in Badakhshan as of 2007. Other initiatives have helped Afghan villages, particularly those in isolated regions, by supplying local electricity. The development of 89 hydroelectric power plants in Bamiyan Province, which together produce 196 kW of electricity, was made possible by funding from the UNDP. In addition to the installation of power panels, 2,163 houses housing over 15,000 individuals are now receiving energy (UNDP, 2014).

The Afghan government struggles to secure financial resources from international donors due to a lack of water-sharing agreements with neighboring countries. Chinese company expresses interest in Kunar River dams. Recently, a Chinese company has expressed interest in investing in three large dams on the Kunar River with a capacity of over 2,000 MW of electricity (Khan, 2024).

Wind Energy Potential

Historically, wind power has been utilized by humans for nearly 3,000 years; however, it was not harnessed as mechanical power until the early twenty-first century (Arshad, 2017). Wind power, the second-largest global electricity generation technology, contributed 7.8% in 2023. Developed economies, such as Germany, Spain, the US, and Denmark, have the highest installed capacity (International Energy Agency, 2023).

Afghanistan has excellent wind potential (66,726 MW wind power), mainly in the south and southeastern provinces like Herat, Farah, and Nimroz provinces. The regions experience

approximately 120 windy days with speeds exceeding 8.5 m/s. The region devoted approximately 90% of the wind capacity (NREL, 2016). Unfortunately, wind power utilization looks impractical for Afghanistan due to high equipment prices and other constraints. The high equipment costs in the wind industry led to a reduction in the installation of wind turbines worldwide after 2020.

In contrast, the cost of solar energy has decreased significantly over time. The cost increases led to the cancellation of more than half the planned projects in the US (Plumer and Popovich, 2024). Afghanistan, as the least developed and aid-dependent country, lacks skilled and professional personnel, making it difficult for the country to manage and maintain sophisticated technology. In addition, wind does not always blow when it is needed.

Geothermal Energy

The energy stored as heat deep within the earth is known as geothermal energy (Barbier, 2002). Afghanistan, situated between three tectonic plates, is home to hot springs, volcanoes, and magma rocks with high thermal potential, which can be harnessed for heating homes and electricity generation (Slimankhil et al., 2020). The primary evaluation indicates that the geothermal energy potential ranges from 3,000 to 3,500 MW in 70 locations with available energy (Afghanistan National Renewable Energy Policy, 2012). In the future, it will be possible to exploit this heat resource in the country. Historically, geothermal energy in Afghanistan has been utilized primarily for medical bathing purposes. Geothermal energy is more efficient than solar and wind energy. The main drawback is the limited area available for establishing geothermal wells for exploitation (Gayen et al., 2020).

Rare Mineral Resources

In the 21st century, governments are promoting decarbonization and renewable energy systems to combat climate change (Chilvers et al., 2024). This includes expanding renewable energy sources and promoting the use of electric vehicles and heat pumps. Key raw materials, such as lithium and rare earth elements, are crucial for this transition (Marlow and Curran, 2021). Afghanistan's rich mining region holds significant potential for economic development and growth, as it has untapped energy and mineral resources, according to the Ministry of Mines and Industry (Rostami et al., 2024). Afghanistan is estimated to have more than $1 trillion in deposits (Chilvers et al., 2024). They include vast reserves of lithium and rare earth elements, which are critical to the global green energy transition. Some reports have suggested that Afghanistan's lithium reserves are the world's largest lithium deposit, equivalent to those of Bolivia (Edward and Qazizai, 2021). The exploitation of resources could facilitate the global green-energy transition; however, weak infrastructure and poor security in a landlocked country hinder these efforts (Danish et al., 2017).

Natural Gas

The share of global electricity generation from gas increased to 23% in 2023 from 18% in 2000. The Middle East and the United States have focused on increasing the share of gas for electricity production .Motyka et al., 2020). Natural gas is the leading source of electricity in

the US due to its lower carbon dioxide emissions and potential to mitigate global warming (Popovich, 2024). Afghanistan should utilize its natural gas field in the Sheberghan region for electricity generation (Cormier and Singh 2023). Afghanistan has 75 billion cubic meters of natural gas, with undiscovered reserves estimated to exceed 440 billion cubic meters (Asian Development Bank, 2012). During the 1980s, Afghanistan exported natural gas to the Soviet Union worth approximately $300 million per year. Afghanistan's natural gas can be exploited and used for electricity production. The country must build natural gas powerhouses of electricity rather than coal-fired power stations. The construction of natural gas powerhouses would have multiple advantages for Afghanistan. Electricity generated from natural gas produces fewer carbon dioxide and other harmful pollutants than electricity generated from coal. Strategically, the country would have long-term access to natural gas, as neighboring countries supply gas to Afghanistan (Aminjonov, 2017). The technical delegations of Afghanistan's power distributor, Da Afghanistan Breshna Sherkat (DABS), are discussing electricity production from coal with Chinese investors in 2022 (TOLOnews, 2022). The government should prioritize electricity generation using natural gas rather than coal.

