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Solar Energy in Kurdistan, Iraq: A Comprehensive Review of Economic and Environmental Implications, Policies, and Advancements

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Abstract

This review article prepares an evaluation of the role that solar energy plays, in Kurdistan, Iraq. Specifically, it concentrates on the implications for the region's economy and environment. By considering sources and empirical studies this review provides a comprehensive overview of the current status of solar energy adoption in Kurdistan. In addition, it explores the associated policy framework. Evaluates both the economic effects, within this specific context. The initial analysis discovers the network of policies and regulations that shape the energy landscape in Kurdistan. It prepares insights, into the opportunities and challenges associated with these policies. The study also considers the advancements in photovoltaic systems, energy storage, and grid integration in this region. These advancements play a significant role in ensuring efficient solar power generation.

Moreover, this review thoroughly evaluates the impact of energy. It emphasizes how cost-effective it is and highlights its potential to increase energy security mitigate reliance on fuels and stimulate growth, in Kurdistan. It also discovers the barriers to adoption, offering insights into financing mechanisms and investment strategies essential for unlocking the full economic potential of solar energy. In the realm of environmental considerations, this review evaluates the profound effect of solar energy adoption in terms of reducing carbon emissions, reducing air pollution, and promoting sustainable development. The results emphasize the regional commitment to a cleaner and more environmentally responsible energy infrastructure.

Finally, this article underscores the multifaceted opportunities and challenges that solar energy presents in Kurdistan. By preparing a balanced evaluation of policy, technology, economics, and environmental aspects, it equips policymakers, scholars, and industry stakeholders with valuable insights for fostering the widespread integration of solar energy in this dynamic region. Through critical analysis and nuanced recommendations, this review contributes to the current discourse on Kurdistan's transition toward a sustainable and economically viable energy landscape.

Keywords: Solar Energy, Kurdistan, Environmental Impact, Economical Effect

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Introduction

Energy is usually compared to the lifeblood of modern society, underlining our irrefutable dependence on a trustworthy and continuous energy supply. However, this dependence has traditionally been placed on non-sustainable resources, particularly fossil fuels that have driven our societal progress for many years. In the previous three decades, a critical issue has emerged, threatening the future of our planet the portentous threat of global warming. Driven by constant technological advancements and an enhancing global population, our reliance on fossil fuels has grown at an alarming rate, leading to a significant environmental crisis. Pollution and environmental devastation have reached concerning levels, causing discomfort and concern. (Salem Algarni et al. 2023, Tran Thai Ha Nguyen et al. 2023).

Recognizing the detrimental ecological repercussions engendered by the utilization of fossil fuels, a conscientious quest to explore alternative energy reservoirs has arisen as an essential pursuit. The pressing need to protect our environment from pernicious pollutants has highlighted the need of conducting an comprehensive investigation into the feasible and ethical dimension of renewable energy sources (RES) as a means for electricity generation. Renewable energy sources, including a diverse range of options such as solar, wind, and hydroelectric power, possess substantial potential to make significant contributions across the multilateral sides of energy sustainability: economic, social, and environmental. The use of such resource's spreads energy availability across a significant portion of a community and thus helps to reduce emissions within the local area as well as on a global scale and is therefore beneficial for clean air and a healthy planet. Furthermore, their implementation has the inherent capability to catalyze localized socio-economic development, initiating in new opportunities for prosperity and growth in communities where RES projects are established.

Population growth is inevitable in most countries, along with their economic development brings about serious ecological problems. The deleterious impacts associated with traditional energy production techniques make them environmentally disruptive. Given that energy is important to wealth creation it becomes quite significant among all economic development issues. As critical elements of the bigger storyline on Sustainable Development and the multi-pronged purpose of

fighting poverty, it plays an integral role. The reach is very broad because it affects different aspects of lives such as the society through the social life, economics, as well as environment. (Ouattara, A. et al. 2013).

The utilization of renewable energy sources has become an important agenda for many countries and governments globally starting from 1991. With this shift, this concern grows due to fear that fossil fuel reserve is getting exhausted and the danger of global warming. (HenrikLund.,2010).

In the year 2007, a considerable amount surpassing $100 billion was allocated to investments in renewable energy, containing various aspects such as production assets, manufacturing, and research and development. This substantial commitment extended its influence globally, contributing to over 2.4 million employment opportunities within the development of renewable energy sector. These investments assumed an essential role in propelling clean energy initiatives and nurturing a sustainable, employment-driven future (REN21, 2007).

Many sustainable energy sources are characterized by unique attributes that help to mitigate our dependence on finite and often geopolitically challenged fossil fuels. Such a change reveals fundamental changes in the energy paradigm bearing enormous implications on energy security as well as the economic strength of nations. Through embracing green sources of power, countries reduce vulnerability to oil market volatilities that result in periodic enhances in fuel prices. Such price spikes can trigger successive shocks throughout global value chains whose operations depend on fuel as an input or for transporting goods. Such resilience is associated with the essential stability and orderly nature of sustainable forms of energy (André Månberger, 2021).

Renewable Energy: A Path to Energy Security, Economic Growth, and Environmental Sustainability

They include the ones based on renewable energy like solar, wind, and hydropower whose sustainability is greater than what comes with interruptions. The stability of the national energy systems is enhanced by this reliable energy production as well as reduced vulnerability to the fluctuating movements of fossil fuel markets. In addition, most sustainable energy installations are tailored to serve specific areas, therefore increasing self-reliance at home thereby reducing dependence on foreign energy supply systems that tend to be fickle at times. A shift towards dependence makes economies less vulnerable to external impacts and assists in developing strong

distributed energy systems that tolerate interruptions and ensure reliability. (André Månberger, 2021).

Additionally, the move towards green energy sources also promises an environment-friendly period that would substantially solidify energy security and economic growth. Such repositioning reduces exposure to price volatility and possible disruption in supplies thus enhancing resilience to operate in an open energy market environment. Multiple domestic renewable energy sources like solar, wind, and HEP are abundant for local harvesting. It cuts down on the amount of energy needed from foreign sources, which improves the country's energy independence and buffers its economy from external forces in the global energy market. Furthermore, moving towards green energy sources leads to a new eco-friendly chapter in history and drastically changes the whole energy scene while promoting energy security and a better business climate. Such strategic realignment reduces vulnerability to pricing volatility and disruption of supplies and thus strengthens state resilience against swings in the international energy arena.

