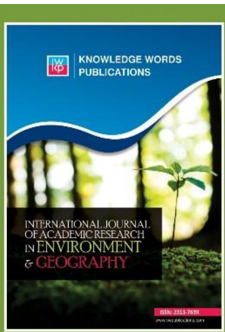


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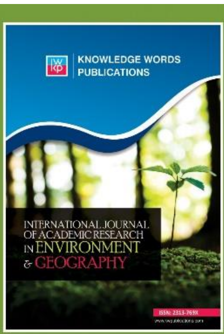


# Green Wireless Networks for Iraq: Transitioning Wireless Base Stations to Renewable Energy

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**Abstract**
Iraqi wireless service providers rely heavily on fossil fuels to power their base stations (BSs), contributing to the country's environmental footprint. By adopting renewable energy, Iraqi Mobile Network Operators (MNOs) can benefit both the environment and the long-term viability of the telecommunications sector. This study serves as a review to analyze the potential benefits, challenges, and real-world implementation of renewable energy-based solutions for powering wireless BSs In Iraq, with a focus on solar, wind, biomass, and other indirect renewable energy sources (RESs). This study reviews the potential and challenges of renewable energy for powering Iraqi wireless BSs. A comprehensive search of various databases and sources identified relevant research focusing on the wireless BSs. Data on implementation, benefits, and challenges have been extracted and presented. We found that transitioning from fossil fuels to renewable energy reduces environmental impact and enhances sustainability. While infrastructure, investment limitations, and clear policies pose challenges, the potential for cleaner energy, energy security, and economic opportunities makes RESs a viable solution. The results emphasize the superiority of hybrid systems combining different RESs and its benefits. As a result, this study finds RESs a promising path for Iraq's wireless service providers, promoting environmental sustainability and economic viability.
**Keywords:** Renewable Energy, Iraqi Telecommunications, Base Stations (BSs), Sustainability, Fossil Fuel

## Introduction

Mobile network operators (MNOs) have been steadily expanding the number of cellular BSs over the past ten years to accommodate the growing number of mobile subscribers and fulfill their substantial data requirements. In the third quarter of 2023, 163 million new 5G subscriptions were added, bringing the total to 1.4 billion (Ericsson, 2023). 4G subscriptions increased by 6 million in Q3 2023, reaching a total of 5.2 billion, marking the peak of 4G subscriptions (Ericsson, 2023). The telecommunications sector is crucial in facilitating global connectivity. The energy consumption of the telecommunications industry has increased significantly due to the reliance of billions of people on its services, leading to a demand for sustainable infrastructures. Statistics demonstrate the importance of this change. As mobile data traffic dramatically and simultaneously continues to grow with the increasing prevalence of long-term evolution (LTE) smartphones and the expansion of 5G, energy consumption has consequently increased. To date, energy represents between 20 and 40% of operators' operational expenses (OPEX), and this figure is projected to increase in the coming years. Hence, MNOs have started considering energy efficiency and sustainability of vital significance to their network transformation strategy. (GSMA, 2023). The swift and extensive installation of cellular BSs worldwide has substantially raised energy consumption, leading to a reduction in fossil fuel reservations and an increase in the emission of harmful greenhouse gases (GHG). Since 2015, the electricity consumption during the use stage and the overall GHG emissions have risen due to the establishment of new mobile BSs and other ICT-related factors (Malmodin et al., 2024).

Due to the facts aforementioned, telecom network operators are constantly looking for an alternative, environmentally friendly, and cost-effective energy source. Hence, harvesting energy from local renewable sources has become a significant focus for academia and researchers(Chang et al., 2022). Solar, wind, biomass, hydro, geothermal, and other RESs are abundant, reusable, and accessible in many parts of the world (Islam, et al., 2020; Rahman et al., 2022). Furthermore, with the aid of contemporary technology, enormous amounts of energy can be obtained from RESs while minimizing expenses. Motivated by the potential advantages of RES, telecom companies are gradually expanding cellular BSs that run on locally available RES. Because RESs are dynamic and weather-dependent, harvesting energy from them presents certain challenges despite the potential benefits. Furthermore, because RESs are unpredictable, using them in the telecom sector could result in an energy shortage or outage. However, the telecom sector restricts energy shortages or outages, which could deteriorate power supply continuity and dependability. Consequently, the following methods can be used to guarantee the dependability of the renewable energy-based supply system: (i) combining renewable and non-renewable energy sources; (ii) combining multiple types of RES; and (iii) combining the RESs with suitable energy storage devices (Islam, et al., 2020).

Iraq is located between 29°04' N and 37°23' N latitude, and 38°50' E and 48°32' E longitude, with a population of approximately 40 million people (World Population Review, 2024). Iraq's primary energy source is its oil reserves. Iraq heavily depends on oil for electricity production, with more than 80% of its power coming from fossil fuels, resulting in a high level of reliance on a single resource(Altai et al., 2022; Obeid, 2023). Because of the grid shortage, Iraqi citizens, industries, and businesses have been using diesel generators (DGs) for the past two decades to meet their electricity needs. The dependence on private generators continues to exist today (Al-Saffar et al., 2021; Al Essa, 2023). Thus, the wireless industry is one of the industries in Iraq that also relies on fossil fuels for their DGs to power their BSs to keep service operating. This practice directly impacts the environment by releasing GHG into the atmosphere. Nevertheless, Iraq possesses significant potential for renewable energy. Iraq's solar, wind, and biomass energy sources are currently not fully utilized, but they have the potential to be crucial in Iraq's sustainable energy development (Hussain et al., 2022). Moreover, Wind and hydropower are feasible RESs in Iraq, with the country having distinct advantages in solar energy (Yassin, 2023). These types of renewable energies can be a crucial solution for establishing environmentally friendly and energy-efficient cellular networks.

The majority of BSs are either grid-connected, which is powered by power plants that rely on fossil fuels, or off-grid, which is powered by DGs. BSs are therefore accountable for emissions of carbon dioxide (CO2) (Baidas et al., 2023). Accordingly, and as referred by (Alsharif et al., 2017; Areas, 2022; Kabir et al., 2020; Rahman et al., 2023), cellular BSs are a primary component of the telecommunications sector that is accountable for approximately 57% of the overall energy consumption as illustrated in Figure 1. Consequently, an optimal and possible solution to this problem is to power the BSs with RES. As a result, mobile industries are focusing on efficient energy usage as a means to reduce costs and emission-intensive carbon footprints without compromising on quality of service (QoS). Thus, incorporating renewable energy from local sources has grown significantly (Islam et al., 2023).

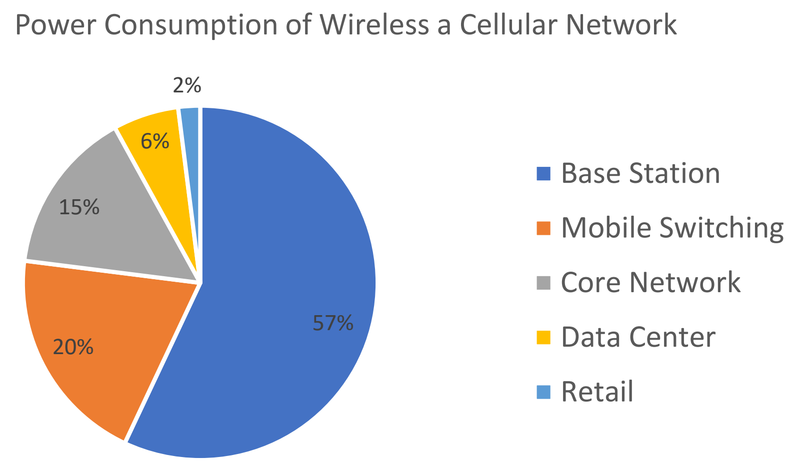


Figure 1: Power Consumption of a Wireless Cellular Network (Rahman et al., 2023)

Researchers are focusing on harvesting green energy from various locally available sources to generate sustainable and eco-friendly energy. RESs like sunlight, biomass, hydro, and wind, which are found locally, are reusable, cost-effective, and environmentally friendly when compared to non-renewable energy sources. RESs are accessible in various regions year-round. RESs are considered reliable when any of the following conditions are met. First, it needs to be integrated with the traditional non-renewable energy source. Additionally, combining two or three RESs through hybridization can enhance reliability. Furthermore, reliability is achieved when a single RES is connected to an adequate battery unit. RESs become reliable when they are integrated into the grid. RESs have become cost-effective, sustainable, and reliable thanks to technological advancements in power generation (Hossain, Jahid, Islam, & Rahman, 2020). Being inspired by the above potential benefits, this study aims to analyze the potential benefits, challenges, and real-world implementation of renewable energy-based solutions for powering telecom stations In Iraq, with a focus on solar, wind, and biomass. Specifically, this study is centered around the following objectives

- To review the environmental sustainability advantages of using solar, wind, and biomass for powering telecom BSs in Iraq.
- To analyze the energy security benefits associated with local sourcing and reduced dependence on imported fossil fuels for telecom BSs In Iraq.