Coal Resources

The global share of electricity generation from coal has decreased from 68 percent to 61 percent between 2012 and 2022 (Nordhaus, 2024; Champenois et al., 2021). In 2023, coal and gas accounted for 61% of global electricity production, with coal contributing 10,434 TWh (35%) of the total. The share of coal decreased by 0.3% between 2022 and 2023. Afghanistan's Ministry of Mines and Industry reports 440 million tons of coal reserves, with approximately 11 high-quality coal mines in the country (Rostami et al., 2024). Coal generation in Afghanistan has increased recently (Fig. 6). The country's per capita consumption stands at 52.9 cubic feet per year, ranking 61st globally. Coal is used for small industries, including textile manufacturing and household heating (Sabory et al., 2021).

Afghanistan still does not generate electricity from its coal reserves, and there is no coal-fired power plant. Recently, the interim government of Afghanistan announced that Chinese investors will construct a coal-fired power plant capable of producing 500 megawatts of electricity (TOLOnews, 2022). Many countries have halted the construction of coal-fired power plants following the COP26 climate summit in Glasgow, Scotland (Kohsar, 2021). International efforts are underway to increase the share of renewable energy resources, reduce the use of non-renewable solid fuels, and phase out coal-fired power projects (Ershad, 2017). Afghanistan is committed to reducing emissions by 13.6% by 2030; however, this commitment is conditional upon international support, as outlined in its INDC (UNFCCC, 2023). The construction of coal-fired power plants is not sustainable or efficient in the long term (Kohsar, 2021).

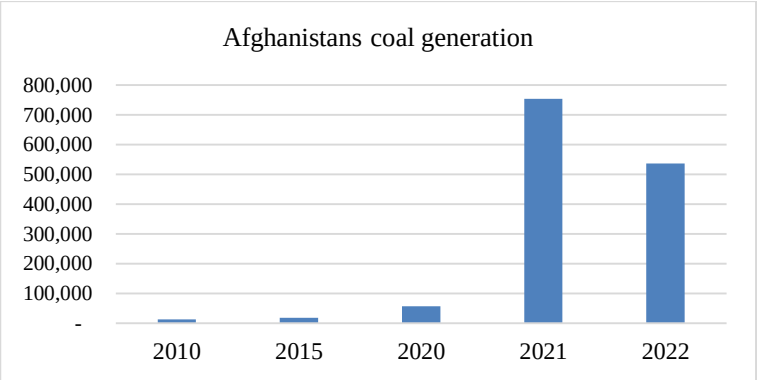

Figure 6. *The coal generation in Afghanistan (2010-2022) (Idoine et al., 2023; Brown et al., 2016)*

Renewable Energy for Sustainable Development and Rural Electrification

The United Nations acknowledges renewable energy and electricity access as crucial for development, directly linked to SDGs 7, 11, and 13 and indirectly influencing other SDGs (UNIDO, ICSHP, 2016; UNDESA_DSDG, 2018). Investment in renewable energy will significantly improve industry and commerce; it is the key to sound economic development (Khan, 2024). Global energy investment in clean energy is growing rapidly, with over $1 billion spent daily on solar deployment, reaching $1.8 trillion in 2023 (Chilvers et al., 2024). The promotion of renewable energy investment creates new jobs and economic opportunities; by 2030, renewable energy investment is expected to generate 17 million additional jobs worldwide (International Energy Agency, 2023). Investing in renewable energy is expected to create employment opportunities and can drive sustainable economic growth by creating new green jobs. Many engineers, project managers, technicians, and manual workers would have reliable jobs (UNDP, 2024). Solar energy supports **seven** to eleven jobs per megawatt-hour produced (MW), while coal supports only one job per MW, and natural gas supports fewer than one job (Daniel, 2006). However, renewable energy production would reduce unemployment and labor migration to regional countries from Afghanistan. Supporting renewable energy production in Afghanistan would lead to economic growth, promoting sustainable development and poverty alleviation. Energy remains the most serious economic, environmental, and developmental matter for Afghanistan. According to UNDP, around 85% of Afghans live below the poverty line (Umarova, 2024). Investment in renewable energy will improve Afghanistan's energy independence and economic development (Khan, 2024). Investment in the renewable energy sector in Afghanistan would save cost and fuel, associated with lower emissions and higher energy independence (Cormier and Singh, 2023). Afghanistan is committed to reducing emissions by 13.6% by 2030; however, this commitment is conditional upon international support, as outlined in its INDC (UNFCCC, 2023). The encouragement of domestic clean energy-producing policies will help the country tackle climate change while achieving energy independence. Afghanistan requires nation-building projects and sustainable practices, supported by the government, NGOs, and the public. Despite being the least developed country, energy transitions are challenging due to economic, political, social, and contextual factors.

