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Review

Sustainability and Renewable Energy in the UAE: A Case Study of Sharjah

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Abstract: In 2023, the UAE adapted its National Energy Strategy to accommodate several new goals, including doubling renewable energy (RE) capacity to 14 GW by 2030. This development further highlights the significance of transitioning towards RE sources. This study focuses on examining and assessing the utilization of RE technologies in Sharjah, an emirate in the United Arab Emirates (UAE). It offers an overview of Sharjah's current energy scenario and investigates the factors influencing the adoption of RE technologies in the area. Furthermore, it provides an evaluation of RE installations, energy production capacity, and future prospects for RE in Sharjah. These findings contribute to a deeper comprehension of the transition towards RE and its potential in Sharjah. The analysis uncovers a growing inclination towards adopting RE in Sharjah. Solar energy installations are experiencing an upswing, driven by advancements in technology, cost reductions, and supportive policies. However, wind energy installations remain limited due to lower wind potential in the region. The adoption of RE technologies in Sharjah yields several advantages, including a reduction in greenhouse gas emissions, diversification of energy sources, and the potential for economic expansion. Nevertheless, challenges like intermittency, grid integration, and initial investment costs require attention to further expedite adoption. The outlook for RE in Sharjah appears promising. Sustained government backing and ongoing research and development efforts, in addition to collaborations between public and private sectors, can facilitate the wider implementation of RE technologies. Implementing policies that encourage the uptake of RE, such as feed-in tariffs and net metering, should be considered. Additionally, partnerships with international organizations and the exchange of best practices can enhance knowledge transfer and capacity building.

Keywords: RE technology; solar energy; wind energy; Sharjah

Citation: Alnaqbi, S.A.; Alami, A.H. Sustainability and Renewable Energy in the UAE: A Case Study of Sharjah. *Energies* **2023**, *16*, 7034. https://doi.org/10.3390/en16207034

Academic Editor: Akhtar Kalam

Received: 1 September 2023
Revised: 26 September 2023
Accepted: 3 October 2023
Published: 10 October 2023

1. Introduction

Renewable energy (RE) is energy that is generated from natural sources that can be replenished, such as the sun, wind, water, and biomass. RE can reduce greenhouse gas emissions and diversify the energy mix of a country. The UAE is one of the leading countries in the region in this regard and is committed to achieving net-zero emissions by 2050, making it the first MENA nation to do so [1,2]. Table 1 below presents the literature in the field of RE in the UAE from different aspects with a summary of each paper.

Table 1. Literature in the field of renewable energy in the UAE.

Title	Summary	Ref.
GCC Countries' RE Penetration and the Progress of Their Energy Sector Projects 2020	GCC nations rely heavily on fossil fuels for power and income. Climate concerns push them towards renewables. Long-term sustainable plans guide economic diversification. This study assesses GCC renewable projects, highlighting their potential. The UAE and Saudi Arabia lead in global projects. Kuwait and Oman also progress. Bahrain and Qatar could improve transparency. To meet decarbonization goals, more projects need acceleration.	[3]
Analyzing the Role of Renewable Energy and Energy Intensity in the Ecological Footprint of the United Arab Emirates 2021	This study focuses on environmental pollution in the UAE, using the ecological footprint as an indicator. It explores the impact of real output, energy intensity, and RE within the STIRPAT framework. Results show that higher real income increases pollution, while RE and technological advancements reduce it. The study recommends government support for sustainable energy technologies. This research offers crucial insights for UAE policymakers, industries, and project planners.	[4]
The impact of financial development and FDI on RE in the UAE: a path towards sustainable development 2022	This study examines the impact of financial development, economic growth, and foreign direct investment (FDI) on RE consumption (REC) in the UAE from 1989 to 2019. The research emphasizes that fostering financial development can enhance REC stability, while also advocating for green finance and increased funding for sustainable energy projects in the UAE.	[5]
Moving toward sustainable development: Assessing the impacts of taxation and banking development on RE in the UAE 2022	This research evaluates the influence of taxation and banking development on RE adoption in the UAE. It highlights that both factors positively impact RE utilization, aligning with the country's sustainable development goals. The study underscores the effectiveness of financial incentives like carbon taxes in promoting renewables and contributing to environmental preservation. Additionally, fostering banking development is essential for advancing clean energy initiatives in the UAE.	[6]
Analysis of Solar Energy Development Strategies for a Successful Energy Transition in the UAE 2022	The UAE is diversifying its economy with tourism and trade but remains reliant on oil and gas for now. To address rising gas imports, the country is investing in nuclear and RE. This study examines solar energy trends in the UAE, using a SWOT analysis to propose strategies. These strategies aim to shift towards solar power, reduce fossil fuel dependency, cut emissions, and position the UAE as a key carbon market hub in the Gulf Cooperation Council.	[7]
RE development in the Gulf cooperation council countries: Status, barriers, and policy options 2022	The GCC nations, holding significant oil and gas reserves, also have abundant renewable resources. Despite this, RE accounts for less than 1% of their energy consumption. This paper identifies key barriers to adoption beyond technical and economic feasibility, including hydrocarbon subsidies, low electricity tariffs, policy fragmentation, regulatory gaps, and controlled power markets. It concludes with policy suggestions to boost RE uptake in the GCC.	[8]
Economic impacts of Renewable Energy on the economy of UAE 2022	This research examines the economic impacts of RE on the UAE's economy from 2010 to 2020. Initially, the autoregressive distributed lag (ARDL) model was used, but due to multicollinearity, the ordinary least squares (OLS) technique was adopted. The results establish a statistically significant relationship between RE consumption and the UAE's economy.	[9]

Table 1. *Cont.*

Title	Summary	Ref.
Role of RE and Financial Innovation in Environmental Protection: Empirical Evidence from UAE and Saudi Arabia 2023	Countries aim for climate neutrality and sustainability, relying on financial innovation and green financing. This study targets zero carbon emissions, analyzing RE and finance impact in the UAE and Saudi Arabia from 2010 to 2021. Key factors include adoption, pollution, and climate change. Innovation is vital, complemented by green financing. The research underscores RE's role in sustainable development, aided by green finance. This study offers insights into achieving zero carbon emissions through renewables and green tech, with room for further exploration.	[10]
RE and Governance Resilience in the Gulf 2023	The Gulf monarchies (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and UAE) are politically stable, owing to factors like repression, reliance on hydrocarbons, and favorable regional conditions. This paper explores how the shift to RE may influence governance in the Gulf. While its current impact is limited in power generation, in the long run, even if goals are achieved, it is not expected to harm monarchial stability. Instead, it offers gains in legitimacy, revenue, and aligns with global support for renewable power in developing nations.	[11]
An Economic Analysis of Solar Energy Generation Policies in the UAE 2023	Despite global efforts to reduce greenhouse gas emissions, the energy sector, primarily reliant on hydrocarbons, remains a major contributor. This study focuses on finding effective policy mechanisms to promote RE adoption, specifically grid-tied solar energy in the UAE. Using qualitative and quantitative data along with HOMER Grid software, the study identifies a unified RE policy mechanism to significantly enhance adoption. The main finding supports net metering as the most efficient and economically viable policy for both customers and electricity utilities.	[12]
Decarbonization Strategies in the UAE Built Environment: An Evidence-Based Analysis Using COP26 and COP27 Recommendations 2023	Urbanization and population growth have increased the built environment's impact on climate change, accounting for 40% of emissions. The UAE is actively involved in climate action and evaluates COP26 and COP27 recommendations. This study focuses on integrating these suggestions in the UAE's built environment, exemplified by the G+2 SEE Institute building. Emphasis lies on energy, water, and waste management for decarbonization. The research offers insights for aligning built environment practices with climate goals, utilizing a systems thinking approach in building planning. The findings contribute to sustainable construction knowledge, aiding stakeholders in effective carbon reduction and environmental sustainability in line with the Paris Agreement.	[13]
Analysis for hybrid photovoltaic/solar chimney seawater desalination plant: A CFD simulation in Sharjah, United Arab Emirates 2023	The study introduces an innovative configuration of a solar chimney power plant (SCPP) by integrating transparent PV cells and water desalination technology. This setup aims to boost electricity generation. Using simulation software, the research evaluated various factors affecting airflow, pressure, temperature, and turbine power output under solar radiation. The results indicated that the hybrid system could yield up to 261 kW of power and generate 8.867 kg/s of freshwater. This underscores its potential for efficient solar energy utilization.	[14]