- To explore the technological advancements and innovations in efficient hybrid power solutions for telecom BSs in Iraq.
- To assess real-world case studies and examples of successful implementation of renewable energy-based solutions for powering telecom BSs.
- To address the challenges and impediments that restrain the application of renewable energy solutions for telecom BSs.

The importance of this research lies in addressing the need for mitigating climate change impacts on infrastructure resilience. It investigates renewable energy solutions (solar, wind, biomass) for powering Iraq's telecom BSs, aiming to reduce reliance on fossil fuels. It assesses environmental benefits, and energy security improvements, and explores hybrid power systems for optimized energy production. Through real-world case studies and barrier identification, the research aims to facilitate the wider adoption of sustainable energy, ensuring a more secure and sustainable future for Iraq's MNOs and wireless service providers.

**Problem Statement**

Iraq has been witnessing severe environmental and climate challenges as a consequence of its heavy dependence on fossil fuels such as oil and gas to produce electricity. This interdependence leads to a considerable amount of GHG emissions, reaching millions of tons. These practices as a result impact the country and the world by exacerbating anthropogenic climate change causing alarming and grave consequences including but not limited to elevated temperatures, scarcity of rain, and desertification. Furthermore, these climatic issues are exacerbated by the unstable supply of electricity due to mismanagement and the population surge Iraq has been facing. Hence, it has become imperative to embrace RESs such as solar and wind to mitigate the aforementioned environmental impacts and ensure a more sustainable future for Iraq with respect to source management and climate change prevention. However, to transition to RES, it is necessary to overcome challenges and obstacles, including the lack of clearly defined policies and insufficient investment in the infrastructure of renewable energy (Abdul et al., 2023; Al-Kayiem & Mohammad, 2019; Hassan & Kadhum, 2021; S. A. Mohammed et al., 2023; Naffakh et al., 2021; Naji & Enawi, 2023; Yahiaoui & Sabrina, 2023; Yehia et al., 2022).

The generation of electricity in Iraq substantially relies on fossil fuels. However, the country has been facing incessant electricity shortages that in turn have made people resort to excessive use of climate-damaging DGs. The country's electricity deficit and discouraging investment environment handicap any efforts to establish a renewable energy transition, although Iraq is deemed a rich area of solar and wind resources. This reliance contributes to climatic degradation, GHG emissions, and air pollution. Operationalizing the transition to RESs addresses climate change, curbs pollutive emissions, and helps to end the utilization of DGs. Thus, and imperiously, it is necessary to prioritize an encouraging investment environment, upgrade the electricity infrastructure, and legislate well-defined renewable energy policies for a more sustainable future in Iraq (Ahmed & Pavlyuchenko, 2019; Al-Wakeel, 2021; Obeid, 2023)

Due to the mentioned electricity deficit, wireless service providers operating in Iraq have resorted to the use of DG as an alternative remedy to face frequent electricity failures and to supply their BSs with the required electricity. These generators ensure uninterrupted electricity supply to BTS. However, the use of DGs poses a significant environmental and human health risk due to the release of toxic emissions linked to these generators. The utilization of DGs in Iraq poses a significant issue as it results in detrimental impacts on both the environment and human well-being. This is primarily due to the release of toxic emissions that are inherently linked to these generators. The reliance on DGs as an alternative power source in Iraq has led to increased fuel consumption of poor quality, causing harm to the environment and the climate. This reliance on generators has also contributed to air pollution and environmental degradation (Sami & Mahmood, 2021).

For instance, according to the sustainability report that was published in 2022 by the headquarters of Zain Telecom Company, the power supply is still considered to be unstable In Iraq. On average, the energy sources from the electricity governmental grid are estimated to be available 12 hours a day. As such, Zain Iraq ends up relying on DGs that burn approximately 2,000 liters per month per site. Due to extremely low fuel prices, it is difficult to transition to RES. Moreover, the report illustrates trustworthy statistics related to fuel usage and CO2 emissions from 2017 to 2022. According to the same report, Zain Iraq used a total of 44,691,794 liters of fuel between 2017 and 2022, as determined by a fuel consumption analysis. This figure depicts the second-highest consumption compared to the countries listed, with Saudi Arabia being the only exception. Zain Iraq's CO2 emissions amounted to 232,106,936 kg, placing it in second position after Saudi Arabia. The report highlights that although Zain Iraq's electricity consumption decreased slightly, there was a corresponding increase in fuel consumption leading to a net rise in CO2 emissions (Zain Mobile Telecom, 2022).

## Significance of The Study

Limited research exists on transforming the BSs of Iraqi wireless service providers into environmentally friendly entities. This study addresses this gap by analyzing the challenges and opportunities for them to adopt renewable energy and minimize their environmental impact. The findings will benefit Iraq's wireless service providers, researchers, policymakers, and academics in the telecommunications and environmental sectors.

## Methodology

This study aims to analyze the potential benefits, challenges, and real-world implementation of renewable energy-based solutions for powering wireless telecommunications BSs in Iraq, with a focus on solar, wind, and biomass energies. This methodology section outlines the approach used to identify, select, and analyze relevant research to meet the aim and objectives of this review paper.

### *Search Strategy*

1. We conducted an extensive search of the literature in the following databases: Google Scholar, ScienceDirect, IEEE, MDPI, Scientific Research Publishing, Scientific Reports (Nature Portfolio), IJRER, Eurasip Journal on wireless communications and networking, Energy Science & Engineering (Wiley), two master's degree theses from different universities due to their important outcomes, and Case studies from international telecom companies.
2. We used the following main phrases: “Renewable Energy for 4G base stations”, “Renewable Energy for 4G LTE base stations”, “Solar Energy for telecom base stations”, “Solar PV for telecom base stations”, “Wind Energy for telecom base stations”, “Biomass Energy for

telecom base stations", and "Battery Energy Storage Systems for telecom base stations".
3. Date Range: Primarily studies published in the last 5 years, with a few highly relevant older studies potentially included.
4. Inclusion/Exclusion Criteria: English language studies are only considered. Also, we focus on studies related to the use of renewable energy for the telecom industry specifically base stations as clarified in the previous point.
5. The following information will be extracted from each selected study:
    - Country: Where the RE-powered BS system was implemented.
    - Publication year: Year of publication.
    - Key findings: Main conclusions drawn by the researchers (specific data related to energy consumption, environmental impact, Challenges, and benefits, etc.)
    - Type of RE-powered base station.
    - Renewable Energy System type.

6. Reporting: The review findings will be presented using narrative summaries in the case studies section, highlighting key points and insights extracted from the included studies (See point number 5). Additionally, tables might be used to visualize specific comparisons or data points when relevant.

**The Current Situation of Telecommunications in Iraq**

In the past, the telecommunications sector in Iraq has consistently faced delays in the implementation of new technologies due to different reasons. For instance, while 3G networks were globally prevalent by the early 2000s, they were only introduced in Iraq by the end of 2014. Similarly, the widespread deployment of 4G LTE, which had occurred in other regions by 2008, was delayed in Iraq until 2021. Additionally, cellular communication in Iraq was introduced relatively late, post-2003, compared to other parts of the world. This delay meant that by the time cellular services were established, the outside world had already progressed through three generations of networks (1G, 2G, and 3G). The deployment of 4G-LTE services began in 2021, continuing the trend of significant delays compared to global deployment patterns, with each generation arriving approximately 13 years later than elsewhere (Aljumaily & Almusawi, 2021). MNOs in Iraq launched 4G wireless access services, joining 239 other countries and territories worldwide that offer LTE licenses. As a result, Iraq now has 4G-licensed mobile operators contributing to the global ecosystem of over 810 operators providing mobile and/or fixed services. Iraq has over 42 million mobile connections, including approximately 21 million high-speed (3G and 4G) connections serving Iraqi citizens and residents (GSMA, 2022). Three major telecom companies lead the telecommunications market in Iraq (Sharify & Dallal, 2022). First, Asiacell is a leading provider of quality mobile telecommunications and data services in Iraq with a subscriber base of 17 million customers. Asiacell offers its services across all of Iraq's 18 governorates including the national capital Baghdad and all other major Iraqi cities(Asiacell Telecom, 2023). Second, Korek Telecom is a telecom company that operates in Iraq and provides GSM services. It serves in 18 provinces of Iraq (Korek Telecom, 2024). Both companies still provide 4G LTE internet service. Third, Zain Iraq is the leading telecommunications company in Iraq. It is part of Zain Group – the pioneer of mobile telecommunications in the Middle East and North Africa (MENA). Zain Iraq has provided Internet service of 4.5G+ for more than 17.6M subscribers through the all-Iraqi governorates. Zain Iraq, the first telecom company in the country to offer 4.5G+ technology (GSMA, 2024).