Afghanistan has mountainous terrain; the geographically largest rural communities are isolated between mountain ranges, making it infeasible to create a synchronized electricity transmission system nationally (Fahimi and Stepputat, 2023). Therefore, the application of off-grid renewable energy technologies can be essential in electrifying isolated rural areas (Rostami et al., 2024). Investments in off-grid renewables, such as solar, help rural communities access affordable, free, and reliable electricity, which has environmental benefits and promotes energy independence (Philipp, 2022). The lower income level and affordability are other challenges that hamper the expansion of the national unified electricity transmission system. Local families will be able to pay the initial costs of solar implementation. The UNDP and UNHCR have launched numerous small-scale solar projects to provide affordable electricity to rural communities. In 2022, UNHCR also distributed solar panels to people in need, providing electricity for 6,000 individuals in remote areas, allowing children to study after dark (UNHCR, 2022; UNDP, 2024). Off-grid renewable sources in rural areas can improve energy accessibility and alleviate poverty, even in Kabul, where winter outages are a common occurrence, necessitating the use of a hybrid energy system.

Afghanistan's Dependency on the Neighboring Country's Electricity

Afghanistan does not produce enough electricity to meet the domestic demand. Therefore, this country imported 900 megawatts of electricity from neighboring Iran, Tajikistan, Turkmenistan, and Uzbekistan (Akhundzadah, 2024). Afghanistan imports from Tajikistan (350 MW), Uzbekistan (320 MW), Iran (108 MW), and Turkmenistan (50 MW) (Slimankhil et al., 2020). Importing electricity and fuel from neighboring countries incurs significant costs for Afghanistan; however, Afghanistan possesses rich renewable energy resources (Asian Development Bank, 2017). According to the Afghan government's master plan, 95 percent of energy is targeted to be supplied with renewable energy by 2032; the volume required will need to increase by 20 times the current production capacity. The hydropower potential was designated as the primary source of energy for achieving energy self-sufficiency; numerous medium- and large-scale hydroelectricity projects were planned to be built by 2023, with a generating capacity of 7,473.5 MW (Aminjonov, 2017). Continuous war and conflict, financial challenges, a lack of skilled personnel, and political concerns hampered the targeted plan. Afghanistan is heavily reliant on imported electricity, which accounts for approximately 80% of the nation's total consumption. Importing electricity from neighboring power plants would have several drawbacks, as discussed below.

Higher-priced electricity

Importing electricity from neighboring countries presents challenges due to high prices, with Afghanistan paying 10 cents per kWh for Uzbek electricity, Tajikistan and Turkmenistan charging 4-6 cents per kWh (Aminjonov, 2017). The United States imports electricity from Canada for a significantly lower rate of 0.05 cents per kWh (Wasti et al., 2019). The Central Asian states export electricity to Afghanistan even during domestic shortages (Tutumlu and Aminjonov, 2023). Low-income households in Afghanistan spend over 15% of their income on electricity bills, which is four times higher than in importing countries, and face the highest

electricity prices globally (Cormier and Singh, 2023). The affordability of electricity remains a significant challenge due to higher prices, which is a primary reason that a substantial portion of the population lacks access to electricity (Shah et al., 2019). Investing in renewable energy can make it more affordable, thereby addressing the issue of energy inequality and accelerating the country's transition towards a more equitable and sustainable energy future.

Unsustainable and Unreliable Source

Energy crises consistently plague Central Asia's energy systems. The region faced power shortages during the winter of 2023-2024 (Tutumlu and Aminjonov, 2023). Central Asian states experience the worst energy crisis during winter 2022-2023. The electricity and gas disruptions in Kazakhstan and Uzbekistan have been cut off. In recent years, Central Asian countries have been facing energy deficits and natural gas shortages (Komilov, 2023). Central Asian countries have struggled to meet their domestic energy demands due to infrastructure shortcomings and increased domestic consumption. The energy supplies to Afghanistan from Central Asia have long been associated with problems for this country. Afghans experience significant unplanned and scheduled power outages and shortages, primarily during the winter season. For example, the supply from Tajikistan during the summer season, from May to September, when electricity production is at its highest, reaches 400 MW per day. In contrast, during the winter and autumn, when electricity production is lower, supplies drop to 25-30 MW per day (Putz, 2022).

Seasonal variation led to shortages and surpluses of electricity in Tajikistan. The World Bank estimated that 70 percent of Tajikistan's population experienced electricity shortages during the winter season, while during the summer, 25 percent of electricity demand exceeded supply (Aminjonov, 2017). Natural gas accounts for approximately 85% of Uzbekistan's electricity generation capacity (International Energy Agency, 2021). Uzbekistan, the leading exporter of electricity to Afghanistan, reduced its exports, disrupting the power supply and causing recurrent outages. The capital was Kabul, and many provinces had access to electricity for only 7 or 8 hours per day (Ludin et al., 2024).