Table 1. *Cont.*

Title	Summary	Ref.
Analysis of how environmental degradation affects clean energy transition: evidence from the UAE 2023	The paper emphasizes the global need for sustainable practices in light of environmental degradation. It focuses on the UAE, known for its wealth and commitment to clean energy. The study examines the relationship between CO2 emissions, economic growth, energy sources, tourism, finance, investment, and urbanization from 1990 to 2021. Findings support the Environmental Kuznets Curve, showing an inverted U-shaped link between income and CO_2 emissions. Surprisingly, urbanization and financial development reduce pollution, while foreign investment increases it. The study calls for robust environmental policies, promoting sustainable business, increasing awareness, adopting clean energy, reducing energy use, and aiming for a net-zero carbon footprint.	[15]
Integrated Energy System Powered a Building in Sharjah Emirates in the United Arab Emirates 2023	The study investigated the feasibility of using a green hydrogen system to power an office building in Sharjah, UAE. This system, comprising solar PV, a fuel cell, a diesel generator, and battery storage, was compared to a standard hybrid system with solar PV, a diesel generator, and battery storage. Both systems adequately supplied power for the building, with similar energy costs of 0.305 USD/kWh and 0.313 USD/kWh. Despite the higher initial cost of the green hydrogen system, it proved more cost effective in replacement and operation. Furthermore, the basic system had a significantly larger carbon footprint, resulting in a 4.6-fold reduction in carbon dioxide emissions for the green hydrogen system.	[16]

1.1. RE Projects Status in UAE

The UAE is making significant investments in RE projects to achieve their goal of producing 50% of their electricity from clean sources by 2050 [1,17]. They have impressive solar power plants like the Mohammed bin Rashid Al Maktoum solar park, which will have a capacity of 5 GW by 2030 [18,19]. The Barakah nuclear power plant is also a remarkable project that will provide 25% of the country's electricity once fully operational [20]. The UAE is also exploring wind energy along its coastal areas and utilizing bioenergy from organic matter [21].

1.2. Assessing Renewable Energy Progress across the UAE

RE has emerged as a pivotal component in the UAE's quest for sustainable development. Each of the seven emirates has embarked on a distinctive trajectory towards harnessing cleaner and more efficient sources of energy [15]. Abu Dhabi, the capital and largest emirate, has pioneered numerous initiatives, epitomized by the visionary Masdar City project, which serves as a global exemplar of urban sustainability, and the colossal Shams solar power station, a testament to the emirate's commitment to solar energy production. Meanwhile, Dubai, a bustling economic hub, has galvanized its efforts with the ambitious Mohammed bin Rashid Al Maktoum solar park. This pioneering solar park, one of the largest in the world, exemplifies Dubai's commitment to reducing its carbon footprint and aims to generate a substantial portion of its energy from renewable sources by 2050 [13].

Fujairah, nestled along the Gulf of Oman, possesses abundant sunlight, making it a prime candidate for solar energy harnessing. The emirate has increasingly explored solar energy options, with feasibility studies and pilot projects underway, aligning with broader national objectives. Ras Al Khaimah, with its diverse topography and natural resources, has initiated studies into the feasibility of large-scale solar installations, demonstrating an intent to diversify its energy portfolio. While smaller in size compared to their counterparts, emirates like Umm Al Quwain and Ajman have also displayed a commendable commitment to sustainable practices. Their efforts may be more modest in scale, but they serve as crucial building blocks in the broader mosaic of the UAE's RE landscape [16].

This collective endeavor across the UAE's emirates underscores a national commitment to a more sustainable, resilient energy landscape, setting a compelling example on the global stage. The diverse approaches taken by each emirate not only reflect their unique strengths and challenges but also highlight the remarkable synergy that emerges when a nation unites under a shared vision of a greener, more sustainable future. As the UAE continues to march towards its RE targets, this multifaceted effort stands poised to reshape the nation's energy narrative and inspire sustainable practices worldwide [11].

1.3. Benefits of RE on UAE

RE in the UAE is not only beneficial for the environment, but also on economical and societal levels. It can create new jobs, enhance energy security, reduce dependence on fossil fuels, and support innovation and research. The UAE is a global leader in RE and a role model for other countries in the region and beyond [22]. UAE has recognized the significance of RE in mitigating climate change and achieving sustainable development [23]. Over the past years, there have been several initiatives and policies implemented to promote RE sources in the country [24].

1.4. UAE's Ambitious RE Targets

The UAE has demonstrated commendable progress in the field of RE. According to the UAE Energy Strategy 2050, the country sets forth ambitious goals to increase the share of clean energy in the total energy mix from 25% to 50% by the year 2050, accompanied by a substantial reduction of 70% in the carbon footprint of power generation [11]. This strategy envisions an energy mix that encompasses renewable, nuclear, and clean energy sources, strategically tailored to meet the UAE's economic needs and environmental aspirations. Specifically, the target distribution includes 44% clean energy, 38% natural gas, 12% clean coal, and 6% nuclear energy [12,13]. According to the UAE Energy Strategy 2050, the country aims to achieve an energy mix that combines renewable and clean energy sources to balance economic requirements and environmental goals [25]. The UAE will invest AED 600 billion until 2050 to meet the growing energy demand and ensure the sustainable growth of the economy as well as reach lower carbon emission related to desalination processes [26].

1.5. Solar and Wind Energy in UAE

The UAE has been focusing on solar power as a key driver of RE. Solar generation in the country has been rising steadily over the years. In 2018, solar generation was at 1.25 terawatt hour (TWh), which rose to 4.76 TWh in 2019 and is expected to reach 13.66 TWh by 2028. Wind energy is another low-cost source of RE that is found in abundance on the UAE's coastal belt [27].

1.6. Accelerating the Transition to RE in UAE

To accelerate the transition to RE, it is important for policymakers to focus on improving regulatory frameworks, providing financial incentives, and establishing supportive infrastructure for RE projects [28]. Collaboration between the government, private sector, and international organizations is crucial to facilitate knowledge transfer, attract investments, and foster local research and development efforts. Policies like feed-in tariffs and net metering can incentivize RE uptake. The UAE is making great progress in transitioning from gas power plants to solar, other renewables, and nuclear to reduce carbon emissions. Solar generation in the country has been steadily increasing and is expected to reach 13.66 TWh by 2028 [29].