**Telecommunications Sustainability**

The telecommunications industry is playing an increasingly important role in global sustainability efforts, acknowledging the environmental impact of its operations. Sustainability requires balancing economic growth with environmental responsibility and social well-being. Wireless service providers are focusing on these three dimensions which are depicted in Figure 2 to develop a future-proof strategy (United Metric, 2023).

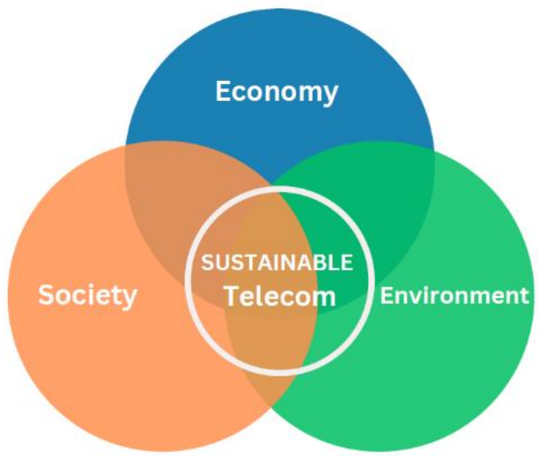


Figure 2: The primary dimensions of sustainability in the telecom industry (United Metric, 2023)

For telecommunications to be sustainable, decarbonization, the reduction of GHG emissions, and the use of RESs such as wind and solar power are essential aspects to be considered. (Deevela et al., 2023). This also includes the adoption of energy-efficient technologies to reduce energy consumption. In essence, sustainable telecommunications practices strive to provide dependable communication services while minimizing perilous environmental impact and preserving resources for future generations. By prioritizing the aforementioned dimensions, Iraqi telecom companies have the potential to make an impactful contribution toward reducing the impact of climate change and fostering a more sustainable environment.

**Renewable Energy**

Since the 1970s, the telecommunications industry has utilized renewable energy to power equipment in remote areas and connect it to grids, thereby granting access to communication services. BSs can be efficiently powered by solar and wind energy sources, which are abundant in remote areas and have the capacity and capability to decrease OPEX and GHG emissions (Alsharif et al., 2017). However, RESs are unpredictable and intermittent, requiring integration with other energy sources like backup generators or energy storage systems (batteries) to ensure reliable service. These backup systems can provide power when renewable energy is unavailable or insufficient, and batteries can store excess energy for later use (Alsharif et al., 2017; Jung et al., 2021).

One critical component of this backup system is the diesel generator (DG), which contributes when the renewable energy system (RES) malfunctions, the BS demand exceeds the RESs power output, or the batteries reach their maximum depth of discharge (DoD). However, with careful design and optimization, the reachability of the RESs can reach up to 99.99%, minimizing the need for the DG to intervene and reducing reliance on fossil fuels (Alsharif et al., 2017). This highlights the importance of optimizing RESs design for reliable and sustainable telecommunications infrastructure.

There are four main types of renewable energy-powered BSs as depicted in Figure 3, categorized by their grid connection and energy storage usage: stand-alone without storage, stand-alone with storage, on-grid without storage, and on-grid with storage. The choice of system depends on factors like the availability of renewable energy resources, grid access, and budget constraints (Jung et al., 2021). We have considered adding the biomass source, but it was not considered by (Jung et al., 2021).

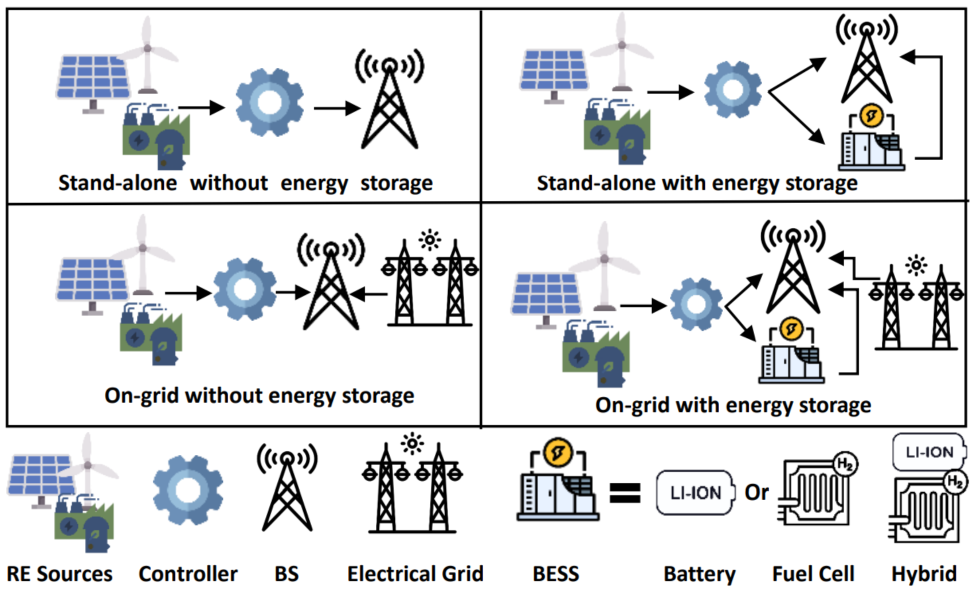


Figure 3: Types of RE-powered BSs (Jung et al., 2021)

*Solar Energy*

Iraq has abundant solar energy potential with extensive sunlight throughout the year as it lies in the Global Sunbelt (see Figure 4). Studies resoundingly agree that Iraq boasts exceptional solar potential, bathed in sunshine exceeding 3,000 hours annually (Yaseen et al., 2022). This translates to impressive irradiation levels, with national averages reaching 2,000 kWh/m²/year and regional peaks exceeding 5,500 kWh/m²/year in the western and southern deserts (Istepanian, 2018; Yaseen et al., 2022). Notably, even the north enjoys substantial irradiation, ranging from 4,266-4,700 Wh/m². This uniform distribution across most of the country makes Solar Photovoltaic (PV) technology well-suited for widespread electricity generation (Yaseen et al., 2022).

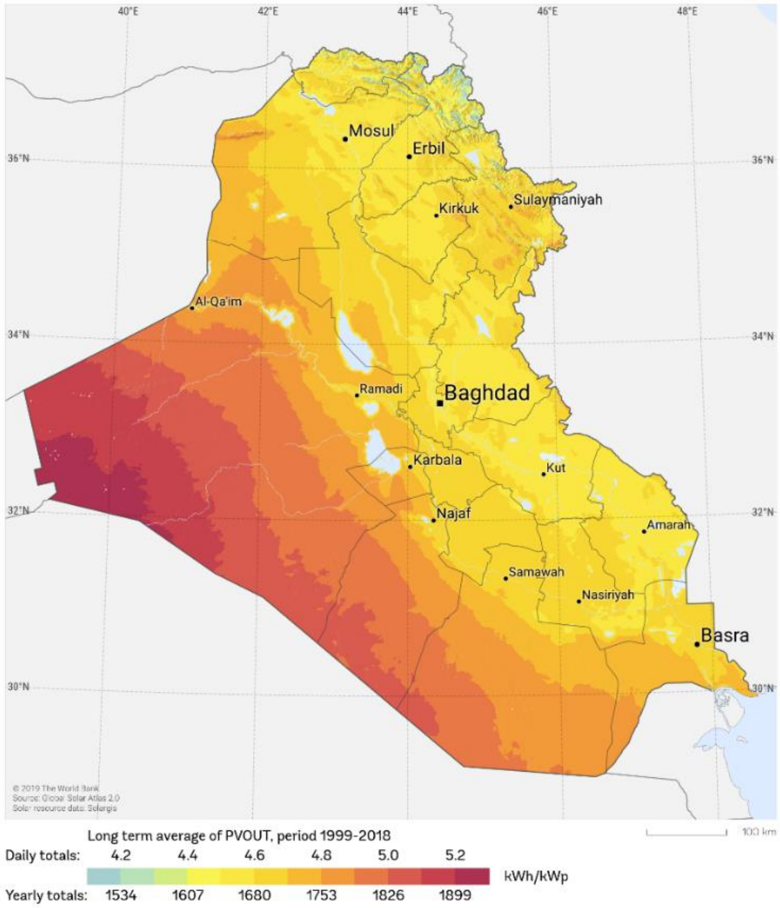


Figure 4: Iraq Solar Annual Horizontal Irradiation Map (The World Bank & Solargis, 2019)