Climate change is expected to exacerbate seasonal variations and increase electricity shortages (Mujeeb et al., 2023). Numerous research findings indicate that hydropower is vulnerable to climate change, with the occurrence of droughts, glacier shrinkage, and increased evaporation (Wasti et al., 2019). Most of the regional rivers originate from high mountains that have vast reserves of snow and glaciers (Lutz et al., 2019). The melting of glaciers supplies water sources for the Amu Darya and Syr Darya. Over the last 70 years, the glaciers of Central Asia have decreased by more than three times, resulting in a significant change in river flow. Melting glaciers and snow in warmer spring seasons lead to flooding in early spring and water scarcity in subsequent seasons (Reyer et al., 2017; Mushwani et al., 2025). The low river flows in the wintertime distress electricity production. The rain and snowfall in exporting countries reduce electricity production at hydroelectric plants, which will eventually decrease the export of electricity to Afghanistan. Tajikistan, which exports 350 MW of electricity, faces an acute energy shortage in the winter due to low water levels in its

rivers. Climate change leads to an increase in temperature, an increase in droughts, a shift in the hydrological cycle, reduced river flow, and an increased use of electricity.

Tajikistan and Uzbekistan supply electricity to Afghanistan without increasing their power production potential, but these countries have increased the capacity of their exports to Afghanistan. Afghanistan needs electricity, and Uzbekistan and Tajikistan need revenues or foreign currency (Putz, 2022). Their exports are unsustainable, unreliable, and unavailable because Afghanistan's electricity demand is higher in the winter, while exporting countries reduce their supply to meet their own domestic needs. Energy is the key to economic development and industrial growth; the country's industry cannot afford to wait for recovery from outages and shortages, which result in lost revenue and other serious challenges to power delivery. Afghanistan would face an increasing risk of electricity imports from these countries (Ludin et al., 2024).

DISCUSSION

This study provides a comprehensive analysis of access to and demand for electricity in Afghanistan, as well as the renewable energy potential, along with the preference and possibility of deploying non-renewable and renewable energy sources. The desired effects of these energy sources on sustainable development are also discussed. Finally, the country's dependency on energy imports from neighboring states and their negative implications are investigated. The annual consumption in Afghanistan has increased by 8.7% over the past 20 years, reaching 1,600 megawatts in 2022, and is expected to continue increasing (Aminjonov, 2017). The country primarily relies on imported electricity, but it has potential for renewable energy sources. Electricity demand is expected to rise in all sectors, including lighting, heating, industry, buildings, and transport. Afghanistan has a potential of 23,000 MW, but currently produces only 300 MW, accounting for 1.3% of its electricity in 2022, generated by 13 medium and small dams. Afghanistan's limited hydroelectric potential renders wind power utilization impractical due to high equipment costs and other constraints. Wind power serves as a complement to solar power because wind often ramps up during the night when solar power is unavailable. Afghanistan has seen significant progress in electricity access over the past two decades; however, the urban-rural discrepancy remains higher, with 70–75% of urban areas having access compared to 15% in rural areas (Ludin et al., 2024). Many rural households rely on alternative sources of electricity, mostly solar panels and small-scale hydropower generation, due to their low cost. Afghanistan's domestic power production is primarily hydro, accounting for 74.7 percent of its electricity in 2022. Solar generation has also been growing rapidly, contributing 9.64% of electricity in 2022. Solar energy has shown the fastest growth among renewable sources in Afghanistan, and in contrast to fossil fuels, electricity generation from solar sources dropped to 15% in 2022. Afghanistan has the lowest rate of electrification at 43%, with a 0.8 percentage increase in access rates from 2010 to 2019.

Afghanistan has fossil fuel resources, including a 75 billion cubic meters natural gas field in the Sheberghan region. Afghanistan should focus on building natural gas power plants

rather than coal-fired power plants. Afghanistan has no coal-fired power plants for electricity generation. The Afghanistan plan aims to produce 500 MW of electricity from coal by constructing a coal-fired power plant, a project undertaken by a Chinese company. The construction of coal-fired plants in Afghanistan is not sustainable and is not aligned with the current international agenda, as international efforts are ongoing to reduce coal consumption. Environmental groups suggest that coal needs to be phased out entirely by 2040 to meet the Paris Agreement. China, the most prominent supporter of coal-fired power in the world, "will not build new coal-fired power projects abroad anymore. The share of global electricity generated by fossil fuels, mainly coal, has fallen from 68 percent to 61 percent over the same period.