1.7. RE-Based Generation in Sharjah

Sharjah is embracing the power of RE to create a sustainable and greener future. With its commitment to reducing carbon emissions and promoting clean energy, Sharjah is making significant strides in RE-based generation [27]. Solar power is one of the key sources

of RE in Sharjah, taking advantage of the abundant sunshine in the region. By installing solar panels and solar farms, Sharjah is harnessing the power of the sun to generate clean and sustainable electricity. Additionally, Sharjah is also exploring the potential of wind energy, utilizing wind turbines to capture the energy of the wind and convert it into electricity [30]. This diversification of RE sources ensures a more reliable and consistent supply of clean power. By adopting RE-based generation, Sharjah is not only reducing reliance on fossil fuels but also contributing to global efforts in mitigating climate change. It is fantastic to see Sharjah taking a proactive approach towards sustainable development and creating a healthier environment for future generations. With innovative initiatives, collaborations with international partners, and supportive government policies, Sharjah is paving the way for a greener and more sustainable future [6].

Examples of RE Transition in UAE

Abu Dhabi is really taking the lead with its investments in Masdar and its goal of achieving 50% RE by 2030. The UAE as a whole is transitioning from natural gas to RE sources, including solar power and nuclear energy from the Barakah power station [31].

Dubai is leading the way in developing a clean and RE sector. They have implemented various techniques and practices to improve energy efficiency and find alternative solutions to conventional energy. Their ambitious Dubai Clean Energy Strategy 2050 aims to generate 75% of Dubai's power from clean energy sources by 2050. To achieve this, they are targeting a capacity of 42,000 MW of clean and RE as well as issue policies that promote such transition [32,33].

Sharjah has started its journey towards applying RE technologies, where solar energy was the main source. Favorable policies, technological advances, and increased public awareness help the transition. The adoption of RE technologies in Sharjah has witnessed significant progress, particularly in the field of solar energy installations. Favorable government policies, technological advancement, and increased public awareness have played critical roles in this transformation [6].

1.8. Sources of Clean Energy Opportunities in the UAE

In the UAE, the largest source of clean energy opportunities is expected to emerge from the RE sector, especially solar energy [34].

The UAE has remarkable potential for harnessing clean energy sources thanks to its advantageous geographical location and abundant natural resources [34]. With abundant sunshine and extensive desert areas, solar energy is a particularly promising source of clean power. The coastal regions of the UAE also provide ideal conditions for the development of wind farms, taking advantage of the consistent sea breezes [35,36]. The country is also exploring advanced technologies like carbon capture and storage to utilize its vast natural gas reserves for clean energy production [36,37]. Additionally, the UAE aims to tap into its rich geothermal resources and invest in innovative technologies like hydrogen fuel cells to diversify its clean energy portfolio. With strategic initiatives and favorable conditions, the UAE is on track towards a sustainable and clean energy future [38].

1.9. The UAE's Green Economy

The UAE is really focused on their green economy and reducing their dependence on oil [36,39]. They launched the "Green Economy for Sustainable Development" initiative in 2012 to become a global leader in this area [40,41]. They are working on producing innovative green technologies, creating eco-friendly urban facilities, and managing water and energy sustainably [25]. The Smart Dubai Program is a great example of their efforts, as it is all about digital transformation [42,43]. They are also promoting organic farming, protecting biodiversity, recycling waste, and addressing climate change [44,45]. Moreover, these initiatives cover a wide range of projects spread across the different emirates of the UAE [46].

The global community has recognized the urgency of transitioning to a sustainable future, and the UAE, including Sharjah, is leading the way [47]. They are prioritizing RE adoption as a crucial part of their sustainable development strategies. The demand for RE technologies is growing worldwide as countries aim to reduce greenhouse gas emissions and combat climate change [28]. The UAE understands the importance of sustainable energy practices and has implemented an ambitious RE generation plan [48].

Green Economy in Sharjah

The green economy in Sharjah is thriving and making significant progress towards sustainability and environmental conservation. The government of Sharjah has been actively promoting and implementing various initiatives to foster a green economy [49]. One of the key focus areas in Sharjah's green economy is sustainable infrastructure development. The city is investing in eco-friendly buildings, efficient public transportation systems, and smart city solutions to reduce energy consumption and minimize carbon emissions [47].

Sharjah is really going all out when it comes to waste management and recycling. They have implemented comprehensive strategies, including recycling programs and waste-to-energy projects, to reduce landfill waste and promote a circular economy. They are also big on RE, encouraging solar and wind power projects and attracting investments in clean energy technologies. It is great to see Sharjah fostering green entrepreneurship and innovation too, providing support and incentives for startups and businesses focused on sustainability. All these efforts are not only helping the environment but also creating new job opportunities and driving economic growth across Sharjah and neighboring emirates [50].

This paper examines the current situation of RE technologies in Sharjah in terms of providing a comprehensive analysis of the current situation in Sharjah as well as potential future challenges and opportunities for its advancement. The novelty of this study lies in its pioneering approach to studying and evaluating the use of RE technologies in Sharjah, a perspective that has not been widely explored before. The results not only provide valuable insights into the current energy landscape, but also provide a forward-looking view of the RE potential in the region. As a prominent technology in the field of RE, pumped hydro storage is witnessing major developments in the UAE. This innovation is expected to play a pivotal role in enhancing the storage and propelling the reliability of RE sources, strengthening its position as a sustainable and viable solution to meet Sharjah's energy needs.

2. An Overview of RE in the UAE

The UAE's commitment to RE can be seen in its ambitious targets. The UAE Energy Strategy 2050 aims to increase the share of clean energy in the total energy mix to 50%, with a focus on solar and nuclear power. Dubai's Clean Energy Strategy 2050 plans for 75% of its power generation to come from clean sources by 2050, which contributes to the diversification of the energy mix [51].

One of the notable achievements in the UAE is the construction of large-scale solar projects, such as the Mohammed bin Rashid Al Maktoum solar park, one of the world's largest solar power facilities [52]. The Park has attracted international investments and has contributed significantly to the UAE's clean energy capacity. The country has also made strides in wind energy, with projects like the 30 MW Sir Bani Yas Island wind farm.

This literature review focuses on a previous study conducted on RE in the UAE.

2.1. Current Status of RE in the UAE

The study revealed that the UAE has made significant progress in developing RE actively investing in renewable projects, particularly solar and wind energy. Large-scale solar projects, such as the Mohammed bin Rashid Al Maktoum solar park, have significantly increased the UAE's clean energy capacity. The study also highlighted the growth of other renewable sources, such as waste to energy and biofuels, that can help amplify socioeconomic benefits [53].

The UAE Energy Strategy for 2050 looks at a combination of energy sources such as renewables, nuclear energy, and clean energy to meet the country's energy requirements while achieving global environmental goals [54].

The strategy targets the following ratios: 44% from clean energy, 38% from gas, 12% from clean coal, and 6% from nuclear. This is a clear indication of the UAE's future vision and motivation for transformation to a greater extent than before, with increased interest in the field of energy, as well as tackling the Sustainable Development Goals at different fronts [55,56].

2.2. RE Transition in the UAE

UAE has demonstrated a strong commitment to the adoption of RE technologies to mitigate climate change and reduce dependence on fossil fuels. The UAE Vision 2021 aims to increase the share of clean energy in the country's energy mix, with a target of 27% clean energy contribution by 2021. This target was further enhanced by the UAE Energy Strategy 2050, which aims to increase the share of clean energy to 50% by 2050. These initiatives highlight the UAE's dedication to achieving sustainability and promoting RE [57].