The western and southern regions are particularly attractive, having 2,800-3,000 hours of sunshine per year and boasting a remarkable 6.5-7 kWh/m² of horizontal irradiation daily (see Figures 5 and 6) (Istepanian, 2018). This concentrated solar bounty provides an even stronger case for large-scale deployment in these areas. Research highlights Iraq's high solar energy potential across the country, with an average irradiation of 5.6 kWh per square meter per day over 3,000 hours of bright sunshine per year, further solidifying its suitability for renewable energy development (Istepanian, 2020).

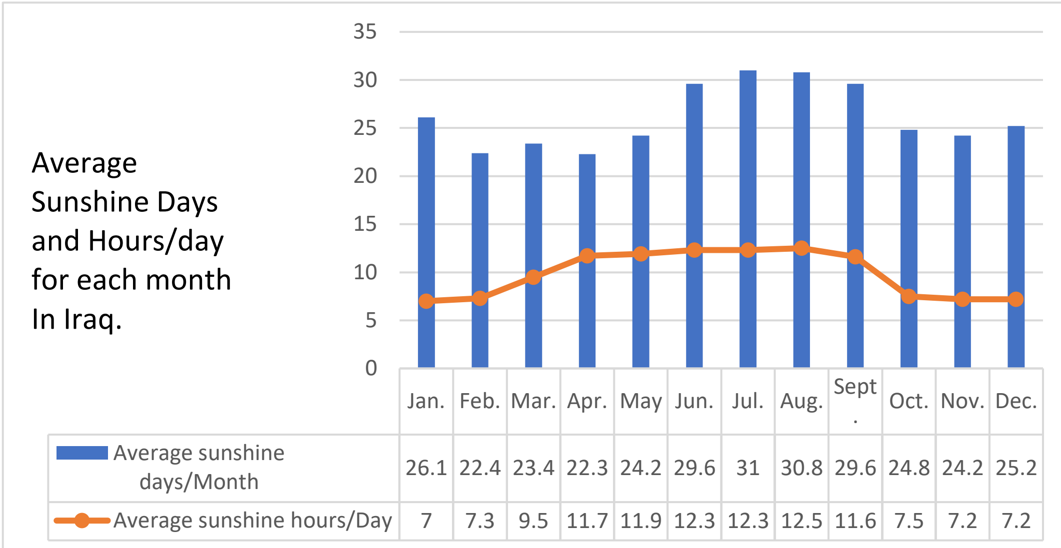


Figure 5: Average Sunshine Days and Hours/day for each month In Iraq (Weather Atlas, 2023)

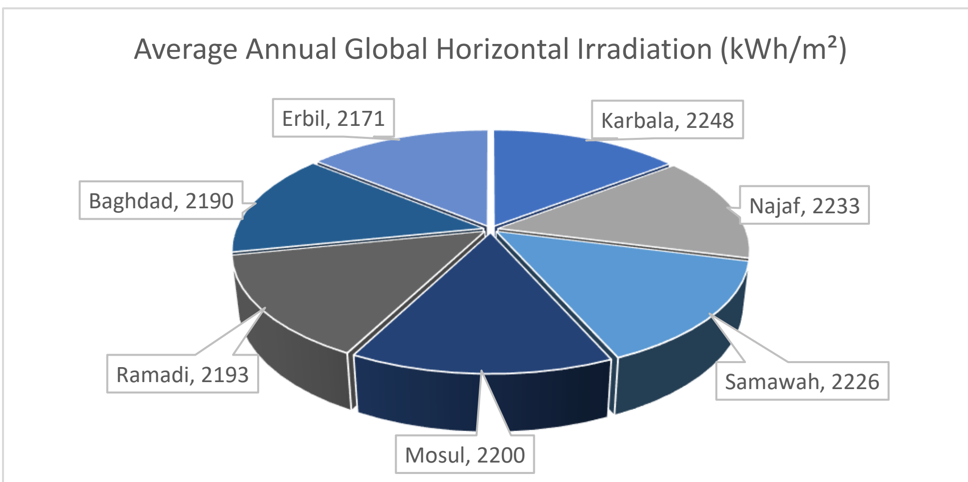


Figure 6: Average Annual Global Horizontal Irradiation in Iraq (kWh/m²)(Istepanian, 2018)

Beyond suitability, the potential is staggering. (Istepanian, 2018) estimates that unutilized desert areas alone hold the capacity to produce 30 million tons of oil equivalent (MTOE) annually using PV panels, translating to a national potential of 3.4 billion kWh and 5.9 GW capacity. This renewable resource presents a compelling solution to Iraq's longstanding electricity shortage and a path towards energy security.

Solar energy or PV systems offer significant benefits to the telecommunications industry, including cost-effectiveness, environmental friendliness, and reliability. Ike et al (2014) emphasizes that solar energy is a low-cost RESs for powering wireless BSs, leading to cost reduction in OPEX. This aligns with findings from Alsharif et al (2017), which highlights savings of up to 48.6% in OPEX when using solar-powered LTE BSs compared to traditional DG systems. In addition, solar energy is devoid of noxious emissions, thereby leading to a decrease in CO2 emissions, as highlighted in Alsharif et al (2017), which further emphasizes the eco-friendliness of PV panels

Furthermore, the use of solar power for wireless BSs ensures a steady supply of energy, which in turn improves the QoS and prevents disruptions. This dependability is of the utmost importance, especially in off-grid or distant areas with limited grid access, as indicated in (Ahmed et al., 2018). What is more, as mentioned in (Ike et al., 2014), solar power systems can revolutionize the telecommunications sector, especially in areas with abundant sunshine, where solar energy is constantly replenished. Cellular networks can achieve greater energy efficiency through the integration of solar PV arrays and other renewable energy technologies, this optimizes energy resources and decreases overall energy consumption, as evidenced by (Ahmed et al., 2018).

*Wind Energy*

Wind energy is an expanding form of renewable energy that has received considerable attention in recent years because of its merits and benefits. Wind power utilization entails harnessing the wind's kinetic energy using wind turbines to produce electricity. One of the key advantages of wind energy is its environmental sustainability, as it is a clean and renewable resource that produces no GHG emissions or air pollutants during operation, unlike traditional fossil fuel-based power plants. Furthermore, wind energy contributes to reducing our reliance on finite fossil fuels, thereby enhancing energy security and independence. The scalability of wind farms allows for flexibility in installation size, ranging from small-scale projects to large utility-scale developments, making it a versatile energy solution for various applications (Nikitas et al., 2020).