The study suggests that Afghanistan must strike a balance between renewable and non-renewable energy sources for sustainable development and electrification. Renewable sources provide sustainable power, while non-renewable, flexible resources like natural gas can ramp up or down quickly to complement variable renewable energy production and ensure a constant supply. The balance is achieved through grid modernization, the strategic use of solar, hydro, wind, biomass, geothermal, and natural gas resources. New research conducted in Nigeria has concluded the same as our findings (Hilili et al., 2024). Renewable energy offers Afghanistan significant benefits, including increased energy independence, economic growth, and improved living standards. Afghanistan has substantial potential in these areas, and harnessing them can lead to a more sustainable and prosperous future. The Afghan interim government should prioritize renewable energy development through private investment. The development of renewable energy technologies, such as solar, can provide rural communities with affordable, reliable, and environmentally friendly electricity. Afghanistan heavily relies on imported electricity, accounting for 80% of its consumption, and importing from neighboring countries presents drawbacks. This shift can enhance energy independence, reduce poverty, and ensure a sustainable electricity supply. The capital, Kabul, can benefit from a hybrid energy system to compensate for unplanned outages. Afghanistan requires international support to implement renewable energy projects, given its high climate risk and vulnerability.

CONCLUSION

This review examines Afghanistan's energy sector, focusing on demand, access, production, and development, as well as its renewable energy resources, performance, and sustainable impact. Afghanistan's energy sector is characterized by its dependence on imported electricity, which creates challenges for its energy policies and infrastructure. Afghanistan has significant energy resources that can meet its domestic electricity demands and be exported to neighboring countries, providing employment and economic activity. Afghanistan, a sunbelt country, has the potential to play a significant role in the global clean energy transition. Solar manufacturing has experienced significant expansion; however, industrial-scale solar power plants are still limited, and small-scale rooftop panels and home solar systems have emerged as alternatives. The share of solar electricity in Afghanistan has

increased from 1% in 2012 to 9.64% in 2022. Large-scale solar arrays are necessary to address Afghanistan's energy challenges and reduce its foreign dependency, resulting in significant savings on electricity bills. The Salma and Kamal Khan dams, built during the Islamic Republic Government, have low water flow potential, affecting electricity production. The Amu Darya and Kabul River basins contribute 94.7% of Afghanistan's total hydropower capacity; however, the Afghan government has struggled to attract financial resources and faces other challenges, including the absence of water-sharing agreements with neighboring countries. The Kunar River, with an estimated 1,500 MW of installed capacity, is crucial for economic development, improving livelihoods, industrialization, and poverty reduction. Afghanistan, with its excellent wind potential of 66,726 MW, experiences around 120 windy days at speeds above 8.5 m/s in regions such as Herat, Farah, and Nimroz. Wind power generation is crucial for Afghanistan. Global electricity generation from gas increased to 23% in 2023. Natural gas produces fewer harmful pollutants and can reduce global warming. Afghanistan has rare mineral resources that are essential for electric vehicles and can play a role in clean energy production.

Renewable energy and access to electricity are crucial for sustainable development and economic growth, as recognized by the United Nations. Investment in renewable energy can create new jobs and economic opportunities for Afghanistan. Investing in renewable energy can reduce unemployment, labor migration to other countries, and poverty. Investing in renewable energy can also enhance Afghanistan's energy independence and economic development, thereby reducing its dependence on neighboring countries and lowering carbon emissions. Afghanistan is committed to reducing emissions by 13.6% by 2030. The Afghan government cannot provide substantial investments and faces numerous challenges, including conflict, financial difficulties, a lack of skilled personnel, and a post-war status; therefore, cooperation between the Afghan government, international organizations, and the private sector is necessary to attract public and private finance for clean energy projects.

Reliance on imported electricity: neighboring countries, such as Uzbekistan and Tajikistan, face numerous drawbacks, including high electricity prices, power outages, and shortages, particularly during winter. This is due to higher winter electricity demand and reduced supply from exporting countries. Low river flows in winter can cause energy shortages, and global warming could strain reservoirs, impacting sustainability in the future. The Afghan government should pursue renewable energy as its future energy source, but challenges such as financial, infrastructure, policy, and technical issues still pose significant hindrances to any effort.

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- Lutfullah Safi: Validation, Writing – original draft, Methodology, Conceptualization. Kawoon Sahak: Writing – review & editing.
- Hayatullah Mushwani: Writing – original draft, Visualization

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REFERENCES

Asian Development Bank. (2012). *Sector Assessment (Summary): Energy*, Asian Development Bank. Link

Asian Development Bank. (2017). *ADB supports first solar power plant to boost renewable energy in Afghanistan. Asian Development Bank*. Mandaluyong City 1550, Metro Manila, Philippines. Link

Akhundzadah, N.A. (2024). Mitigation of Climate Change Through Using Renewable Energy in Afghanistan. In: Chenchouni, H., et al. Recent Advancements from Aquifers to Skies in Hydrogeology, Geoecology, and Atmospheric Sciences. MedGU 2022. Advances in Science, Technology & Innovation. Springer, Cham. https://doi.org/10.1007/978-3-031-47079-0_66

Aminjonov F. (2017). *Afghanistan's energy security: Tracing Central Asian countries' contribution*. Friedrich-Ebert-Stiftung (FES). Link

Afghanistan National Renewable Energy Policy. (2012). *Hydropower plants designed to produce electricity. "Afghanistan National Renewable Energy Policy.*

Ariana News (2024). *Herat company produces 300 solar panels a day*.