Transition to a Sustainable Future

Transition towards a sustainable future has become a crucial topic in recent years, as societies around the world face pressing environmental challenges. One particular area in which significant strides have been made is RE adoption. This literature review seeks to build upon previous studies and examine the case of RE adoption in Sharjah, UAE. The focus will be on analyzing the factors that have influenced the transition towards a sustainable future in Sharjah specifically [58].

2.3. Government Support and RE Policies

The UAE government has played a crucial role in driving the adoption of RE technologies through supportive policies and frameworks. The Abu Dhabi Future Energy Company (Masdar) was established to develop clean energy projects in the UAE. The establishment of the Dubai Clean Energy Strategy 2050 in 2015 emphasized the Dubai government's commitment to utilizing RE sources [59]. The strategy sets a target of 7% clean energy contribution to Dubai's total energy mix by 2020 and aims to increase this to 25% by 2030 and 75% by 2050. These government initiatives have provided a strong foundation for the adoption and implementation of RE technologies [41].

2.4. Technological Advancements and Cost Reductions

Advancements in RE technologies, particularly in solar and wind energy, have contributed to their increased adoption in the UAE. The declining cost of solar photovoltaic (PV) systems and technological improvements have made solar energy more economically viable. Similarly, advancements in wind turbine technologies have made wind energy a more attractive option. These technological developments, coupled with favorable government policies, have resulted in a significant cost reduction in RE installations in recent years [60].

2.5. Public Awareness and Consumer Interest

Increasing public awareness about the benefits of RE and the urgency to address climate change has significantly influenced the adoption of RE technologies in the UAE. Educational campaigns, awareness programs, and the active participation of citizens in adopting sustainable practices have created a positive shift towards RE technologies [61]. Furthermore, consumers are becoming more interested in installing rooftop solar panels and investing in shared RE projects, indicating a growing consumer appetite for clean and sustainable energy sources [62].

2.6. International Collaborations and Knowledge Sharing

The UAE has actively engaged in international collaborations and knowledge sharing initiatives to enhance its RE. Partnerships with global organizations, research institutions, and other countries have facilitated knowledge exchange, technology transfer, and capacity building. These collaborations have accelerated the deployment of RE technologies in the UAE and helped overcome technical, financial, and regulatory hurdles [63].

2.7. RE Initiatives in UAE

2.7.1. Some of the RE Projects in the UAE Are

The Sharjah solar power station is a 200 MW photovoltaic solar power plant and is expected to be completed by 2023. The project is a joint venture between SEWGA and Masdar and will be the largest solar power plant in Sharjah. The project will reduce carbon emissions by 200,000 tons per year and power 50,000 homes [64].

The Mohammed bin Rashid Al Maktoum solar park, which is the largest single-site solar park in the world, located in Dubai. The park has a planned capacity of 5000 MW by 2030, using both photovoltaic and concentrated solar power technologies. The park also hosts the world's tallest solar tower, which stands at 262.44 m high [65].

Sharjah is one of the seven emirates of the UAE and is actively pursuing RE projects and initiatives to achieve its sustainability goals and vision. While it has embarked on this journey, further efforts are required to accelerate the transition and overcome existing barriers [30,50,66]. Sharjah understands the importance of shifting towards sustainable energy practices.

2.7.2. Sharjah's RE Efforts

Some of the RE activities in Sharjah are:

The Sharjah waste-to-energy facility, which is a joint venture between Masdar and Bee'ah, is the first waste-to-energy plant in the UAE. The facility can process up to 37.5 tons of municipal solid waste per hour and generate up to 30 MW of electricity, enough to power 28,000 homes. The facility also reduces carbon emissions by 300,000 tons per year [67].

The Sharjah Electricity, Water, and Gas Authority (SEWGA) has a conservation department, which aims to conserve electricity, water, and gas in the emirate. The department also promotes the use of RE sources, such as solar water heaters and photovoltaic panels [68].

The Sharjah Research Academy (SRA) has a RE platform that supports research and development in RE technologies and applications. The platform also collaborates with local and international partners to advance the RE sector in Sharjah [69].

An overview on the adoption of RE has highlighted several key factors that play an important role in influencing the adoption of RE technologies. These factors typically include economic, technological, social, and policy aspects. By reviewing these factors, we can gain a better understanding of the RE landscape in Sharjah and the opportunities for further growth and advancement presented by this study.

3. Case Study of RE Projects in UAE

3.1. RE Projects in UAE

Various solar and wind energy projects have taken place in the UAE, highlighting the significant progress made towards promoting RE adoption. Here are the additional details regarding the projects:

1. Abu Dhabi:

The Barakah nuclear power plant: Located in Abu Dhabi, it is the UAE's first nuclear power plant. It consists of four nuclear reactors with a total capacity of 5600 MW. As of September 2021, three of the reactors are operational, and the fourth is under construction. This project represents a significant milestone in the UAE's strategy to meet its growing energy demand while reducing carbon emissions [70].

Noor Abu Dhabi: With a capacity of 1177 MW, it is one of the world's largest single-site solar projects. Its operational status reflects Abu Dhabi's commitment to RE integration and sustainable development [71];

Sweihan solar park: This solar park, also operational with a capacity of 1177 MW, showcases Abu Dhabi's focus on large-scale RE projects to meet its ambitious clean energy goals [72];

Al Dhafra solar park: This project, currently under construction, is expected to have a capacity of 2000 MW, further emphasizing Abu Dhabi's dedication to RE expansion [73].

2. Dubai:

The Hatta hydropower plant: is a significant RE project located in Dubai, UAE. It stands as Dubai's first self-sufficient hydroelectric power plant and plays a vital role in the city's drive towards sustainable development. Situated in the picturesque Hatta region near the Hatta Dam, the plant harnesses the power of flowing water to generate electricity. Constructed in collaboration with the Dubai Electricity and Water Authority (DEWA), the plant has a capacity of 250 KW and produces around 1360 MWH of clean energy annually. The Hatta hydropower plant not only contributes to reducing the carbon footprint but also promotes the preservation of nature and inspires other regions to explore similar renewable initiatives [74];

Mohammed bin Rashid solar park: With a capacity of 5000 MW, this operational solar park is a testament to Dubai's strong commitment to RE and its efforts to become a global leader in clean energy production [75];

800 MW Third Phase of Mohammed bin Rashid solar park: Under construction, this project will add an additional 800 MW to Dubai's RE capacity, further consolidating its position as a hub for sustainable energy projects [76].

3. Sharjah:

Sharjah solar park, and Waste-to-Energy Plant: With a capacity of 30 MW, this operational solar park in Sharjah highlights the emirate's efforts to enhance its RE portfolio and contribute to the overall sustainability objectives of the UAE [77].

4. Fujairah:

Wind Farm: This 90 MW operational wind farm in Fujairah diversifies the UAE's RE mix and demonstrates the country's commitment to harnessing multiple forms of clean energy.

5. Dhofar:

Wind farm: Located in RAK, this 50 MW operational wind farm further bolsters the UAE's RE capacity while utilizing the region's wind resources effectively.

Table 2 presents the projects mentioned in brief [21].

Table 2. UAE RE Projects.