In connection with wind energy in Iraq, several studies examined specifically the wind energy in Iraq, starting from 1988, Darwish & Sayigh (1988) estimated the wind power potential in Iraq using monthly wind speed. The study concluded that the potential for wind energy in Iraq is highly promising. Iraq can be categorized into four regions, with 50% of the country experiencing an average wind speed of 3.1ms. Additionally, 17% of the country has an average speed ranging from 2.00 to 3.00ms, while 16% of the country has a relatively high average speed exceeding 5.0ms. To illustrate these ranges, the cities of Mosul, Anah, Baghdad, and Basra can be considered representative of the different wind speed ranges. Using Weibull distribution, Mohammad (2007) conducted research in 2007 to determine the wind potential and the viability of deploying wind turbines at 19 stations in various locations throughout Iraq. The findings illustrated the wind attributes and evaluation of the wind capacity at the designated locations. The findings demonstrated that there are multiple viable locations in Iraq where wind turbines can be economically installed and utilized to generate energy. Another recent study Mohammed et al (2020) provided an accurate analysis of Weibull wind speed distribution and wind characteristics in four sites in Iraq namely Nasiriyah, Al-Hay, Basrah, and Amara in Iraq and concluded that all four sites are promising sites for wind turbines to conduct wind energy. Moreover, a study from Nature Climate Change Journal showed that from 1978 onwards, wind speeds witnessed a decline of around 2.3% every decade. However, since 2010, wind speeds have been increasing at a pace roughly three times faster (Zeng. et al., 2019). Hence, the wind speed increase rate can lead to more generated electricity. We have collected statistics about the maximum wind speed in some cities in Iraq from the Iraqi Agrometeorological Center Iraqi Agrometeorological Center (2023) and these data are represented in Table 1 below.

Table 1
*2023 Monthly Maximum Wind Speed for Different Iraqi Cities (m/s)*

| City | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abu_Ghraib | 7.3 | 7.9 | 8.9 | 8.3 | 8.1 | 9.0 | 8.9 | 8.2 | 7.1 | 6.2 | 6.6 | 5.5 |
| Fao | 7.2 | 8.1 | 8.9 | 9.0 | 9.7 | 12.7 | 9.9 | 8.3 | 9.1 | 7.4 | 7.5 | 6.8 |
| Tlleafer | 6.7 | 8.4 | 7.9 | 9.2 | 10.3 | 10.4 | 10.1 | 9.5 | 9.1 | 7.2 | 7.4 | 6.0 |
| Khanaqeen | 6.1 | 7.5 | 7.0 | 7.0 | 9.2 | 8.6 | 8.4 | 7.5 | 6.8 | 6.4 | 6.0 | 5.9 |
| Sawayrah | 6.5 | 7.7 | 8.4 | 8.7 | 10.3 | 10.7 | 10.1 | 8.5 | 9.1 | 7.5 | 7.5 | 6.3 |
| Al-qasim | 6.0 | 8.4 | 8.4 | 8.5 | 9.2 | 9.5 | 9.6 | 8.2 | 7.6 | 7.0 | 6.7 | 6.0 |
| Mishkhab | 6.1 | 7.8 | 8.4 | 7.9 | 8.6 | 7.8 | 8.4 | 6.7 | 5.7 | 6.0 | 6.0 | 5.6 |
| Kahla | 5.0 | 5.5 | 6.2 | 6.7 | 6.8 | 8.7 | 7.6 | 6.3 | 6.4 | 5.8 | 5.4 | 5.2 |

On the subject of telecommunications sustainability, wind energy has gained significant attention as a renewable energy source (RES) that can be effectively integrated into BSs for telecommunications purposes. In the rest of this section, we will provide a comprehensive overview of wind energy's role in powering BSs.

According to La et al (2014), wind turbines, both large and small sizes, are being utilized to power not only factories and homes but also telecom BTS. The nominal power of small wind turbines used for BTS typically ranges from 1.5 to 7.5 kW, contributing to the increasing power demands of future mobile networks like LTE-4G and 5G. Ahmed et al (2018) highlights wind energy as a significant RES that can be integrated into BSs to conserve energy in the field of telecommunications. Wind energy can provide a continuous power source throughout the day, unlike solar energy. It offers versatility in terms of installation, as wind turbines can be installed in various wind corridors. Moreover, wind energy can complement other RESs like solar power, providing a hybrid energy solution for BSs.

Integrating wind energy in BSs can decrease dependence on high-carbon energy sources such as DG, resulting in cost reductions and environmental advantages. Moreover, wind turbines can be modeled to determine the annual energy production, allowing for the optimal sizing of power distribution systems for BSs. Collaborative arrangements between BSs can be enhanced by utilizing wind energy, which enables the exchange of excess energy and reduces reliance on unsustainable energy sources. Deevela et al (2023) underscores the viability of wind energy as power source for wireless telecommunications towers, specifically in areas endowed with sufficient wind resources. Wind turbines with capacities between 1 kW and 10 kW present a viable option for supplying electricity to telecommunications towers. In addition, the scalability of wind energy systems in accordance with the energy demands of the telecom tower provides a degree of adaptability in the design and implementation of the system. The fact that wind energy-powered hybrid systems can reduce diesel consumption at telecom tower sites by as much as 90%, according to studies, demonstrates the substantial contribution of wind energy to the reduction of reliance on fossil fuels. Additional support for the integration of wind energy into BSs is provided by (TRAI, 2017). Particularly at lower loads, it emphasizes the cost-effectiveness of wind-DG hybrid systems, implying that wind energy may contribute to cost savings in telecom tower powering. In hybrid systems, load matching and equipment sizing are critical, and depending on the wind speed, various configurations of PV-wind-DG hybrid systems can be optimized. Goel & Ali (2014) highlights the utilization of wind energy as a RES capable of supplying power to BSs. Wind energy can be combined with other energy sources, such as solar and grid power, to maximize energy usage and lower utility costs. The study also emphasizes the significance of wind energy collaboration among various BSs, resulting in substantial energy conservation. Moreover, the utilization of wind energy in BSs can actively contribute to environmentally friendly practices and have a beneficial effect on the issue of climate change. Lorincz & Bule (2013) evaluates the high energy consumption of BSs sites in the mobile industry and explores the potential of using RESs such as wind, solar, and fuel cells to minimize energy expenses and enhance operational effectiveness. Hybrid systems combining different RESs are highlighted as outperforming those with only one source. Innovative site designs and energy-efficient hardware are also mentioned as ways to save energy and promote the utilization of wind power in BSs. Finally, all the above studies agree that wind energy, a promising RES, is poised to revolutionize the power of telecom BSs. Advancements in technology offer BSs significant advantages: reduced reliance on fossil fuels (especially in remote areas), cost savings, and lower environmental impact through hybrid systems with solar and diesel.

*Biomass Energy*

There is no universally accepted definition for biomass Energy or bioenergy (Gonzalez-Salazar et al., 2014). But the International Energy Agency (IEA) which has become a world authority on bioenergy defines bioenergy as a renewable energy derived from biomass. Biomass is defined as biological material which is directly or indirectly produced by photosynthesis. Examples are wood and wood residues, energy crops, crop residues, and organic waste/residues from industry, agriculture, landscape management, and households. The biomass is converted to solid, liquid, or gaseous fuel which can be used to produce heat and/or electricity, or can be used as a transport fuel (IEA, 2020). Alhassany et al (2022); Saleh et al (2022) are studies that highlight the emerging significance of biomass energy in Iraq as a renewable resource derived from various organic materials like energy crops, agricultural residues, and waste products. Iraq's rich agricultural sector provides a diverse range of potential sources, including wood, waste cooking oils, and household trash. This renewable nature, coupled with the potential to mitigate climate change through reduced carbon emissions, underscores its importance in the country's energy landscape (Saleh et al., 2022). However, notwithstanding this potential, the assessments of present utilization vary among the studies. Saleh et al (2022) emphasizes the emerging approach for sustainable energy production, while Alhassany et al (2022) highlights that this resource is not sufficiently leveraged by providing a real-world domestic example, which states that Iraqi farmers currently use biomass for local purposes such as crop fertilization and cooking gas, demonstrating its availability and obtainability but underutilization. Although these viewpoints differ, both studies concur on the potential merits of biomass energy. These merits encompass the improvement of energy security, the promotion of economic opportunities, and the facilitation of rural development Saleh et al (2022) Moreover, biomass provides cost-efficient and eco-friendly benefits, offering an opportunity to mitigate dependence on fossil fuels, alleviate environmental repercussions, and foster rural economic growth (Alhassany et al., 2022). Given Iraq's current electricity shortages and growing energy demands, both studies emphasize the imperative of investigating and utilizing the potential of biomass energy, in addition to other renewable sources such as wind and solar, to attain a sustainable energy future. Nevertheless, Alhassany et al (2022) emphasizes the critical significance of biomass conversion technology advancements in facilitating the generation of electricity on a large scale. This underscores the necessity for additional research and development to be conducted in this domain. Hossain et al (2020); Intelligent Energy (2013) demonstrated the potential of biomass energy to power telecom BSs in a renewable and sustainable manner. Biomass, which is obtained from organic sources such as plants, agricultural residues, and animal waste, presents numerous benefits within this particular framework.