Arshad M., (2017). Clean and sustainable energy technologies. Clean Energy for Sustainable Development. 73-89. https://doi.org/10.1016/B978-0-12-805423-9.00003-X.

Bakkari M., Bossoufi B., El-Kafazi I., Bouderbala M. & Karim M. A. (2024). Review of wind energy potential in Morocco: New challenges and perspectives. *Wind Engineering*, 48(1), 101-120. https://doi.org/10.1177/0309524X2312005

Barbier E. (2002). Geothermal energy technology and current status: an overview. *Renew Sustain Energy Rev* 6(1–2):3–65. https://doi.org/10.1016/s1364-0321(02)00002-3.

Brown, T. J., Wrighton, C. E., Idoine, N.E., Raycraft, E. R., Shaw, R. A., Deady, E .A., Rippingale J. and Bide T. (2016). *World mineral production 2009-14*. NERC.

Burns, R. K. (2011). Solar assets, electricity production, and rural energy factors. *Renewable and Sustainable Energy Reviews, 15*(4), 2144–2148. https://doi.org/10.1016/j.rser.2010.12.002

Champenois, F. Hummer, L. Lim, J. Pitre. J, Clark. G and Stylianou N. (2024). Boom and Bust Coal: Tracking the Global Coal Plant Pipeline. *Global Energy Monitor*. Link

Chilvers R., Denmark L. and Howlett M. (2024). Fostering Effective Energy Transition Insite Report. *World Economic Forum.*

Coleman L. (2024). This is how the MENA region can accelerate its renewable energy production. *World Economic Forum.*

Cormier C. & Singh J. (2023). The Transition to Sustainable Heating in Central Asia Is Critical and Achievable. *The diplomate*.

Daniel M. K., Kamal K. & Fripp M. (2006). "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?" Renewable and Appropriate Energy Laboratory Report, University of California. Link

Danish, M. S. S., Senjyu, T., Sabory, N. R., Danish, S. M. S., Ludin, G. A., Noorzad, A. S., & Yona, A. (2017). Afghanistan's aspirations for energy independence: Water resources and hydropower energy. *Renewable Energy*. 113, 1276–1287. https://doi.org/10.1016/j.renene.2017.06.090.

Edward WE. & Qazizai F. (2021). Chinese mining groups scour Afghanistan for opportunities. *The Financial Times Limited*.

EMBER (2024). *Ember Electricity Data Explorer, ember*. Link

Ershad A.M. (2017). Institutional and Policy Assessment of Renewable Energy Sector in Afghanistan. *Journal of Renewable Energy*. (1), 5723152. https://doi.org/10.1155/2017/5723152n.

Evans S. & Viisainen V. (2024). *Wind and solar added more to global energy than any other source in 2023*. *Swiss Academy of Sciences* (SCNAT).

Fahimi A. & Stepputat K. (2023). *Low-Carbon Energy Transformation in China, India, Pakistan, and Afghanistan: An Overview*. *In:* S. Groh et al. (eds.), Electricity Access, Decarbonization, and Integration of Renewables, Energiepolitik und Klimaschutz. Energy Policy and Climate Protection, https://doi.org/10.1007/978-3-658-38215-5_5.

FP Analytics (2023). *Mobilizing Financing for Inclusive Development*. Link

Gassner, K., Merle-Beral, E., Terenteva, O., Rosenthal, N. & Hankinson, D., (2017). *Small Hydro Power Plant in the Kyrgyz Republic: Assessment of Potential and Development Challenges (Organization Report). ESMAP*. World Bank. Link

Gayen, D., Chatterjee, R. & Roy, S. A. (2024). *Review on environmental impacts of renewable energy for sustainable development.* International Journal of Environmental Science and Technology, 21, 5285–5310. https://doi.org/10.1007/s13762-023-05380-z.

Hamad J., Ahmad M. & Zeeshan M. (2024). Solar energy resource mapping, site suitability and techno-economic feasibility analysis for utility scale photovoltaic power plants in Afghanistan. *Energy Conversion and Management*, 303, 118188. https://doi.org/10.1016/j.enconman.2024.118188.

Helper S, Krueger, T and Wial H. (2012). Why Does Manufacturing Matter? Which Manufacturing Matters? A Policy Framework. Brookings.