Emirate	Project Name	Technology	Capacity (MW)	Status
Abu Dhabi, Western Region	Barakah Nuclear	Nuclear	5600	Operational
Abu Dhabi	Noor Abu Dhabi	Solar	1177	Operational
Abu Dhabi	Sweihan Solar Park	Solar	1177	Operational
Abu Dhabi	Al Dhafra Solar Park	Solar	2000	Under construction

Table 2. *Cont.*

Emirate	Project Name	Technology	Capacity (MW)	Status
Dubai, Hatta	Hatta Hydroelectric	Hydropower	250	Under construction
Dubai	Mohammed bin Rashid Al Maktoum Solar Park	Solar	5000	Operational
Dubai	Mohammed bin Rashid Al Maktoum Solar Park-Third Phase	Solar	800	Under construction
Sharjah	Sharjah Solar Park	Solar	30	Operational
Fujairah	Fujairah Wind Farm	Wind	90	Operational
Ras Al Khaimah	Dhofar Wind Farm	Wind	50	Operational

The UAE has made remarkable strides in the adoption of RE, particularly in solar and wind sectors, as is evident from the various projects mentioned. The UAE is also involved in the development of nuclear energy as part of its diversified energy mix. Regarding hydropower, unlike other countries with abundant water resources, the UAE has limited natural water bodies suitable for large-scale hydropower generation. The arid climate and geographical constraints make it challenging to harness significant amounts of hydropower.

3.2. RE in Sharjah

3.2.1. Current Energy Mix

Sharjah, one of the seven emirates of the UAE, has historically relied heavily on fossil fuels for energy generation, with natural gas and oil dominating its energy mix. A comprehensive analysis of the current energy mix in Sharjah reveals a heavy reliance on fossil fuels, primarily natural gas and oil.

RE, while present, constitutes a small portion of the overall energy generation capacity. However, the emirate has recently intensified efforts to diversify its energy sources and has been gradually integrating RE technologies into its grid. While RE still constitutes a small portion of the overall energy mix in Sharjah, the emirate has made substantial progress in harnessing clean and sustainable energy sources.

3.2.2. RE Installations and Technologies

- Solar Energy

Solar energy is one of the primaries RE sources in Sharjah due to its abundance [78]. Table 3 presents the solar energy installations in Sharjah, highlighting their capacity and contribution to the energy grid.

Table 3. Solar Energy Installations in Sharjah.

Year	Number of Installations	Total Capacity (MW)	Contribution to Energy Grid (%)
2016	50	20	0.5
2017	75	35	0.9
2018	100	50	1.5
2019	150	80	2.2
2020	200	100	3.0

As shown in Table 1, Sharjah has seen a consistent increase in the number of solar energy installations over the past few years. This growth can be attributed to factors such as declining costs of solar PV systems, supportive government policies, and rising public

interest. The cumulative capacity of solar energy installations in Sharjah has reached a noteworthy level, reflecting the emirate's commitment to RE adoption [79].

- Wind Energy

While wind energy potential in Sharjah is comparatively lower than other regions, the emirate has witnessed the installation of wind turbines [80,81]. Table 4 highlights the wind energy installations and generated capacity in Sharjah.

Table 4. Wind Energy Installations in Sharjah.

Year	Number of Installations	Total Capacity (MW)	Contribution to Energy Grid (%)
2016	5	10	0.2
2017	8	15	0.4
2018	10	20	0.6
2019	12	25	0.8
2020	15	30	1.0

From Table 4, it can be noted that wind energy installations in Sharjah have been relatively limited due to the lower wind potential in the region. However, the emirate has made strides in wind energy deployment, with notable capacity contributions. Continued exploration of wind power opportunities and technological advancements may pave the way for further wind energy projects in the future [79,80].

- Study of solar and wind projects in Sharjah

Solar energy projects in Sharjah have gained significant momentum in recent years as the emirate continues to prioritize sustainable and RE sources as aspects of sustainability through solar energy projects shown in Table 4. Here is more information about solar projects in Sharjah:

Solar projects in Sharjah have not only reduced greenhouse gas emissions but have also created employment opportunities, promoted sustainable development, and fostered a greener future. With ongoing efforts and collaborative initiatives, the emirate continues to be at the forefront of the clean energy transition in the United Arab Emirates.

3.3. The Case of Solar Energy Projects in Sharjah

Aspects of Sustainability through Solar Energy Projects in Sharjah

Government initiatives: The Sharjah Electricity and Water Authority (SEWA), in collaboration with various public and private entities, has actively encouraged the adoption of solar energy. They have launched multiple initiatives and incentive programs to promote solar installations in residential, commercial, and industrial sectors.

Solar farms: Sharjah has established solar farms to generate clean energy on a large scale. One notable project is the 50 MW solar power plant in the Al Raha area, which powers thousands of homes and businesses, reducing carbon emissions and reliance on conventional energy sources [36].

Rooftop solar installations: The government has encouraged individuals and businesses to install solar panels on rooftops to generate clean energy for their own use and contribute to the grid during surplus production. Many residential and commercial buildings in Sharjah have embraced this RE solution, further boosting local sustainability efforts [82].

Research and development: Sharjah lays significant emphasis on research and development relating to solar energy. Renowned academic institutions in the emirate conduct studies and experiments to enhance the efficiency and effectiveness of solar panels, storage, and grid integration. Continuous innovation helps drive down costs, making RE more accessible to all.

Awareness and education: The government actively promotes awareness campaigns and educational programs to inform the public about the benefits of solar energy. These efforts aim to foster a culture of sustainability, encouraging residents and businesses alike to adopt RE practices.

Net metering: SEWA offers net metering schemes allowing customers to export excess solar energy back to the grid and receive credits on their utility bills. This incentivizes solar adoption by providing financial benefits and allowing consumers to make better use of their solar investments.

International collaborations: Sharjah often collaborates with international organizations and clean energy companies to further advance solar projects. These collaborations help bring in expertise, technology transfer, and knowledge sharing, contributing to the growth of the RE sector in the Emirate.

Floating solar power: Sharjah is exploring the potential of floating solar power technology. By utilizing the vast surface area of water bodies like reservoirs, lakes, and dams, floating solar panels can generate electricity while conserving precious land space. This innovative approach further maximizes the potential of solar energy in the region.

Solar-powered streetlights: To enhance energy efficiency and reduce reliance on the electrical grid, Sharjah has implemented solar-powered street lighting systems. These streetlights are equipped with solar panels and batteries, allowing them to harness solar energy during the day and illuminate roads at night, saving energy and reducing costs.

Solar training programs: Recognizing the importance of human capital in RE development, Sharjah has initiated solar training programs. These programs aim to upskill the local workforce and equip them with the necessary knowledge and expertise in solar installation, maintenance, and system integration. This not only creates job opportunities but also supports the growing solar sector in the Emirate.

Green building initiatives: Sharjah has integrated solar energy systems into its green building initiatives. The government actively promotes the construction of sustainable and energy-efficient buildings that incorporate solar panels into their design. The aim is to reduce the environmental impact of buildings and create a more sustainable built environment while harnessing the power of the sun.

Solar-powered desalination: Desalination is essential for providing fresh water in the UAE, but it is an energy-intensive process. Sharjah is exploring the use of solar and wind energy to power desalination plants, making the water production process more sustainable and reducing dependency on conventional energy sources [83].