- Renewable and carbon footprint reduction: In contrast to fossil fuels, biomass is a replenishable resource that promotes environmental sustainability (Hossain et al., 2020; Intelligent Energy, 2013). As an additional measure to ensure environmental sustainability, its carbon neutrality is achieved via CO2 absorption during plant growth, which aids in the reduction of GHG emissions and the mitigation of climate change. (Intelligent Energy, 2013).
- Local sourcing and reduced dependence: Utilizing local biomass resources enhances energy security for telecom stations, particularly in remote areas, by reducing reliance on imported fossil fuels (Hossain et al., 2020; Intelligent Energy, 2013). This fosters a more decentralized and resilient energy supply for cellular networks to ensure energy security (Hossain et al., 2020)
- Innovation and integration: The use of biomass energy encourages technological advancements in efficient biomass conversion technologies, energy management systems, and hybrid power solutions for telecom stations. This also promotes the deployment of advanced energy storage and smart grid technologies to facilitate the seamless integration of biomass energy into cellular networks (Hossain et al., 2020).

While both above studies focus on the potential benefits, (GSMA, 2014) provides a valuable example of real-world implementation in Africa. MNOs are adopting biomass energy to reduce costs, address operational challenges, and potentially increase coverage and subscriptions. This practical application underscores the viability of biomass in the telecommunications industry beyond theoretical considerations. Therefore, research and empirical evidence support that biomass energy has significant potential as a sustainable alternative for generating power in BSs, particularly in remote areas with abundant biomass resources, due to its environmental benefits and technological potential.

*Battery Energy Storage Systems (BESS)*

BESS are prevalent energy storage systems or devices that convert stored chemical energy into electrical energy (Jung et al., 2021). Although batteries are not classified as primary energy sources, they are essential for storing surplus renewable energy produced during periods of high solar or wind activity. The energy can be stored and utilized to operate during low-demand periods or when there is no power supply from the grid, thereby improving the dependability of renewable energy systems. Ali et al (2023); Zeljković et al (2022) highlight the crucial significance of battery storage in hybrid RESs for BTS. Typically, these systems integrate solar, wind, and DG to guarantee a reliable and environmentally friendly power source. Battery storage mitigates the sporadic characteristics of RESs such as solar and wind by accumulating surplus energy during periods of high generation and supplying electricity during periods when these sources are not accessible. This guarantees a consistent and uninterrupted provision of service to BTS sites, particularly in remote regions with unreliable access to the power grid (Zeljković et al., 2022). Moreover, the utilization of battery storage systems allows for the seamless incorporation of RESs into the power grid. This, in turn, enables the MNOs to decrease their dependence on DGs and mitigate the environmental impacts associated with their use (Ali et al., 2023; Zeljković et al., 2022). This transition to more environmentally friendly energy sources promotes sustainability and decreases GHG emissions. Studies emphasize the potential cost-saving advantages of battery storage in terms of economic and operational benefits. This is achieved through optimized energy usage and decreased reliance on expensive and harmful diesel fuel (Ali et al., 2023; Zeljković et al., 2022). It is also deserving of attention that BESS enables better control over the consumption and distribution of energy, further enhancing system efficacy (Zeljković et al., 2022).

Also, the battery depth of discharge (DoD) quantifies the extent to which the battery is discharged as a percentage. Its utmost value serves as an additional parameter that elucidates the battery, complementing the minimum SoC in percentage. Given that the cost of the battery constitutes a significant portion of the capital expenditure (CAPEX), it is prudent to consider the battery's lifespan. The computation of battery lifetime in years involves the tally of charge/discharge cycles to failure (CTF) for every range of DoD over one year. It is anticipated that batteries possessing a significant proportion of maximum DoD will experience a limited lifespan because an increased maximum DoD results in a lower CTF value, as shown in Figure 7.

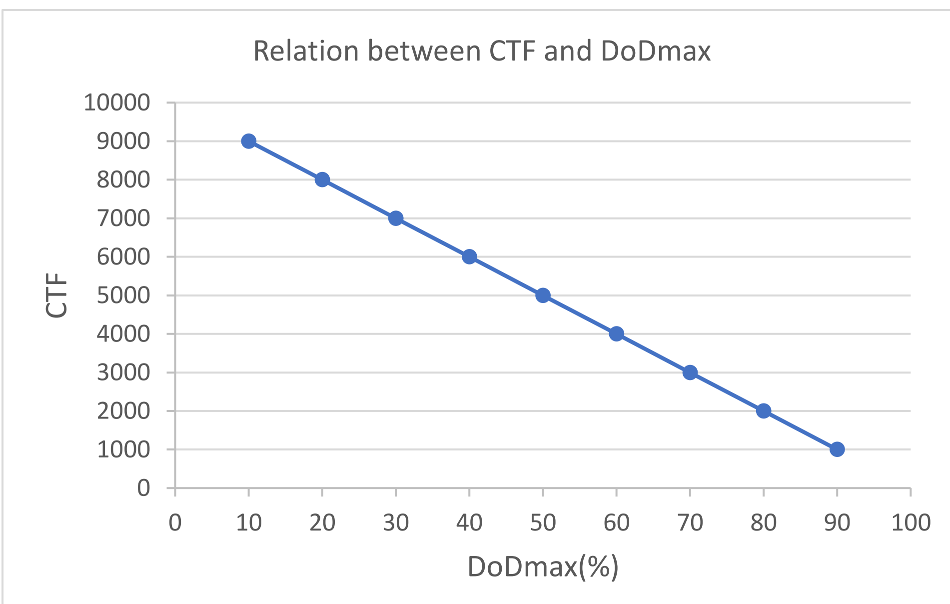


Figure 7: Relation between CTF and DoDmax (Jung et al., 2021)

The type and size of the battery are essential factors in designing RE-enabled BSs and specifying the duration that BS supports load demand without relying on other energy sources. They should be determined according to the following system requirements: cost, the number of charge/discharge cycles, operating temperature, and weight (Jung et al., 2021). Table 2 outlines the specifications of different battery types utilized in BSs. The lead-acid battery is the most commonly utilized for solar-powered BSs because of its lightweight, high-energy density, efficient storage, and affordability, despite its non-environmentally friendly disposal. When cellular BSs are not connected to a power grid, certain mobile network operators opt for modern lead-acid batteries, such as OPZS or OPZV, instead of the traditional ones. Despite the numerous advantages of the lithium-ion battery over the lead-acid battery in terms of storage efficiency, cycle life, operating temperature, and energy density, it is associated with expensive CAPEX and the negative consequence of deep draining. The sodium-sulfur (NaS) battery is highly regarded as the most promising option because of its anticipated reduction in capital cost to $120 per kilowatt-hour (kWh) and its potential to achieve 5000-6000 cycles.

Table 2
*The requirements of various battery types used in BSs (Jung et al., 2021)*

| Battery type | Capital cost ($/kWh) | Roundtrip efficiency (%) | No. of cycles | Max DoD (%) | Operational temperature (°C) | Energy density (Wh/kg) | Operation & Maintenance cost |
|---|---|---|---|---|---|---|---|
| Lead-acid (conventional) | 110~140 | 75~85 | 500~1000 | 70 | -20~50 | 30 | Very low |
| Lead-acid (OPZS-OPZV) | 140~340 | 80~90 | 1200~1800 | 80 | -20~50 | 30 | Very low |
| Nickel-cadmium | 400~900 | 70~80 | 1500~3000 | 100 | -40~50 | 50 | ≈0 |
| Nickel metal hydride | 800~1200 | 65~70 | 1000~1500 | | -40~50 | 80 | ≈0 |
| Lithium-ion | 1000~1700 | 95~100 | 1500~3000 | 80 | -30-90 | 90~150 | ≈0 |
| Lithium polymer | 950~1650 | 90~100 | 600 | 80 | -20-60 | 100-150 | ≈0 |
| Sodium sulfur (NaS) | 350~1200 | 89~92 | 2500~3500 | 100 | 300~350 | 100 | Medium (heating) |
| Vanadium redox (VRB) | 250~800 | 65~75 | 5000~10000 | 80 | 0~40 | 30~50 | High (pumps) |
| Zinc bromine (ZnBr) | 300~950 | 70~80 | 4000 | 100 | 0~40 | 70 | High (pumps) |
| Metal air | 50~250 | 50 | 100~500 | | -20~50 | 450~650 | Low |

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**Case Studies**

Table 3 summarizes global telecommunications companies' net-zero strategies, focusing on targets, technologies, and implementation details. This facilitates comparison for industry stakeholders. We will then analyze studies from various countries on RE-powered BSs and their outcomes for further insights.