Domestic clean energy resources such as sunshine, wind, and hydro-power are generally readily available for harnessing and use. As such, it lowers the expense of importing energy thus leading to energy independence and reduction of vulnerability in the international energy market. Employment is one of the ways that renewable energy improves the economy in this country. There are new jobs on both sides – manufacturing, installation, and maintenance as well as research and development (R & D) for clean energy investments that create employment and thus foster economic growth. In this regard, there is an impressive economic perspective from the Netherland's point of view. By 2030, this step will have resulted in over 50,000 additional jobs and contributed one percent to the country's GDP (Tatyana Bulavskaya, 2018).

Our dependence on finite and sometimes insecure geological reserves, by their nature, is substantially lessened by sustainable energy sources (Tansu Galimova, 2022). Such an adjustment in energy paradigms carries significant bearing on a nation's economic stability and energy safety. Through using sustainable energy, countries become less susceptible to the fickleness of international gas markets where one may unexpectedly experience sharp price swings leading to a shortage of supplies that can have significant ramifications. The strength is because of the natural nature of renewable energy which makes it stable and easily predictable. Some of these sources like solar power, wind power, and hydroelectric power have high sustainability capability for energy generation while their output is almost constant and less subject to interruptions by

external factors. The stable and dependable power production associated with low vulnerability to fluctuations in oil prices stabilizes a nation's energy system. Additionally, most sustainable energy installations are geared towards the local markets, thus improving domestic independence, which converts to lower dependency on more vulnerable external supplies. Moving to self-dependence in economies means isolating those economies from exogenous disturbances that make them more stable. This also helps to create flexible, wide-ranging, energy grids that can weather attacks and support energy security (Tansu Galimova, 2022).

Energy Challenges and Opportunities in Kurdistan: A Focus on Renewable Solutions

The Kurdistan Region is situated in the southwestern part of Asia and the northeastern region of Iraq. It encompasses three distinct governorates, namely Erbil (Hawler), Suleimani, and Duhok, all of which are situated within the northern sector of the Federal Republic of Iraq. The climate in Kurdistan is distinguished by its pronounced extremities and embodies the conventional characteristics of a continental interior climate. This meteorological profile is illustrated by significant differentials in temperature, not only between day and night but also between the contrasting seasons of winter and summer, imparting to the region a specified climatic temperament (Kurdistan Regional Government Area of Iraq, 2009).

The Kurdistan region occupies a strategic geographical position, defined by specific longitudinal and latitudinal coordinates. located between the longitudes of 42 degrees 25 minutes East and 46 degrees 15 minutes East, as well as the latitudes of 34 degrees 42 minutes North and 37 degrees 22 minutes North, this region contains a distinctive expanse of our planet. Within this geographical framework, the region is further subdivided into three distinct governorates, each characterized by its own unique area. Sulaymani boasts an expansive area of 17,023 square kilometers, Erbil occupies 15,074 square kilometers, and Duhok covers an area of 11,715 square kilometers. These precise geographic measurements delineate the territorial dimensions of these governorates within the larger geopolitical condition of the Kurdistan region.

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dimensions of these governorates within the larger geopolitical context of the Kurdistan region (Rashid R.H.M., 2014).

Located in the northern expanse of Iraq, the Kurdistan Regional Government (KRG) has struggled with a complicated energy conundrum. The inherent shortage of electricity within its energy infrastructure underlines a collection of complex challenges that need resolution in prediction of the forthcoming upsurge in power demand. It is noteworthy that a substantial proportion, approximately 85%, of the power generation in the region remains fundamentally contingent on fossil fuels, exemplifying a reliance on conventional energy sources. In contrast, the remaining 15% is apportioned to the domain of hydroelectric facilities, constituting a comparatively limited contribution from renewable sources (Diler Haji Morad, 2018).

Within the expanse of Iraqi Kurdistan, home to a population exceeding five million, the notion of secure and ongoing access to energy resources is, unfortunately, a privileged exception (Yaseen Hasan, 2018). While the region indeed possesses fossil fuel resources, the prevailing challenge lies in the deficiency of electrical generation capacity. As a result, the demand for electricity remains deep-rooted disproportionated, a discrepancy that is notably pronounced during the sweltering summer months and the freezing winter season when energy consumption reaches its zenith. Consequently, the Kurdistan region finds itself necessitating the procurement of electricity from neighboring countries, specifically Turkey and Iran, to bridge the considerable energy deficit (Mirza, S. A. and Arif,A. A., 2015).

As per the Ministry of Planning's records, a conspicuous energy deficit of 579 megawatts was discerned in the power supply landscape during the year 2012. An overwhelming majority, amounting to nearly 82% of the aggregate power requisition in the northern region of Iraq, is underpinned by the government's provision (Government, 2013). The zenith of electricity demand manifests during the summer season, precipitating an approximate 50% surge in the typical requisition for electrical power. This seasonal peak corresponds with an increasing of the electricity demand-supply deficit (Kazem, A.A., 2014).

In the annum of 201, an illuminating tableau emerged, outlining the complexities of electricity market distribution. Principally, the residential sector, constituting the realm of households, asserted its dominance with a commanding 54% share of the overall consumption. In a contrasting role, the agricultural sector assumed a discernible position, contributing a significant 13% to the collective electricity utilization. Intriguingly, the government and commercial sectors

exhibited a notable symmetry, each converging at an analogous consumption ratio of 12%. This mirroring effect underscores the balance maintained within these two sectors. In addition, the industrial sector inhabited the lowest level of the consumption range, its share comprising a modest 9% of the total electricity demand (Issa, B., 2014).

The significance demand for electrical energy emerges from the domestic sector, mainly driven by the escalating dependency on electricity for an array of purposes, notably air-conditioning, water heating, space heating, and culinary applications. This heightened usage is particularly pronounced during the climatic extremes of both winter and summer. In the contemporary landscape, the collective installed capacity of power stations throughout the broad area of the Kurdistan region attains a notable 3200 megawatts (MW) (Yassen, H., 2016).