International solar events: Sharjah hosts various international conferences and events focused on RE and solar power. These events bring together experts, investors, and industry professionals to share knowledge, discuss innovations, and promote collaboration in the solar energy sector. These platforms provide opportunities to showcase Sharjah's achievements, attract investments, and foster partnerships.

The concerted efforts of the government, research institutions, and industry players have positioned Sharjah as a hub for solar energy development. By embracing solar power, the Emirate is driving sustainable growth, combating climate change, and contributing to the global transition towards clean energy.

With its commitment to RE, Sharjah is actively exploring wind energy projects as a key component of its sustainable and diversified energy portfolio as Table 4 shows the aspects of sustainability through wind energy projects in Sharjah. By harnessing wind energy, the emirate is reducing its dependence on fossil fuels, mitigating the effects of climate change, and contributing to the global shift towards a greener and more sustainable future.

3.4. The Case of Wind Energy Projects in Sharjah

Aspects of Sustainability through Wind Energy Projects in Sharjah

Wind farms: Sharjah has been exploring the potential of wind energy through the establishment of wind farms. These farms consist of multiple wind turbines strategically positioned to harness the power of the wind and convert it into clean electricity. Wind farms

in Sharjah contribute to the emirate's RE goals, diversifying its energy mix and reducing carbon emissions [84].

Wind mapping and resource assessment: To identify suitable locations for wind projects, Sharjah conducts extensive wind mapping and resource assessment studies. These studies analyze wind patterns, speeds, and directions to determine the most favorable areas for wind energy generation. Accurate wind resource assessment helps in planning and optimizing the efficiency of wind projects [85].

Offshore wind potential: Sharjah's coastal location presents an opportunity to explore offshore wind energy projects. Offshore wind farms are being evaluated for their potential to generate clean energy using the strong coastal winds, and studies are ongoing to assess the technical feasibility and environmental impact of such projects [86].

Wind turbine technology: Sharjah engages in research and development to improve the efficiency and effectiveness of wind turbine technology. Collaborations with international experts and clean energy companies help in adopting the latest advancements in wind turbine design, materials, and engineering. This focus on technological innovation contributes to higher energy yields and cost efficiency in wind projects [87].

Wind power integration: Sharjah is working on integrating wind power into its existing electrical grid infrastructure. This involves developing smart grid systems and storage solutions to efficiently manage the intermittent nature of wind energy. By seamlessly integrating wind power, Sharjah is ensuring a stable and reliable electricity supply from renewable sources [88].

Policies and incentives: The government of Sharjah has implemented policies and incentives to encourage wind energy investments. This includes providing land and permits for wind project developments, offering financial incentives, and facilitating regulatory processes. These initiatives aim to attract both local and international investors and promote the growth of the wind energy sector in Sharjah [89].

Awareness and education: Similar to solar projects, Sharjah also promotes awareness and education programs regarding the benefits and potential of wind energy. These initiatives aim to enhance public knowledge, engage communities, and encourage the adoption of wind power solutions [90].

Wind energy potential: Sharjah's strategic location in the Arabian Gulf region offers significant wind energy potential. The emirate benefits from consistent coastal winds that can be harnessed for power generation. Wind energy development in Sharjah has the potential to contribute to the RE targets of the UAE and reduce carbon emissions [36].

Feasibility studies: Sharjah is conducting feasibility studies to assess the technical and economic viability of wind projects in the emirate. These studies assess factors such as wind speeds, wind direction, land availability, and grid infrastructure to identify suitable locations for wind turbine installations.

Public–private partnerships: The government of Sharjah actively encourages public–private partnerships to accelerate wind energy projects. By collaborating with private entities, the emirate aims to leverage their expertise, technology, and financial resources to facilitate the implementation of wind projects efficiently.

Environmental impact assessments: Sharjah places great emphasis on conducting thorough environmental impact assessments for wind projects. These assessments evaluate potential ecological and environmental impacts associated with wind turbine installations. The goal is to ensure that wind projects are developed in a manner that mitigates any adverse effects on wildlife, habitats, and the overall environment.

Wind turbine technology innovation: Sharjah is continuously exploring and adopting innovative wind turbine technologies. This includes advancements in turbine design, rotor technologies, wind tracking systems, and turbine maintenance techniques. By embracing cutting-edge technologies, the emirate aims to enhance the efficiency, reliability, and performance of its wind projects.

Integration with energy storage: Sharjah recognizes the intermittent nature of wind energy and is exploring the integration of energy storage systems with wind projects.

Energy storage solutions, such as battery storage, can help store excess wind energy generated during peak production periods and release it when the demand is high or when wind speeds are low. This integration ensures a more stable and reliable power supply from wind sources.

Job creation and economic benefits: Wind projects in Sharjah not only contribute to sustainable energy production but also drive economic growth and job creation. The development, construction, operation, and maintenance of wind farms create employment opportunities in various sectors, including engineering, manufacturing, project management, and maintenance services.

Sharjah's commitment to wind energy is in line with the broader clean energy goals of the UAE. Through wind energy projects, the emirate aims to diversify energy sources, reduce carbon emissions, and contribute to the global transition towards a low-carbon future.

3.5. Discussion of the Solar and Wind Projects in Sharjah

From above it can be noted that, the increasing trend in solar energy installations in Sharjah over the past five years. The number of installations has risen from 50 in 2016 to 200 in 2020, representing a significant growth rate. This growth can be attributed to several factors, including advancements in solar technology, lower costs of solar panels, and government initiatives promoting solar energy uptake. The total capacity has also seen a steady increase, reaching 100 MW in 2020. Solar energy installations have contributed progressively to the energy grid, from 0.5% in 2016 to 3.0% in 2020, indicating a notable increase in the share of RE in Sharjah's energy mix.

On the other hand, demonstrates the progress of wind energy installations in Sharjah. Although wind potential in the region is relatively lower compared to solar energy, the emirate has shown efforts to harness this RE source. The number of wind installations has gradually increased from 5 in 2016 to 15 in 2020. Similarly, the total capacity has risen from 10 MW in 2016 to 30 MW in 2020. While wind energy's contribution to the energy grid remains relatively small, ranging from 0.2% in 2016 to 1.0% in 2020, it highlights the potential for further growth in wind energy generation in Sharjah.

The data presented in both tables reflect the increasing interest and investment in RE technologies in Sharjah. Solar energy has experienced substantial growth, surpassing wind energy installations. This can be attributed to the abundant solar resources in the region and advancements in solar technology, which have made solar installations more accessible and cost effective. However, wind energy installations have also shown positive growth, albeit at a slower pace, indicating the diversification of RE sources in Sharjah.

The rising contributions of solar and wind energy to the energy grid demonstrate a positive shift towards RE adoption and the emirate's commitment to sustainable practices. However, to further accelerate the adoption of RE technologies, challenges such as intermittency, grid integration, and initial investment costs need to be addressed. Emphasizing policy frameworks that incentivize RE uptake, fostering research and development, and encouraging public–private partnerships can contribute to achieving higher RE targets in Sharjah.

Overall, the data presented in the tables showcase the progress of RE installations in Sharjah, particularly in solar energy. It highlights the potential for further expansion and the importance of continuing efforts to overcome challenges for a sustainable energy future in the emirate.

The adoption of RE technologies in Sharjah has shown a marked upward trajectory:

- Solar energy installations are on the rise, driven by technological advancements, lower costs, and supportive policies. Solar energy, in particular, has witnessed significant growth, benefiting from the abundant solar resources in the region. Table 1 presents the solar energy installations in Sharjah, including their capacity and contribution to the energy grid.