Table 3
*Sustainability strategies of various telecommunication companies worldwide*

| Company | Target | Technology | Details |
|---|---|---|---|
| AT&T (USA) (AT&T, 2022) | Carbon neutral by 2035, 100% renewable energy | Solar & wind PPAs, on-site solar, battery storage | Invest in renewables, promote energy efficiency |
| T-Mobile (USA) (T-mobile, 2022) | 100% purchased electricity sourced from renewable energy | Virtual PPAs (wind & solar) | Secure clean electricity off-site. |
| Verizon (USA) (Verizon, 2024) | Net-zero operational emissions by 2035 | They are forming long-term renewable energy purchase agreements (REPAs) for solar and wind power. | Collaborate for renewables, explore on-site solutions |
| Telefónica (Spain) (Telefonica, 2022) | Net-zero emissions by 2050 | Diverse mix (wind, solar, hydro, biomass) | Reduce consumption, invest in renewables, responsible sourcing |
| Vodafone (UK) (Vodafone, 2023) | Net-zero emissions by 2040 | Focus on wind & solar | Long-term PPAs, advocate for supportive policies |
| Deutsche Telekom (Deutsche Telekom, 2022) | Net-zero emissions by 2040 | Primarily wind & solar, and explore other emerging technologies. | Invest & procure renewables, research innovative solutions |
| NTT Group (Japan) (NTT, 2023) | Net-zero emissions by 2050 | Invest in global renewable projects, data center efficiency | A global approach, optimize data center operations |
| Orange (France) (Orange Telecom, 2023) | Net-zero emissions by 2040 | Diverse mix (wind, solar, hydro, geothermal) | A geographically diverse portfolio, promotes energy efficiency |
| América Móvil (Mexico) (América Móvil, 2022) | Net-zero emissions by 2050 | Invest in wind & solar farms, energy efficiency initiatives | Direct investments & partnerships, implement |

| | | | |
|---|---|---|---|
| | | | energy efficiency measures |
| Etisalat (UAE) (Etisalat UAE, 2021) | Net-zero emissions by 2050 | Primarily solar power, explore green hydrogen & battery storage | Prioritize solar, explore emerging technologies |
| BT Group (UK) (BT Group, 2021) | Net-zero emissions by 2045 | Invest in renewables (wind & solar), energy-efficient technologies | Invest in projects, PPAs, optimize cooling systems, upgrade equipment |
| China Mobile (China Mobile, 2022) | Decrease GHG 20% by 2025 | Invest in renewables (solar & wind), energy-saving measures | Invest in solar projects, purchase renewable electricity, improve data network efficiency. |

Table 3 paints a hopeful picture of the telecommunications sector's accelerating fight against climate change. Most of the telecommunications companies aim for net-zero emissions in the short and long term, reflecting a growing sense of urgency. Renewable energy reigns supreme, in companies like AT&T, Deutsche Telekom, and Orange. Energy efficiency also shines, with data center optimization and equipment upgrades featuring prominently in strategies like Verizon's and BT group. However, while leaders like T-Mobile have already achieved 100% renewable energy in their electricity supply, others like China Mobile have a longer roadmap, as they aim for 20% renewable energy by 2025 without a zero-carbon goal that has not been set yet (China Mobile, 2022). Notably, most of telecommunications companies have a long roadmap to achieve scope 1,2, and 3 zero-carbon targets. However, some of them have net-zero targets for scop1 and 2 in the near future. For instance, Telefónica reported that they achieved 81% of Scopes 1 and 2 GHG emission reduction goals (Telefónica, 2023). Diverse strategies showcase the various paths companies are taking towards a greener future. This collective effort holds immense potential for mitigating climate change, highlighting the telecommunications industry's crucial role in building a sustainable future.

Furthermore, multiple studies have explored the utilization of renewable energy systems for powering BSs. A study conducted in Algeria demonstrated that a stand-alone system incorporating PV, wind, biomass energy, and battery storage had a 31% lower net present cost and 30% lower energy cost. The energy produced (34,879 kWh) was sufficient to meet the annual demand without any unmet load. The reduction in diesel consumption was 56% and GHG emissions decreased by more than 50% (Zegueur et al., 2023). A study conducted in Bangladesh demonstrated the effectiveness of a grid-connected system utilizing PV, biomass energy, and BESS. The system was deemed feasible and demonstrated substantial cost savings (NPC: 3.20%, COE: 6.82%) in comparison to an off-grid system. The system fulfills the energy requirements of the base station and also exports surplus energy (3141 kWh/year) to the grid while emitting minimal carbon (Hossain et al., 2020). Research conducted in Comoros revealed that a stand-alone system incorporating PV, wind energy, and BESS is the most economically efficient choice with minimal environmental consequences (no GHG emissions). However, the cost of battery storage still poses a challenge (Maoulida et al., 2021). (Bahgaat, 2023) which is a study conducted in Egypt using a stand-alone energy system with energy storage. The study determined that utilizing photovoltaic power plants is both environmentally and economically advantageous. The findings of Atchou (2020) in Ghana demonstrated that a stand-alone system incorporating PV, BESS, and fuel cell technologies can achieve a cost of $0.537 per kilowatt-hour. This system successfully met the daily energy demand, with 73% coming from solar energy and 26% from the fuel cell. Despite the battery being the priciest component, accounting for 30% of the total cost, these findings indicate that solar PV and fuel cells have potential as a cost-efficient and eco-friendly option for powering BSs. At higher loads, a stand-alone system with energy storage that combines PV, wind, and a DG is the most cost-effective option, according to a study, which was conducted in India. In particular, when loads exceed 41 kWh/day, the solar-wind-DG system emerges as the superior alternative, and its energy cost further diminishes at even greater loads (Goel & Ali, 2014). Drawing from the results of the initial Indonesian case study Wibowo et al (2018), the stand-alone system incorporating PV and BESS can effectively provide power to a base station. The solar PV system effectively powered the base station (1.15 kW) and the 2.9 kW battery supplied backup power that exceeded the demand (1.2 kW), demonstrating stable performance. An extensive and practical research carried out in Italy, demonstrated that a field study on multiple off-grid telecommunications sites revealed that hybrid renewable energy systems (stand-alone systems with energy storage) have the potential to achieve both energy efficiency and minimal fossil fuel consumption (Cordiner et al., 2017). Moreover, a study specified to Kenya revealed that a stand-alone system incorporating PV, wind energy, and a DG is a cost-effective solution. Economically, the hybrid system of solar, wind, and DG has the lowest cost at $6.89/kWh, compared to using just a generator at $21.8/kWh or relying solely on solar/wind at $8.24/kWh. However, the inclusion of a battery remains crucial to address the fluctuating nature of solar power (Patrick, 2017). Another undertaken research in Kuwait which is a neighboring country of Iraq and has the same weather conditions as Iraq's north part demonstrated that a grid-connected system incorporating PV, BESS, and a DG can reduce costs and emissions compared to a non-renewable system. Additionally, the inclusion of batteries and trackers can enhance these benefits (Baidas et al., 2021). A RE system involving RE-powered Bs connected to the grid with energy storage was tested for Lebanon and Mali. The types of RE systems used were PV and Wind Energy. Migrating to fully hybrid power supply systems in mobile networks can substantially decrease OPEX and $CO_2$ emissions (Mina & Sakr, 2019). For Libya, (Khalifa et al., 2021) demonstrates that using renewable energy-powered battery systems connected to the grid with energy storage. The renewable energy system types included PV, Wind Energy, and DG. Grid-connected Hybrid Renewable Energy Systems (HRES) exhibited lower Levelized Cost of Energy (COE) ranging from 0.106 to 0.154 $/kWh compared to standalone systems with COE ranging from 0.184 to 0.263 $/kWh in remote regions. Each HRES base station in the HRES systems reduces annual $CO_2$ and $SO_2$ emissions by approximately 14,924 kg and 63 kg, respectively. According to the findings of a study conducted in Malaysia, a stand-alone system consisting of energy storage, PV, and a DG can significantly reduce costs and emissions while ensuring sustainability and reliability. MNOs can gain environmental enhancement and achieve annual OPEX savings of 43-47% (Alsharif et al., 2015). In comparison to relying solely on a generator, the implementation of a stand-alone system comprising PV, BESS, and a DG can reduce annual $CO_2$ emissions by 16.4 tones, according to the findings of a study conducted in Nigeria. A cost-effective option, this system is installed at a cost of $69,811 plus $0.409 per unit of electricity. (Olatomiwa et al., 2015). Notably, the results of a Pakistani study indicate that a self-contained system comprising PV, wind, biomass, BESS, and a DG may be the most economical and environmentally beneficial option. A combination of solar power, DG, and battery storage is the most viable energy solution for the central and northern regions, given that its Levelized Cost of Electricity (LCOE) falls within the range of $0.1267 to $0.1815 per kilowatt-hour. Due predominantly to the importance of wind energy in that region, the most optimal energy combination for the southern region is a combination of solar, wind, DG, and battery, with a Levelized Cost of Electricity (LCOE) ranging from $0.1096 to $0.1294 per kilowatt-hour (Ahmed et al., 2018). In consequence of a study in South Africa, the outcomes revealed that a stand-alone system comprised of PV and BESS can be the most cost-effective and environmentally advantageous option. Comparative to conventional DGs, this has a lower OPEX and cost-effectiveness, and it emits no GHG (Aderemi et al., 2018). Additional researchers from South Korea embarked on a study that showed that a stand-alone system incorporating PV, BESS, and a DG can be environmentally sustainable and cost-effective (Alsharif, 2017). Differently, a study carried out in Zimbabwe unveiled that the integration of PV, BESS, and a DG into an on-grid energy storage system can substantially mitigate operational expenses, deliver 37% more power, and avert the release of 41.13 tons of GHG emissions annually. This system is regarded as the most efficient option for supplying power to BSs as claimed by (Mwanza & Mapfumo, 2023).