The mean energy consumption per individual in the Kurdistan Region stands at 3,918 kWh, a figure that markedly surpasses that of neighboring countries such as Jordan, where per capita energy consumption is registered at a comparatively lower 1,539 kWh. As attested by the Ministry of Electricity in Kurdistan, during the spring of 2016, Kurdish residents experienced an unfortunate daily shortfall in electricity supply, averaging four hours, while the winter months subjected them to a far more pronounced scarcity, with power outages stretching beyond a staggering 13 hours per day. These interruptions stemmed from government-imposed mandates, intended to manage the electricity grid. Notably, such erratic availability can be attributed to an escalating demand for electricity in tandem with the region's burgeoning economic growth, rendering the challenge of power provision a pressing concern (Dashti Adil, 2023).

Kurdistan finds itself grappling with a pronounced deficit in electricity production, which is further exacerbated by a substantial and ever-increasing demand. This heightened call for maybe usually attributed to the speedy proliferation of the residential production zone that has burgeoned over the last few years.

The complexity of the electricity situation in Iraqi Kurdistan is undeniable. While the region maintains its independent power grid, self-sufficiency remains a distant goal, reliant as it is on external electricity imports from the larger Iraqi network. Over the recent years, recurrent power blackouts have become increasingly commonplace, giving rise to widespread disturbances and stoking public discontent. The intricate web of factors contributing to the electricity predicament in Iraqi Kurdistan encompasses multiple dimensions. Foremost is the stark underinvestment in the power grid, a glaring impediment. The antiquated and inefficient state of the region's power

plants only exacerbates the inability to meet the surging power demand. Adding to the labyrinthine nature of the problem is the persisting political instability within Iraq. The enduring strife between the central Iraqi government and the Kurdistan Regional Government (KRG) has significantly hampered the harmonization of power imports and exports, thereby further complicating the electricity dilemma in this setting (Shafaq news, 2023).

Drawing upon the insights gleaned from an in-depth literature review, it's miles discerned that the energy needs within the Kurdistan region amount to a widespread 3,279 megawatts (MW). In comparison, the prevailing strength supply, aggregated from diverse assets, currently stands at approximately 2,700 MW. Consequently, this dichotomy indicates a considerable deficit in the realm of power generation, amounting to a noteworthy 579 MW (Salar Salah Muhy Al-Din et al.2017).

The statistical data pertaining to Northern Iraq paints a vivid picture of the region's energy landscape. In 2004, the total energy demand stood at a modest 829 megawatts (MW). However, in a remarkably transformative span of just eight years, this figure skyrocketed to a substantial 3,279 MW by 2012. This awesome surge represents an almost fourfold increase in electricity demand over the direction of a single decade. Of particular note is the astonishing jump in energy demand within the span of a single year, reflecting an almost 100% increase. These compelling statistics serve as a testament to the region's rapid economic development, technological advancements, and expanding population, all of which converge to drive the relentless need for power generation and the modernization of energy infrastructure (Meurs, P. v., 2008).

The persistent and unyielding surge in the requirement for electrical power within the Kurdistan Region represents a substantial and pressing quandary. Extended electrical disruptions exert a profound and far-reaching influence on the expansion of all economic domains within the Kurdistan Region. Enterprises and manufacturing facilities reliant on substantial power consumption find themselves compelled to limit their activities during power blackouts or opt for the deployment of costly generators. The on-site generation of electricity through diesel generators, in the present economic climate, incurs a cost twice as high for industrial and commercial sectors when juxtaposed with the expense associated with electricity sourced from the public grid. This pronounced disparity notably undermines the competitiveness of locally produced goods against imports, owing to the heightened operational overheads. Electricity losses represent a formidable challenge for the Kurdistan Regional Government (KRG), wherein

the Ministry of Electricity (MOE) asserts that a notable 40% of the electricity supply dissipates within the distribution network (Dashti Adil, 2023).

Preceding the pivotal year of 1991, the administration of Kurdistan's electric grid was orchestrated by way of the critical authorities of Iraq. However, in the aftermath of 1991, while the place launched into its path towards self-governance, the energy distribution framework in city centers like Sulaimania, Dohuk, and Erbil became subjected to a lamentable state of disrepair. This country of disrepair changed into no longer simply an end result of herbal attrition but, lamentably, an immediate consequence of orchestrated acts of destruction. Numerous electricity stations and essential substations met their death through planned explosive detonations and different kinds of orchestrated sabotage, thereby compounding the vicinity's strength woes (Diler Haji Morad, 2018). Energy expenditure within the realm of architectural structures undeniably stands as a central facet of the global energy paradigm, constituting a substantial 40% of the overall planetary energy utilization. Notably, this consumption pattern within the building sector exhibits a consistent upward trajectory, marked by an annual growth rate of 2.2%. This persistent trend accentuates the compelling necessity for pioneering and sustainable methodologies to ameliorate the escalating energy requisites, placing a heightened emphasis on the facets of efficiency, conservation, and the seamless integration of renewable energy sources. These imperatives are of paramount significance in the overarching global pursuit of energy sustainability and the concurrent commitment to environmental stewardship (Zhao H. and Magoulès F. A, 2012).

In 2013, the Kurdistan Regional Government (KRG) formulated its Vision 2020, delineating a set of objectives for both the governmental and private sectors. While this visionary document endorsed the integration of renewable energy sources, it did so with a measured approach. It stipulated that these sources ought to not only be environmentally beneficial but also financially viable (Hannah Lynch, 2018).

The Kurdistan Regional Government (KRG) emphasized its dedication to renewable power, underscoring its efforts to strengthen power production to three,500 megawatts. However, regardless of this increase, the persisting demanding situations of gasoline shortages and water scarcity continue to obstruct the area's capability to fulfill the ever-developing demand for power. In this transformative landscape, sun strength, especially harnessed via photovoltaic (PV) cells, emerges as a beacon of promise. This candidate not best holds the potential to lessen our

dependence on fossil fuels but also represents a sustainable, eco-conscious, and environmentally harmonious trajectory. It offers a ray of desire in our collective enterprise to fight global warming, safeguard our planet, and chart a route towards a sustainable and wealthy future for all generations to come back (Azhi Rasul, 2023).