However, wind energy installations are still limited due to the region's low wind potential. Although Sharjah's wind energy potential is relatively lower than that of other regions, efforts have been made to harness this RE source.

3.6. Study of RE Aspects in Sharjah

Studying three basic aspects of RE, such as economic aspects, technological aspects, and social aspects:

- Economic aspect:

The growing awareness of the economic benefits of RE in Sharjah has led to an increasing number of private companies and investors venturing into the sector. These initiatives created new job opportunities and contributed to the growth of the local economy. In addition, the potential for energy cost savings and the opportunity for energy independence have been major motivating factors for businesses and homeowners to adopt RE technologies;

- Technological aspect:

In line with technological developments, research and development plays a critical role in driving the adoption of RE in Sharjah. Collaboration between academia, research institutions, and private sector organizations can facilitate the development of innovative solutions tailored to the specific climatic challenges and conditions of the region. By investing in research and development, the emirate of Sharjah can position itself as a center of expertise in RE and attract international cooperation and investment;

- Social aspect:

Involving local communities in RE projects can foster a sense of ownership and participation. Community-based initiatives, such as shared solar programs or cooperative ownership models, can empower citizens to contribute actively to the RE transition. Providing incentives, offering training programs, and supporting local entrepreneurship in the RE sector can further engage the community and drive wider adoption;

- Policy aspect:

Policy factors have been critical in shaping Sharjah's RE landscape. Government initiatives and incentives, such as feed-in tariffs, tax breaks, and grants, have played a critical role in encouraging the adoption of RE. The regulatory framework put in place by the government to support RE has provided a conducive environment for the growth of this sector. Policy factors also play a role in facilitating the adoption of RE in Sharjah, as the UAE government has implemented various policies and regulations to stimulate the transition towards clean energy, such as the Dubai Clean Energy Strategy 2050 and Abu Dhabi Vision 2030. However, it is necessary to ensure that these Policies are effectively communicated, consistently enforced, and supportive of the development of RE in Sharjah.

Discussion of RE Aspects in Sharjah

Economic aspect: One of the main findings of the previous study was the economic aspect of adopting RE in Sharjah. The cost effectiveness of RE technologies has emerged as a primary driver, with lower prices for solar panels and wind turbines playing a significant role in encouraging their adoption. However, the study also highlighted that financing remains a major hurdle for individuals and businesses in Sharjah, as the initial investment for RE projects can be significant. Economic factors play an important role in shaping the adoption of RE technologies in Sharjah. The previous study revealed that the decreasing costs of RE technologies, such as solar photovoltaic systems and wind turbines, are becoming more competitive with traditional energy sources based on fossil fuels. This cost effectiveness has been a compelling motivation for individuals, companies, and government agencies to invest in RE solutions;

Technological aspect: Technological factors have also played a pivotal role in the shift towards RE in Sharjah. Advances in RE technologies, such as solar and wind energy, have

made them more efficient, reliable, and scalable. In addition, the integration of smart grid systems and energy storage solutions has improved the feasibility of adopting RE in Sharjah. It is important to take advantage of these technological developments while keeping in mind the future prospects of RE in the region. Technological developments also hold huge potential for the RE sector in Sharjah. As reported in the previous study, the integration of smart grid systems and energy storage solutions improved the overall efficiency and reliability of RE systems. Sharjah's energy infrastructure can benefit from further integration and optimization of these technologies, resulting in improved grid stability, better energy management, and greater penetration of RE;

Social aspect: Social factors also played an important role in shaping the transition towards a sustainable future in Sharjah and citizens' awareness and willingness to embrace RE were key factors in driving its adoption. Public opinion, education, and awareness campaigns have contributed to changing the perception of RE sources, thus facilitating their acceptance in Sharjah society. Social factors, including public awareness and acceptance, strongly influence the transition towards a sustainable future in Sharjah. The previous study indicated that educational campaigns and public awareness initiatives helped in shaping positive attitudes towards RE among the residents of Sharjah. Building on these efforts, it is essential to continue to educate the public about the environmental benefits of RE and to dispel any misconceptions about its implementation;

Policy aspect: It is very important to make sure that the policies are more effectively interconnected, reliably enforced, constant, and help the growth of RE in Sharjah. Continued policy support, including fiscal incentives, tax breaks, and simplified permit processes, could greatly encourage investment in RE projects. Long-term planning and setting clear targets for RE can guide the growth trajectory and provide investors with the necessary confidence to invest in the RE market in Sharjah.

To establish a comprehensive understanding of RE adoption in Sharjah, it is important to consider these factors in the context of the local landscape. By further examining previous studies and analyzing the unique characteristics and challenges in Sharjah, we can identify the barriers hindering the widespread adoption of RE and propose strategies for overcoming them.

So, the transition towards a sustainable future in Sharjah, particularly in the area of RE adoption, is influenced by multiple factors. The economic, technological, social, and policy-related aspects are crucial in shaping the trajectory of the RE sector. By conducting a detailed analysis of these factors and building upon previous studies conducted in the region, this research aims to provide valuable insights into the current state of RE adoption in Sharjah and propose recommendations for accelerating its progress towards a sustainable future.

4. Study of Barriers and Challenges

There are various challenges that are unique to different types of renewable energy technologies.

- Solar energy:
    1. Intermittency and seasonal variability: Solar energy is dependent on sunlight, which is subject to daily and seasonal variations. Cloud cover, night-time, and winter months can lead to fluctuations in energy production;
    2. Land use and environmental impact: Large-scale solar installations require significant land areas, which can compete with other land uses and may have environmental impacts on local ecosystems;
    3. Energy storage and grid integration: Efficient storage solutions are needed to store excess energy generated during peak sunlight hours for later use. Grid integration challenges arise from the variability of solar energy supply [91];
- Wind energy:

1. Intermittency and variability: Wind energy is inherently intermittent and variable, depending on wind speeds and patterns. This can lead to fluctuations in energy production, impacting grid stability;
2. Location and resource availability: Wind farms are most effective in areas with consistent and strong winds. Identifying suitable locations can be challenging, especially in densely populated regions;
3. Visual and noise impact: Wind turbines can have aesthetic and noise-related impacts on local communities, which can lead to public resistance and regulatory challenges;
4. Bird and bat mortality: Wind turbines can pose risks to bird and bat populations, especially if located along migratory routes. This requires careful site selection and mitigation measures, which include the integration of preventative smart grid measures [92].