The studies above highlight the RESs successful implementation in wireless BSs, despite highlighting different challenges for best designs, underscoring the potential benefits of this approach

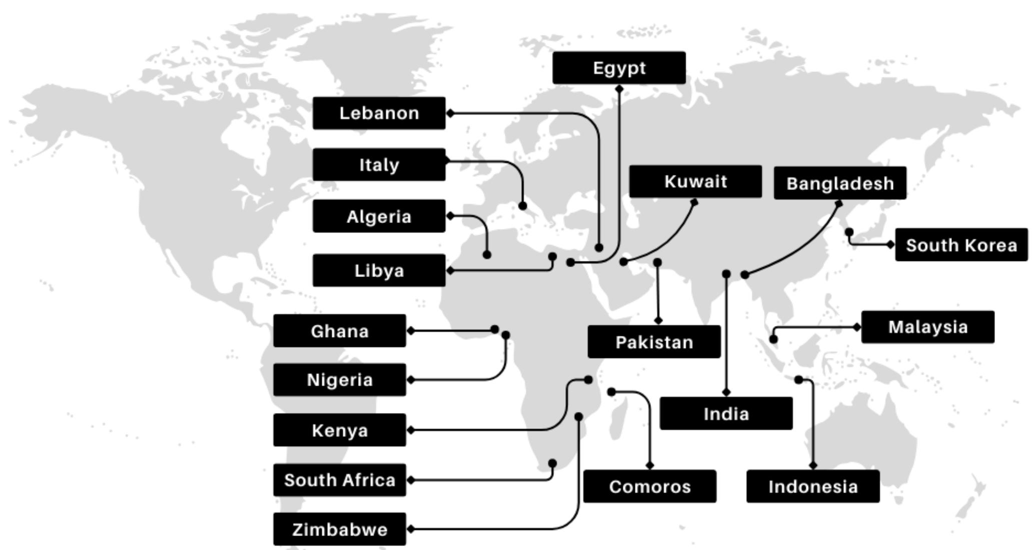


Figure 8: Country-based Distribution of RE-powered BSs Studies

**Study Key Findings**

This review's analysis underscores the significant dependence of the Iraqi wireless service providers and MNOs on fossil fuels, specifically DG, to supply power to their BSs. This reliance gives rise to substantial ecological ramifications, such as elevated carbon emissions and unsustainable and hazardous impacts. The transition to RESs emerges as a crucial strategy for mitigating the industry's environmental footprint. Specifically, solar, wind, and biomass energy

offer immense potential in Iraq due to their availability, diversity (sun, wind, organic materials), and ability to reduce carbon emissions.
However, the review identifies challenges hindering the adoption of RESs, including infrastructure limitations and unfavorable investment climates in the telecommunications sector. Despite these challenges, the review also underscores the opportunities for leveraging RESs for sustainable energy development. To facilitate the transition towards RESs, the study proposes integrating various renewable and non-renewable energy sources while emphasizing the need for clear policies, infrastructure development, and technological advancements. Additionally, this research highlights the importance of advances in biomass conversion technology for enabling large-scale electricity generation from renewable sources. Overall, transitioning the Iraqi telecommunications industry to RESs offers multifold benefits, including:

- Reduced carbon emissions and environmental impact.
- Enhanced energy security.
- Economic opportunities.
- Rural development.

The review also emphasizes the superiority of hybrid systems combining different RESs sources compared to single-source systems, highlighting the importance of diversifying energy generation methods. Furthermore, the review suggests that focusing on environmental aspects can lead to effective sustainability measures for Iraqi wireless service providers or MNOs. These measures can contribute to:

- Safeguarding ecosystems.
- Decreasing GHG emissions.
- Enhancing air quality.
- Mitigating climate change.
- Promoting healthier communities.

Also, we found that renewable energy emerges as a promising solution for powering telecommunications BSs, particularly in remote areas. However, careful design and integration with other energy sources, including backup generators for critical situations, are crucial for ensuring reliable service. Furthermore, optimizing RESs design can minimize the need for backup generators, contributing further to sustainability. In the domain of RESs, PV systems stand out as an especially appealing alternative. These are among their benefits:

- Environmental friendliness.
- Cost-effectiveness.
- Reliability.
- Significant savings in OPEX.

This is following the sector's dedication to diminishing its environmental impact and advocating for energy-saving adoption, thereby making a positive contribution towards a more ecologically sound and sustainable telecommunications paradigm. Likewise, wind energy provides an analogous sustainable, and dependable alternative for generating power for BSs. Integration of wind energy with other resources may result in

- Cost savings

- Minimized carbon emissions
- Enhanced energy independence

This study also sheds light upon the significance of additional research and development endeavors for maximizing the potential of RESs for a sustainable Iraqi telecommunications sector. After all, this review illuminates the important function of BESS to cavernously ensure constant operations, efficacy, and efficiency in energy management, eco-friendly practices, and ecological responsibility for wireless BSs, especially in remote areas that suffer from inadequate electricity supply. The integration of BESS with other RESs participates in enhancing the functionality and efficacy of a RES system.

**Conclusion**

This study sheds light on the problem of using DGs to power telecommunications BSs in Iraq due to the electricity deficit the country has been experiencing for more than two decades. This practice has led to a hazardous impact as a result of GHG emissions caused by fossil fuels. Therefore, the transition to the use of renewable energy has become an urgent necessity. Accordingly, this study analyzed the potential benefits, challenges, and real-world implementation of renewable energy-based solutions for powering wireless stations In Iraq, with a focus on solar, wind, and biomass. The study found that transitioning to RES offers significant benefits, including environmental sustainability and potentially improved economic viability. Additionally, hybrid systems combining different RESs sources emerge as a promising strategy for a greener and more sustainable future for Iraqi telecommunications. However, overcoming infrastructure limitations, securing investment, and establishing clear policies remain crucial steps for successful implementation.

**Future Research and Recommendations**

Future research can significantly contribute to a smooth transition to RESs for Iraqi wireless service providers. Techno-economic analyses of specific renewable energy options, like varying-sized solar PV systems, could provide crucial data on costs, energy production, and payback periods. Additionally, a roadmap outlining strategies for infrastructure development, attracting investment, and establishing clear renewable energy policies would be highly valuable. To optimize system resilience, future studies could explore incorporating battery storage solutions alongside RESs. Furthermore, research into lifecycle assessments of different RESs options could provide valuable insights into their environmental impact throughout their entire lifespan.

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