Solar Energy Potential in Kurdistan

Kurdistan, akin to numerous locales within the geopolitical limitations of Iraq, is endowed with a sizeable inflow of sun irradiance throughout everything of its annual calendrical cycle. It is vital to underscore that the precise geographic coordinates, in phrases of each latitude and longitude, at a given area within Kurdistan, play a pivotal position in figuring out the quantum of solar power that can be correctly harnessed. The climate of Kurdistan can be categorized as semi-arid, with a summer time that unfolds from June to September. During this era, the weather turns intensely warm and dry, with the maximum excessive temperatures commonly going on in July and August. It's no longer unusual for the mercury to upward push to a sweltering 45°C at some stage in these sizzling summer season months (Kurdistan Regional Government, 2023).

The geographical positioning of Iraqi Kurdistan places it within a notably sun-drenched locale. Here, the daily solar radiation averages almost 4.81 kilowatt hours per square meter ($kWh/m^2/day$), a level that closely parallels the daily solar potential of California, a U.S. state renowned for its solar energy resources. This abundant solar irradiance underscores the region's substantial untapped solar energy potential (Yaseen Hasan, 2018).

The extraterrestrial hourly solar radiation values exhibit a notable spectrum of variation, contingent upon both location and the time of year. To exemplify, at the Qadish location, the monthly values fluctuate between 4.32 kilowatt-hours per square meter per day ($kWh/m^2.day$) in the month of December, marking the winter months, and a substantial 11.57 ($kWh/m^2.day$) in the month of June, characterizing the height of summer. The Gopal, Jelan, and Qadish locations all resonate with this pattern, showcasing the distinctive annual cycles of solar radiation availability. The summer season, encompassing the months of June, July, and August, stands as the zenith of temperature extremes within the Kurdistan region. During this period, the mercury soars to a scorching 42 degrees Celsius, with the most torrid days witnessing a blistering 48 degrees Celsius. This period is marked by an abundance of sunshine, with an average of approximately 12.5 hours of bright sunlight per day.

Based on the data presented in Table 1, it is evident that Kurdistan exhibits significant solar energy potential on a monthly basis.

In contrast, the winter season, spanning December and January, unfolds as the nadir of temperature variation, with average temperatures plummeting to a chilly 2 degrees Celsius, and the coldest days recording frigid -5 degrees Celsius. Sunshine becomes scarcer during these months, with an average of 5.5 hours of daylight per day. Moreover, the daily solar radiation fluctuates significantly, ranging from around 7.7 kilowatt-hours per square meter (kWh/m²) during the sweltering summer months (June, July, and August) to approximately 2.4 kWh/m² during the frigid winter period (December and January) (Hamadamin, H. K. et al. 2015).

Furthermore, the global recorded hourly values also showcase noteworthy variations. In the same Qadish location, the monthly values range from a modest 1.64 kWh/m². day in the month of December to a far more substantial 9.14 kWh/m². day in the month of June, reflecting the pronounced influence of seasonal changes and geographical location on solar radiation patterns. This data underscores the dynamism of solar radiation, offering invaluable insights for those seeking to harness this vital resource for energy generation and environmental applications (Saeed, M.A., and Qadir, K.W. 2010, Salar Salah Muhy Al-Din et al. 2017).

Table 1. The Average Monthly Solar Radiation in the Kurdistan Region (Husami, M. S., 2007)

Month	**Monthly Sunshine (h/month)**	**Average Monthly Solar Radiation (kwh/m^2/month)**
January	158.10	77.21
February	160.79	91.03
March	208.22	134.26
April	209.00	154.51
May	303.80	207.53
Jun	375.00	237.22
July	360.12	231.50
August	360.12	219.73
September	301.00	173.06
October	255.49	131.97

November	175.50	84.31
December	112.38	60.78
Total	2979.5 hr/year	1803.09 kWh/m^2/year
Average	8.16 h/day	4.94 $kWh/m^2/d$

The assessment of solar energy potential in Kurdistan relies on data collected by FAO Agro-meteorological stations within the region. The evaluation unveils the following key metrics: An annual average total sunshine duration of 2979.5 hours, equivalent to about 8.16 hours per day. An average annual solar radiation level of 1803 kWh/m²/year, approximately 4.94 kWh/m² per day (Rozhan Sardar, 2020). At present, within the region, only a mere 2% of renewable energy resources have been harnessed and put to use (Azad Azabany et al. 2014).

In Kurdistan, various studies have examined the potential of harnessing wind and solar energy resources. The collective findings of these investigations affirm that the region boasts a promising opportunity to tap into the abundant solar and wind energy sources for heat and power generation (Hussein, A. K. and Miqdam, T. C., 2012). The Kurdistan Region, despite its substantial solar energy potential, currently hosts only a limited number of solar power initiatives. These include a few healthcare clinics, an educational institution, and a water pumping station, all of which receive backing from the United Nations' International Organization for Migration (IOM). This underutilization of solar technology underscores the vast untapped possibilities within the region (Hannah Lynch, 2018).

The geographical location of this region affords it the advantage of abundant sunshine for a significant portion of the year, with an average daily solar radiation intensity spanning from 2000 kWh/m² to 2500 kWh/m². This ample solar resource presents a valuable opportunity not only for harnessing electricity but also for the utilization of solar energy in its thermal form (Al-Mazroay and Tareq Aziz Dawood, 2023).

Research efforts and studies in the Kurdistan region of Iraq have delved into the multifaceted aspects of solar energy, drawing data from Erbil city via the solar radiation database "PVGIS-CMSAF." In the Erbil area, the analysis of power output reveals an annual average power output of approximately 0.79 kilowatt-hours per square meter (kWh/m²). Additionally, a separate study

was conducted in the city of 'Koya' to assess the potential of photovoltaic (PV) systems for generating power, specifically for a 200-kilowatt (kW) setup (Azad Azabany et al. 2014).

A predominant application for solar photovoltaic (PV) panels lies in their use for off-grid purposes. In this context, the advantage is twofold: firstly, there's no requirement for the extensive and costly construction of long power lines to reach remote areas, and secondly, it necessitates the incorporation of storage solutions to ensure a consistent power supply. In these off-grid PV systems, surplus electricity generated during periods of abundant sunlight is stored within batteries. This energy reservoir serves a crucial role, enabling the PV cells to continue functioning even when sunlight is limited or unavailable. It represents an elegant and practical solution, ensuring that off-grid locations can access a stable and continuous supply of electricity, thereby bolstering self-sufficiency and reducing the need for costly and logistically complex infrastructure development (Trapani, K. and D. L. Millar, 2013).