Hilili, M.J., Akadiri, S.S. & Eneanya, C.N. (2024). Powering Nigeria's future: balancing renewable and non-renewable energy for environmental sustainability. Energy System. 1-22. https://doi.org/10.1007/s12667-024-00686-4

Idoine, N.E., Raycraft, E.R., Hobbs, S.F., Everett, P., Evans, E.J., Mills, A.J., Currie, D., Horn, S. and Shaw, R.A. 2024. *World Mineral Production 2018-22*. British Geological Survey, Keyworth, Nottingham.

International Energy Agency, (2021) Uzbekistan Energy Profile. International Energy Agency. Link

International Energy Agency, IRENA, UNSD, World Bank, WHO. (2021). Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC. © *World Bank.*

International Energy Agency, (2022). *World Energy Outlook 2022*. Link

International Energy Agency, (2023). *World Energy Outlook 2023*. Link

International Hydropower Association, (2020). Hydropower status report. International Hydropower Association. International Hydropower Association. Link

Institute for Economics and Peace (2022). Ecological threat report 2022: Analysing ecological threats, resilience & peace, sydney.

Irfan Z. (2023). *Domestic Manufacturing Is Essential to India's Green Energy Transition. Council on Foreign Relations*. Link

Isha F.A. (2024). Bangladesh solar power surge set to unlock thousands of green jobs.

Kabul Times. Kunar power dam's construction would ease electricity shortages. Link

Khan A.U. (2024). Chinese Dam Construction in Afghanistan: Implications for Pakistan. *The diplomate.*

Khan H. (2024) Catalyzing Renewable Energy: Path to Afghanistan's Economic Revival. *The Diplomat.*

Kohsar W (2021). Afghans rely on coal to keep warm as winter cold sets in the harsh Afghan winter. *Al-Jazeera*.

Komilov A. (2023). How the EU Can Contribute to the Green Transition in Central Asia. *The Diplomat.*

Lempriere M (2024). Wind and solar are 'fastest-growing electricity sources in history. Link

Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y., (2020). Reviewand outlook on the international renewable energy development. Energy and Built Environment, 3(2) 139-157, http://dx.doi.org/10.1016/j.enbenv.2020.12.002.

Ludin G.A. et al., (2024). Power transmission in Afghanistan: Challenges, opportunities and proposals.

Ludin GA, Nakadomari A, Yona A, et al. (2022). Technical and economic analysis of an HVDC transmission system for renewable energy connection in Afghanistan. Sustainable 14: 14-68. https://doi.org/10.3390/su14031468.

Lutz, A. F., ter Maat, H. W., Wijngaard, R. R., Biemans, H., Syed, A., Shrestha, A. B., Wester, P., & Immerzeel, W. W. (2019). South Asian River basins in a 1.5 degrees C warmer world. *Regional Environmental Change*, 19(3), 833–847. https://doi.org/10.1007/ s10113-018-1433-4.

Mainali B, Silveira S. (2013). Alternative pathways for providing access to electricity in developing countries. *Renew Energy*; 57:299–310. https://doi.org/10.1016/j.

Marlow I. & Curran E. (2021). China Eyes Afghanistan's $1 Trillion of Minerals with Risky Bet on Taliban. *Bloomberg*.

Mujeeb, M., Safi, L., & Mirzazada, A. (2024). Comparison of Newton Raphson – Linear Theory and Hardy Cross Methods Calculations for a Looped Water Supply Network. *Journal of Natural Science Review*, *2*(2), 75–90. https://doi.org/10.62810/jnsr.v2i2.40.

Mujeeb M. Sahak, K., Safi L., Ahmadzai M R. (2023). Climate Change Impacts and Surface Water Accessibility Analysis in the Ghorband Sub River Basin, Afghanistan. *KPU International Journal of Engineering & Technology*. 3(01)105-122. Link

Mushwani, H., Arabzai, A., Safi, L. (2025). Evaluation of flood hazard vulnerabilities and innovative management strategies in Afghanistan's central region. *Natural Haz*. https://doi.org/10.1007/s11069-024-06974-7

Nagheeby, M., Warner, J. (2018). The geopolitical overlay of the hydropolitics of the Harirud River Basin. *Int Environ Agreements*, 18, 839–860. https://doi.org/10.1007/s10784-018-9418-9.

Najafizada E (2021) Afghanistan could go dark as power bills remain unpaid. *Aljazeera*.

Nordhaus T. (2024). Why Wind and Solar Won't Solve Climate Change.*Foreign policy.*

NREL (2016). Focus on creative answers to today's energy challenges to transforming the way the world uses energy. National Renewable Energy Laboratory.

Philipp J. (2022). Renewable Energy in Afghanistan. *Borgenproject.org*

Plumer B & Popovich N. (2024). As Solar Power Surges, U.S. Wind Is in Trouble. *The New York times.*

Popovich N. (2024). How Does Your State Make Electricity? *The New York Times.*

Putz C. (2022). Central Asia Continues to Supply Electricity to Afghanistan. *The Diplomat.*

Qooyash HR. (2024). Solar Power Project in Kabul Begins, Projected to Produce Ten Megawatts. *TOLOnews*.