The utilization of Photovoltaic Geographic Information System (PVGIS) or radiation databases represents a pivotal component of this system's operation. In essence, these data sources require access to information on solar radiation, which serves as the foundational bedrock for generating estimations of photovoltaic (PV) system performance. However, it is imperative to recognize that these estimations are contingent upon solar radiation levels, which exhibit considerable variability driven by climatic differences. This inherent variability implies that the data's accuracy is not absolute, underscoring the necessity to discern the strengths and limitations of the data sources. Solar radiation data at the Earth's surface can be derived from two primary sources: ground measurements and calculations based on satellite data. Both sources have their unique attributes and applicability, and a judicious understanding of their strengths and weaknesses is paramount for the precise assessment of PV system performance and the overall effectiveness of the system in question (Šúri M., 2005).

Advancements in Solar Energy Initiatives within Kurdistan

A comprehensive theoretical analysis of recent studies regarding the potential of Photovoltaic Panels (PV) in the Kurdistan region reveals a promising and practical application across various domains within the area. Evidently, there exists a compelling imperative to reduce the reliance on fossil fuels and transition towards the utilization of renewable energy sourced from solar means. Over the past decade, a substantial body of research and development initiatives has been

undertaken, notably within the Kurdistan region of Northern Iraq. These endeavors encompass a broad spectrum of aspects pertaining to solar energy, with a specific focus on the energy output of photovoltaic (PV) modules, elucidating disparities across diverse regions within Iraq.

However, it poses a perplexing paradox that, despite the abundant solar resources at its disposal, the region has exhibited hesitance in earnestly embracing distributed solar power. Currently, the landscape is adorned with only a trifecta of modest, privately-established solar photovoltaic (PV) installations, collectively contributing a meager 500 kilowatts (kW) to the overall generating capacity. Notably, the Iraqi-Kurdistan government has conspicuously refrained from pursuing renewable energy infrastructure. This hesitance is primarily ascribed to the region's substantial endowment of oil and gas reserves, which have historically taken precedence, in conjunction with a severe fiscal quandary dating back to 2014 (Yaseen Hasan, 2018).

In a meticulous comparative analysis, Kurdistan and the United Kingdom were scrutinized concerning their utilization of 20% efficient silicon solar cells. The outcomes of this investigation, conducted over a span of 307 days, reveal an intriguing narrative. Kurdistan, through its adept utilization of silicon solar cells, exhibited the capacity to generate a substantial daily electricity output, amounting to 14.4 kilowatt-hours (kWh/day). In stark contrast, the United Kingdom's corresponding daily electricity generation, over the same temporal framework, reached a more modest 4.8 kWh/day. This discernible dichotomy underscores the remarkable efficiency and dynamism of Kurdistan, rendering it threefold more proficient in electricity production compared to its British counterpart. Such empirical findings, when contextualized within the broader spectrum of preceding research endeavors, collectively underscore the region's prodigious potential and innate aptitude for harnessing solar energy as a preeminent source of electricity generation (Azad Azabany et al. 2014).

The utilization of a 100-square-meter solar panel array yields the capacity to generate approximately 1% of the requisite electricity for the region. This seemingly modest contribution, however, bears substantial importance in fulfilling the local populace's electricity demands. The compelling proposition lies in the scalability of this technology, whereby the allocation of larger surface areas facilitates even greater electricity production. Moreover, the advent of cutting-edge flexible solar cell technologies currently under development holds the promise of a more profound transformation. This technological evolution could potentially supplant a substantial proportion of the electricity currently derived from fossil fuel sources, thereby ushering in a

renewable solar energy era, which is both environmentally and economically advantageous (Azad Azabany et al. 2014).

As per the data compiled by researchers, an evaluation of the efficiency of photovoltaic (PV) systems within the region indicates a noteworthy dependency on solar energy. This renewable energy source exhibits a compelling capacity factor, hovering around an impressive 70%. This robust capacity factor underscores a level of efficacy that is decidedly satisfactory, affirming solar energy's status as a dependable and pivotal renewable energy source within the Kurdistan region (Mirza, S. A. and Arif,A. A., 2015). A recent research endeavor conducted in 'Sulaymani' undertook an examination of carbon dioxide (CO_2) emission reduction facilitated by the implementation of a Solar Photovoltaic (PV) project with a 315-kilowatt (kW) capacity. This comprehensive study engaged in a comparative analysis between the emissions stemming from electricity generated through PV panels and those produced via fossil fuel sources (Khan, K. et al. 2014).

In 2010, Saeed and Qadir presented in their study underscore the considerable wealth of solar energy resources within the Kurdistan region. By harnessing solar energy applications, the region can substantially reduce its reliance on fossil fuels, thereby mitigating pollution and preserving the local environment, ensuring its cleanliness and ecological health. In the context of technical specifications, the study scrutinizes the performance of the photovoltaic panel, specifically the LA361 K51S model, boasting a rated power of 51 watts. The total surface area of this solar panel amounts to 0.44 square meters, resulting in an impressive rated power output of 115.9 watts per square meter (W/m^2). With this configuration, it is estimated that this type of solar panel, when installed and operational in Kurdistan, can generate approximately 520 kilowatt-hours per square meter (KWh/m^2) annually. This estimation assumes that the system operates during the hours when solar radiation is available in the region's various locations. Such data highlights the substantial potential for clean energy production through solar panels in the region.

The Ministry of Electricity in Kurdistan has made a strategic decision to engage three local enterprises in the construction of 100-megawatt solar power plants in the governorates of Duhok, Erbil, and Sulaymaniyah. This directive was relayed by an official spokesperson representing the ministry. These projects are scheduled for swift implementation, with the commencement slated for early 2022, and a projected completion within six months. The electricity generated by these solar facilities has been efficiently integrated into the public grid. It is essential to recognize that

these three projects represent integral components of Kurdistan's visionary, long-term agenda, aiming to harness 900 megawatts of environmentally sustainable energy by the year 2030 (Anna Ivanova, 2021).

The research findings illuminate a compelling insight: a considerable 63% of the participants expressed a preparedness to incur supplementary costs beyond their current electricity bills to secure a renewable energy power supply. Notably, within this subset, approximately 42% are amenable to absorbing an additional expenditure ranging from 1% to 10%. However, the sentiment regarding regional production of renewables emerges as nuanced and heterogeneous. Participants display a mixed array of opinions and degrees of acceptance on this front (IRENA 2021, 2021).

In 2015, Asian Development Bank highlights the variability in power output potential, with certain locations yielding an annual average of approximately 0.30 kilowatt-hours per square meter (kWh/m²). Moreover, specific regions exhibit even higher levels of solar energy potential, soaring to approximately 0.79 kWh/m². Concurrently, the system efficiency falls within the range of 15-19%. The results from the 'Koya' study elucidate that the total power output amounts to approximately 0.3 kWh/m², and the area designated for PV panels spans 1,400 square meters. In the pursuit of these investigations, Photo-Voltage Geographical Information System (PVGIS) software was harnessed to simulate critical parameters. These simulations encompassed the assessment of irradiation rates, optimal panel inclinations, and the calculation of the average energy yield obtained from these PV systems (Diler Haji Morad, 2018).

Challenges and Solutions:

In the Kurdistan region, there has been a gradual introduction of solar collecting panels into the local markets. However, the pace of adoption is hindered by several key factors. Firstly, there exists a noteworthy absence of comprehensive knowledge regarding renewable energy, particularly the intricacies of solar energy, among the general populace. This lack of awareness contributes to the prevailing reluctance to embrace these innovative technologies.

Additionally, the limited enthusiasm and financial support from the government further exacerbate the challenge of cultivating popularity for these novel sustainable energy solutions. The dearth of incentives and investment in this sector consequently acts as a significant impediment to the widespread utilization of solar collecting panels within the region (Mohamed

Shwan Husami, 2007). Nonetheless, the year 2014 bore witness to a fiscal crisis of notable proportions, a turning point that compelled the government to undertake a profound reassessment of its policies, notably its profound reliance on oil as a financial mainstay. This catalytic moment served as a catalyst for the government to imbue renewable energy sources with a newfound seriousness, and this transition in perspective was underscored by Kareem's advocacy (Hannah Lynch, 2018).

At this juncture, the Kurdistan Region finds itself characterized by a conspicuous dearth of oversight and standardized norms governing the realm of solar power. The absence of such a structured framework underscores an exigent need for comprehensive regulations to guide this burgeoning sector. Remarkably, this necessity has become even more apparent in the wake of a burgeoning interest from the private sector, a noteworthy development that stands in contrast to the initial reticence demonstrated by the government (Mahmud Mustafa et al. 2020).

The investment in distributed solar power in the region has been deterred by several formidable challenges. Foremost among these is the cost factor, with solar energy currently priced at approximately $0.25 per kilowatt-hour (kWh). This stands in stark contrast to the modest $0.02 per kWh that domestic consumers pay for electricity sourced from the conventional grid. Furthermore, the inherent limitations of solar power infrastructure are a cause for concern, as these installations can only operate at their maximum capacity for a duration of 6 to 8 hours per day. This stark intermittency underscores their inability to comprehensively compensate for the persistent energy deficit. In addition to the economic constraints, there is an environmental dimension that merits scrutiny. These solar installations, albeit renewable in nature, are not without ecological repercussions. They are not immune to the production of noxious pollutants, thereby contributing to hazardous air pollution. Moreover, these systems, paradoxically, release greenhouse gases into the atmosphere, diminishing the purported environmental benefits. This raises questions about their overall sustainability and highlights the need for a more comprehensive approach to address the multifaceted energy challenges in the region (Yaseen Hasan, 2018).

The prevailing billing policy acts as a disincentive for the adoption of residential solar power systems. Presently, enterprises operating within the renewable energy sector encounter challenges in generating sales, primarily because the period required to reach the break-even point for

transitioning to a solar power system extends beyond seven years (Mohamed Shwan Husami, 2007).

Solar Energy Solutions for Kurdistan's Electricity Shortages and Economic Growth

Kurdistan contends with a pronounced inadequacy in electricity production, coinciding with a substantial and escalating demand. This heightened demand can be principally attributed to the swift expansion of the residential construction sector, fostered by substantial investment initiatives over the past few decades (Mahmud Mustafa, 2020).

In 2018, Diler H. M. underscored the considerable potential of the Kurdistan region in harnessing renewable energy sources. It is discerned that the long-term economic feasibility of integrating renewable energy systems in households remained an ambiguous prospect for 40% of the 320 individuals interviewed. Notably, a substantial 63% of the survey participants expressed a willingness to incur additional costs in exchange for the adoption of renewable energy solutions.

Furthermore, the prevailing sentiment among the majority of participants suggest a proactive role for the public sector in spearheading renewable energy production. This sentiment is accompanied by a call for the establishment of incentives and innovative business models, designed to stimulate broader adoption of renewable energy practices within residential and commercial structures.

The research outcomes undeniably affirm that the study area is richly endowed with an abundance of solar radiation, thus highlighting its significant potential for the deployment of electric power generators. It is worth emphasizing that photovoltaic (PV) systems, while offering substantial advantages, entail a relatively high initial capital investment and comparatively lower ongoing operational costs. The overall cost of the PV system can be broken down into two distinct components: the upfront investment and the recurring operational expenditures. According to the findings, it becomes apparent that the cost associated with generating 1 kilowatt-hour (1 kWh) results in an estimated monthly expense of approximately $12 over a span of 24 years (2013).

The deployment of PV panels is contingent on the specific power requirements, thus revealing the necessity for tailored configurations. Furthermore, it is important to acknowledge that land use represents a significant concern in the context of solar technologies, as it necessitates a substantive footprint.

Assessing the economic aspect, the projected cost for a PV project aimed at generating 200 kW of power is estimated at $326,340 USD, equating to $1,631.7 USD per kilowatt as the initial cost alongside maintenance expenses. Furthermore, the research indicates that each kilowatt requires an allocation of 7 square meters of land. In light of these insights, the total financial outlay necessary to alleviate the electricity shortage within the region by implementing PV panels is projected to be in the vicinity of $944,754,300 USD. This endeavor would further demand the allocation of approximately 4,030,000 square meters, equivalent to nearly 4.03 square kilometers of land. These findings underscore both the significant potential and the financial investment required for the application of solar energy solutions to address the pressing energy deficit within the Kurdistan region. Moreover, the potential for harnessing this solar energy in its thermal form is a compelling prospect, further enhanced by the assurance of a cost as low as 0.23 US cents per kilowatt-hour (kWh) (Salar Salah Muhy Al-Din et al. 2017).