Rahimzoda, S. (2024). Water-Energy Equation in Central and South Asia: A Perspective from Tajikistan. In: Adeel, Z., Böer, B. (eds) The Water, Energy, and Food Security Nexus in Asia and the Pacific*. Water Security in a New World*. https://doi.org/10.1007/978-3-031-29035-0_4.

Reyer, C. P. O., Otto, I. M., Adams, S., Albrecht, T., Baarsch, F., Cartsburg, M., Coumou, D., Eden, A., Ludi, E., Marcus, R., Mengel, M., Mosello, B., Robinson, A., Schleussner, C., Serdeczny, O., & Stagl, J. (2017). Climate change impacts in Central Asia and their implications for development. *Regional Environmental Change*, **17**(6), 1639–1650. https://doi.org/10.1007/s10113-015-0893-z.

Rostami R., Khoshnava, S.M. Lamit, H. Streimikiene, D. & Mardani, A. (2016). An overview of Afghanistan's trends toward renewable and sustainable energies. Re*newable and Sustainable Energy Reviews.*76, 1440-1464 https://doi.org/10.1016/j.rser.2016.11.172

Sabory, N. R., Senjyu, T., Danish, M. S. S., Maqbool Sayed, S., Ahmadi, A., & Saeedi, E. (2021). Post-2000 building industry in Kabul city from sustainability perspective. Sustainability, 13(14), 7833. https://doi.org/10.3390/su13147833

Safi, L. (2024). *Review of Afghanistan's development pattern from 2001 to 2021: a relative lack of sustainability, inclusiveness, and prosperity*. Journal of Social and Economic Development, 26, 333–352. https://doi.org/10.1007/s40847-023-00268-7.

Safi, L., Mujeeb, M., Sahak, (2024). Climate change impacts and threats on basic livelihood resources, food security and social stability in Afghanistan. *GeoJournal* 89, 85. https://doi.org/10.1007/s10708-024-11077-8.

Shah, S., Zhou, P., Walasai, G., & Mohsin, M. (2019). Energy security and environmental sustainability index of South Asian countries: a composite index approach. *Ecological Indicator*. 106, 105507 https://doi.org/10.1016/j.ecolind.2019.105507.

Slimankhil, A. K., Anwarzai, M. A., Sabory, N. R., Danish, M. S. S., Ahmadi, M., & Ahadi, M. H. (2020). Renewable energy potential for sustainable development in Afghanistan. *Journal of sustainable Energy Revolution*, 8-15. http://dx.doi.org/10.37357/1068/jser.1.1.02.

TOLOnews (2022) China Interested in Investment in Coal-Fired Power.

TOLOnews (2024). Boosting Energy: Wind and Solar Projects Progress in Four Provinces.

Tutumlu A., & Aminjonov A. (2023). Central Asia's Great Energy Paradox. The diplomate.

UNDESA_DSDG. (2018). HLPF review of SDG implementation: SDG 7-ensure access to affordable, reliable, sustainable and modern energy for all.

UNDP (2014): Micro-hydro lights up homes and lives in Afghanistan. Link

UNDP (2024). Harnessing the sun to power Afghanistan's development.

UNFCC 2023. NDC Registry.Link

UNHCR (2022). *Global Report 2022.* Link

UNIDO, ICSHP (2016). The World Small Hydropower Development Report .2016United Nations Industrial Development Organization (UNIDO) and International Center on Small Hydro Power (ICSHP), Vienna and Hangzhou.

Wasti, A., Ray, P., Wi, S., Folch, C., Ubierna, M., & Karki, P. (2022). Climate change and the hydropower sector: A global review. *Wiley Interdisciplinary Reviews: Climate Change*, 13(2), e757. https://doi.org/10.1002/wcc.757

White E. and Ding W. (2024). Gridlock in China: spending on network surges to support green energy transition. *The Financial Times Limited.*

Motyka W. M, Fulghum N, & Jones D. (2024). Global Electricity Review-2024.

World Bank. (2021). Afghan communities reap benefits from a cross-regional energy project. Link

World Bank. (2022). The Global Health Cost of PM2.5 Air Pollution. https://doi.org/10.1596/978-1-4648-1816-.

Zafar M. W., Sinha A., Ahmed Z., Qin Q., Zaidi S. A. H. (2021). Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific economic cooperation countries. *Renew Sustain Energy Rev, 142*:110868. https://doi.org/10.1016/j.rser.2021.110868.

Zaheb, H., Obaidi, O., Mukhtar, S., Shirani, H., Ahmadi, M., & Yona, A. (2024). Comprehensive Analysis and Prioritization of Sustainable Energy Resources Using Analytical Hierarchy Process. *Sustainability*, 16, 4873. https://doi.org/10.3390/su16114873.