Considering a total cost of $10,000 USD for a complete photovoltaic panel system and assuming a lifespan of ten years, the cost of generating 1 kilowatt-hour (kWh) per square meter with this solar photovoltaic panel system can be calculated. This type of solar panel system has the potential to provide sufficient electricity to power central heating in houses through the utilization of solar warm water circulation designs. Furthermore, it can be employed to operate water pumps for lifting water from shallow wells on agricultural lands. This dual-purpose application has the potential to bring substantial economic relief to marginalized farmers across Kurdistan, particularly in regions heavily dependent on agriculture with low rainfall catchment.

Moreover, this initiative has the potential to contribute significantly to overcoming the prevailing electricity shortage crisis in the region. By harnessing solar energy for both residential heating and agricultural irrigation, it offers a practical and sustainable solution, enhancing livelihoods and addressing critical energy needs in Kurdistan (Saeed, M.A. and Qadir, K.W., 2010).

The installation of a 10-megawatt photovoltaic (PV) plant in the designated regions of As-sulaymaniyah, Erbil, and Kirkuk is inherently feasible. The assessed simple payback period for these installations falls within a range of 6.8 to 7.2 years, signifying the time required to recoup the initial investment. It's pertinent to note that the extended payback period observed in this analysis starkly contrasts with the significant briefer payback durations achieved in developed nations where comparable PV installations often yield returns on investment within a span of three years or less. This variance underscores the nuanced economic landscape within the

Kurdistan Region when juxtaposed against more economically advanced counterparts. The implementation of a two-axis, 10-megawatt photovoltaic (PV) plant in As-sulaymaniyah promises substantial annual savings, estimated at approximately US$1,573,327 (Olusola Bamisile et al. 2019).

Kurdistan's Environmental Challenges and Solar Energy Solutions

The environmental predicaments facing Kurdistan are inextricably intertwined with the global challenge, particularly in the context of concerns related to global warming. A substantial reduction in the region's forested areas serves as a stark illustration of the repercussions of intensified fossil fuel combustion. Ongoing culprits such as electricity generators, vehicular emissions, and domestic heating apparatuses, notably ovens, persist as unrelenting contributors to environmental degradation within the Kurdish landscape (Hayder H. Abbas, 2013).

The combustion of fossil fuels significantly contributes to climate change by releasing carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. Transitioning to sustainable energy sources plays a pivotal role in reducing these emissions, thus helping to mitigate the far-reaching impacts of climate change. This study relies on a comprehensive panel dataset spanning the years 2002 to 2021, covering 32 African nations. The findings reveal a compelling connection: urbanization and increased trade openness are linked to elevated levels of carbon dioxide (CO_2) emissions. Conversely, the adoption of renewable energy sources emerges as a mitigating factor, leading to a discernible reduction in CO_2 emissions. This convergence of results carries profound implications, notably suggesting that a focused emphasis on expanding and integrating renewable energy infrastructure could serve as a potent instrument in countering the escalating trajectory of carbon dioxide emissions in the African context. Furthermore, the strengthening of institutional frameworks appears to hold promise in curbing CO_2 emissions, thereby underlining the multifaceted strategies required to address the complex challenge of environmental sustainability on the continent (Paul Adjei Kwakwa, 2023).

In the realm of carbon emissions, the findings reveal a substantial disparity. Solar Photovoltaic (PV) systems, exhibiting an average emission rate of 0.105 kilograms of CO_2 per kilowatt-hour (kg CO_2/KWh), manifest as a notably eco-friendly energy generation approach. In stark contrast, conventional coal-based electricity generation records a significantly higher carbon footprint, with an emission rate of approximately 0.909 kg CO_2/KWh(Khalid Khan et al. 2014).

In this context, the research aspires to elucidate the carbon dioxide emissions linked to the production of 1 kilowatt-hour of electricity through PV systems. A pertinent point of comparison is found in natural gas, the primary source of electricity generation in the Kurdistan region. It is of significance to note that natural gas-powered electricity generation registers a markedly lower carbon footprint in comparison to coal, with an emission rate nearly half that of coal, standing at approximately 0.5 kg CO_2/KWh. This comparison underscores the substantial potential for solar PV systems to significantly diminish carbon emissions in the region, especially when juxtaposed with fossil fuel-based electricity generation. This further solidifies the environmental advantages associated with the adoption of solar energy solutions within the Kurdistan region (Parliamentary Office of Science and Technology, 2006).

The environmental benefits of solar photovoltaic (PV) systems become strikingly apparent when compared to traditional natural gas-powered electricity generation. The adoption of solar PV results in a remarkable 79% reduction in the carbon footprint, a substantial and commendable feat in mitigating environmental impact. Such a significant reduction holds the potential to make a positive contribution to the global environment, and as a result, merits financial support from other countries, signifying a collective responsibility towards a cleaner and more sustainable future. The proposal to integrate both solar PV and natural gas technologies to address the prevailing electricity shortage within the region embodies a forward-thinking and environmentally responsible decision. By diversifying the energy resources and harnessing the inherent advantages of each technology, it sets the stage for a more resilient and sustainable energy landscape in the Kurdistan region, while simultaneously aligning with broader global environmental objectives (Salar Salah Muhy Al-Din et al. 2017).

The escalation in energy consumption within the Kurdistan region transcends its economic implications; it also assumes the dimensions of a formidable environmental predicament. The predominant source of electricity generation is reliant on fossil fuels, as substantiated by recent reports. The striking absence of renewable energy sources in the energy mix accentuates this concern. Consequently, this fossil fuel-dependent electricity generation system yields an elevated release of greenhouse gases, thereby engendering adverse climatic repercussions. A poignant indicator of environmental pollution in the Kurdistan region manifests in the form of the ominous black pollutants cloud that intermittently looms over cities such as Hawler. This disquieting presence is a source of genuine health apprehension among the local populace. The absence of

robust regulations, legislation, and overarching environmental policies compounds these concerns, as it fails to provide adequate safeguards for the ecological well-being of Kurdistan (Zanist Hama-Aziz, 2021).

The region currently lacks effective environmental policies and legislation. This absence hinders efforts to reduce fossil fuel usage while failing to promote alternative renewable energy sources for electricity generation. This regulatory gap presents a substantial challenge in curbing pollution and environmental degradation. Implementing robust environmental policies is essential to guide the region toward sustainability and eco-conscious energy practices. The Kurdistan region has observed a notable escalation in carbon dioxide emissions from 2003 to 2008, with the figures ranging between 25 to 30 million metric tons. This trajectory underscores the mounting presence of pollutant gases within the region, raising concerns about its environmental impact (Hayder H. Abbas, 2013). Nevertheless, the proliferation of numerous power generators tasked with electricity production, coupled with a substantial fleet of vehicles, culminates in a substantial emission of carbon dioxide (CO_2). This collective discharge has significant implications, exacerbating the greenhouse effect and contributing to environmental challenges, particularly within urban areas (Ministry of Electricity KRG, 2013).

The establishment of a 10-megawatt photovoltaic (PV) facility in any of the three designated locations, including As-sulaymaniyah, Erbil, and Kirkuk, holds the potential to curtail atmospheric emissions significantly. It is anticipated that no less than 419,357 tonnes of carbon dioxide equivalence emissions will be averted through this sustainable initiative (Olusola Bamisile et al. 2019). In 2010, Saeed and Qadir illustrated a profound disparity in CO_2 emissions. Precisely, the average CO_2 emission levels associated with electricity generated through PV panels are a mere 0.105 kilograms of CO2 per kilowatt-hour (kg CO_2/KWh). In stark contrast, electricity derived from coal, a conventional fossil fuel source, yields considerably elevated CO_2 emissions, averaging around 0.909 kg CO_2/KWh. This data accentuates the noteworthy environmental advantages of employing solar PV systems, given their significantly reduced carbon footprint in comparison to conventional fossil fuel-based power generation.

Future Prospects

The United Nations Development Programme (UNDP) is resolutely committed to improving the transport of sustainable energy offerings to benefit the human beings of Iraq. This commitment is

found via the efficient harnessing of sun photovoltaic energy. This particular initiative is strategically directed in the direction of raising the nice of life, with a pronounced emphasis on marginalized groups, especially those living in peri-city and rural regions within Iraq. Furthermore, it's intrinsically geared toward achieving tangible development in mitigating the emission of Greenhouse Gases (GHGs), for that reason contributing to environmental sustainability. Today, a trio of groundbreaking tasks dedicated to the development of sustainable electricity solutions have been inaugurated in collaboration with the European Union and the United Nations Development Programme (UNDP) in Iraq. These tasks are in particular tailor-made to the governorates of Erbil, Sulaymaniyah, and Duhok, and seek to bring in pioneering solutions for the pursuit of sustainable electricity initiatives in the region (The United Nations Development Programme, 2021).

Executing these strategic imperatives would expertly situate the Kurdistan Region upon a progressive trajectory towards the holistic decarbonization of its energy infrastructure. This trajectory is underscored by the meticulous demolishing of financial barriers that have, until now, determinedly hindered the widescale integration of residential and commercial solar power systems. Central to this transformative paradigm shift is the revision of the dominant billing policy, an instrumental form poised to enrich the return on investments across the range of solar infrastructure, spanning residential and commercial domains. By artfully encouraging the harmonious integration of solar power systems into the existing electrical grid, the Kurdistan Regional Government (KRG) is not merely poised to hasten the progress of the growth of its energy generation capacity. It is poised to do so with a consistent dedication to the singular cause of mitigating carbon emissions, thereby aligning itself with the global vanguard in sustainable energy practices. This determined alignment indicates the KRG's unwavering commitment to environmental protection and energy self-reliance on the greatest of scales.

Discussion

Solar energy in Iraqi Kurdistan has tremendous prospect as they have high solar resource availability and favorable situation. Realizing this potential however is multi-facetted and includes advancing technological means as well as establishment of appropriate policies. It should therefore be a conducive environment that ensures business, community and individual understand how solar energy solution are economically viable and socially appropriate. The key

elements of such a strategic development trajectory are very careful analysis of costs effectiveness of introducing solar technologies on power market, coping with some complicated issues of integration into electricity grid and never losing focus on environment protection. Together, these elements constitute the basis for the absorption of solar energy within Kurdistan.

The cost effectiveness is just but one aspect of the discussion and involves more than just the initial capital costs. This entails minimising long-term costs for operation and management by incorporating technology, achieving economies of scale and using well-structured finance that makes solar investments appealing to many participants. The issue of environmental sustainability is also extremely important. In addition to promoting reduced greenhouse gas emission, the transitions should be inclusive enough to ensure proper land use that is not at expense of its people, environmentally sound disposal of its waste, as well as the preservation of their indigenous ecosystems. Achieving this balance will be important for the Kurdistan region towards achieving energy security, economic development, and environmental protection.

Conclusion

Summarily, the materialization of the significant solar energies available in Kurdistan is a lofty task which requires strategic plans as well as steadfastness towards environmental protection. A holistic approach based on cutting-edge technologies, judicious costs management practice and environmental considerations may be used as the pillars for turning the abundance of solar resources in this region into sustainable power. In order to integrate fully with solar energy, Kurdistan must create conditions in which different actors would find such transition both economically sound and morally justified. Such demands call for appropriate policies crafted on costs effectiveness, grids integration, and environment sustenance. Carefully dealing with issues associated with these factors and developing appropriate politics is what Kurdistan must do to usher in a period of energy security, strong economy and ecological safety. The venture may not be easy, but the possibility of the region's solar capacity exists, and with viable measures it could be attained for a greater benefit of the current as well as the coming generations. The harnessing of Kurdish's abundant solar energy potential is a daunting task but one realizable if appropriate policies are set up and sustainable commitment is sustained. Although the solar resources are available in abundance with natural geographical advantage, the effective integration of solar energy should incorporate new technologies, economic benefits and sustainable environmental

approaches. For Kurdistan region to be able to fully depend on solar energy, there is need to create a platform where everyone including investors finds it cost effective as well as socially meaningful to shift from other energy alternatives to solar power. As such, formulating appropriate policies with regards to cost-efficiency, grids connection and environment friendly. Through careful consideration of this factor and logical adoption of policies, Kurdistan will herald an era of energy security, strong economic progress and sustainable environment. Although this may seem as an uphill task, the solar energy potency of the region certainly lies within our grasp, and given proper approaches, the benefits shall accrue not only to current people of Kurdistan but to generations yet unborn.

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