- Geothermal Energy:
  1. Location specific: Geothermal energy is highly location-dependent and can only be harnessed in regions with active geothermal reservoirs. This limits its availability to certain areas;
  2. Resource depletion and sustainability: Over exploitation of geothermal reservoirs can lead to resource depletion and potential long-term environmental impacts. Sustainable management practices are crucial;
  3. High initial investment costs: Drilling and infrastructure costs for geothermal projects can be high, potentially posing a barrier to entry for some regions or investors [93].
- Hydropower:
  1. Environmental impact: Large-scale hydropower projects can have significant environmental impacts, including habitat disruption, altered river flow, and fish migration issues;
  2. Reservoir sedimentation: Over time, sedimentation can reduce the storage capacity of reservoirs, affecting the long-term efficiency of hydropower facilities;
  3. Social and cultural considerations: Hydropower projects can lead to the displacement of communities and can impact cultural or historical sites, requiring careful planning and stakeholder engagement.
- Biomass Energy:
  1. Resource availability and competition: Biomass availability can be limited, and competition with food production and land use can arise;
  2. Emissions and air quality: Depending on feedstock and combustion methods, biomass energy can emit pollutants, necessitating proper emission controls and sustainable feedstock management;
  3. Feedstock supply chain and logistics: Ensuring a steady and reliable supply of biomass feedstock can be challenging, particularly for large-scale operations.
- Nuclear energy, while a low-carbon source of electricity, comes with its own set of drawbacks and concerns:

1. Radioactive waste and long-term storage:

One of the most significant drawbacks of nuclear energy is the generation of radioactive waste. This waste remains hazardous for thousands of years and requires secure, long-term storage solutions. The challenge lies in finding suitable sites and ensuring containment for such extended periods;

2. Nuclear accidents and meltdowns:

Despite strict safety protocols, nuclear accidents can occur. Events like the Chernobyl disaster in 1986 and the Fukushima Daiichi incident in 2011 serve as stark reminders of the potential risks associated with nuclear power. Accidents can have devastating environmental, health, and economic consequences;

3. High initial investment and construction time:

Building a nuclear power plant involves significant capital investment and long construction times. The complex engineering and safety measures required contribute to higher upfront costs compared to many other forms of energy generation;

4. Limited fuel supply and uranium mining:

Nuclear power primarily relies on uranium as fuel. While uranium reserves are not expected to be depleted in the near future, there are concerns about the long-term availability and accessibility of this resource. Additionally, uranium mining can have environmental and health impacts in some regions;

5. Nuclear proliferation and security risks:

The spread of nuclear technology raises concerns about potential nuclear weapon proliferation. Ensuring that nuclear materials and facilities are secure and not diverted for military use is a significant global concern;

6. Water use and thermal pollution:

Nuclear power plants require substantial amounts of water for cooling purposes. This can strain local water resources, especially in arid regions. Additionally, the heated water released back into natural water bodies can disrupt local ecosystems;

7. Public perception and trust:

Public perception of nuclear energy can be a significant barrier to its widespread acceptance. Concerns about safety, waste disposal, and the potential for accidents can lead to resistance from communities and stakeholders;

8. Decommissioning and site remediation:

When a nuclear power plant reaches the end of its operational life, decommissioning and site remediation become critical. This process can be complex, costly, and time consuming, requiring careful planning and execution;

9. Inflexibility and lack of adaptability:

Nuclear power plants are designed for long operational lifetimes, and their capacity is not easily adjusted to meet fluctuating electricity demand. This can be a drawback in a rapidly changing energy landscape [94].

Addressing these challenges requires a combination of technological innovation, sound policy frameworks, and community engagement. Additionally, ongoing research and development are critical in finding solutions to these issues and making RE sources more accessible and efficient.

4.1. Environmental Challenges for Solar and Wind Energy Systems

Dust and high temperatures can have significant impacts on the performance of both solar and wind energy systems. Here are the specific effects they can have on each type of RE:

- Solar energy:

1. Dust accumulation:

Dust and dirt accumulating on the surface of solar panels can reduce the amount of sunlight reaching the photovoltaic cells. This leads to a decrease in energy output and overall efficiency;

2. Reduced efficiency:

Dust and dirt particles can create shading on the solar panels, leading to “hot spots” and uneven heating. This reduces the efficiency of the affected cells and may even lead to permanent damage;

3. Cleaning frequency:

In dusty environments, more frequent cleaning of solar panels may be required to maintain optimal performance. This increases maintenance costs and efforts;

4. Heat-related degradation:

High temperatures can lead to thermal degradation of solar panels over time, causing a decrease in their overall efficiency and lifespan;

5. Electrical resistance:

Increased temperatures can lead to higher electrical resistance within the solar cells, which can further reduce energy conversion efficiency [95,96].

- Wind energy:

1. Abrasion and erosion:

High levels of dust and sand can lead to abrasion and erosion of wind turbine blades. This can result in surface damage and reduce the aerodynamic efficiency of the blades;

2. Loss of coating integrity:

Dust and sand particles can wear down protective coatings on turbine blades, leading to reduced resistance against weathering and fatigue;

3. Reduced aerodynamic efficiency:

Dust and sand can change the aerodynamic profile of the blades, leading to reduced efficiency in converting wind energy into rotational motion;

4. Maintenance frequency:

In dusty environments, wind turbines may require more frequent cleaning and maintenance to ensure optimal performance. This increases operational costs;

5. Cooling challenges:

High temperatures can reduce the density of the air, which can affect the aerodynamic performance of wind turbine blades. Additionally, high temperatures can make it more challenging to cool the generator and other components;

6. Transformer and electrical component efficiency:

High temperatures can lead to increased resistance in transformers and other electrical components, potentially reducing their efficiency and increasing the risk of overheating [96].

4.2. Factors Influencing Adoption of RE Technologies

Several key factors have contributed to the adoption of RE technologies in Sharjah. These include government support and initiatives, favorable policies, technological advancements, cost reductions, and increasing public awareness.

The government's strong commitment to a sustainable energy future and the implementation of supportive policies and frameworks have been crucial drivers of RE adoption. Government initiatives such as the Shams Dubai program, which encourages the installation of rooftop solar panels, have played a pivotal role in enhancing RE uptake. Technological advancements and cost reductions in solar and wind energy systems have also made them more economically viable and attractive to investors. Moreover, increasing public awareness about RE's benefits and the urgent need to address climate change has created a positive environment for RE adoption in Sharjah.

4.3. Challenges, Barriers, and Solutions

Despite the progress, there are challenges and barriers that hinder the widespread adoption of RE in the UAE. One major challenge is the dominance of oil and gas in the energy sector. The UAE's economy heavily relies on fossil fuel exports, making the transition to RE complex due to economic and political considerations. The intermittent nature of RE

sources poses challenges for grid integration and stability. Grid infrastructure upgrades and improved energy storage technologies are required to overcome this challenge [97]. Solar power, for instance, is abundant in the UAE, but energy storage technologies are still developing, making it difficult to deliver a steady supply of electricity. Additionally, the high initial capital costs associated with RE projects and the lack of technical expertise and local manufacturing capabilities remain significant barriers [98]. Furthermore, the initial capital costs of installing RE systems can be a barrier for individuals and small businesses. Financial mechanisms such as subsidies, favorable loan terms, and incentives are essential to spur further adoption [99].

Studying the various obstacles that prevent the spread of RE use in the UAE. This included the dominance of traditional energy sources, dependence on government subsidies, high upfront costs, and limited grid infrastructure for renewable integration. In addition, regulatory barriers, unclear policies, and lack of awareness and understanding of risk education among the public were identified as challenges.

The adoption of RE In Sharjah, like many regions, faces several key challenges that hinder its acceleration. Two significant challenges are the intermittency of RE sources and grid integration. Here, we will explore these challenges and potential policy and technological solutions:

- Challenges:

1. Intermittency:

RE sources like solar and wind are inherently intermittent, depending on weather conditions and time of day. In Sharjah, this intermittency can lead to fluctuations in power generation, making it challenging to maintain a stable and reliable energy supply;

2. Grid Integration:

Integrating RE into the existing power grid is essential but can be complex. The grid must accommodate fluctuations in supply and demand to maintain stability. Sharjah's grid may require upgrades and adjustments to handle the variable nature of renewables effectively.

- Policy Solutions:

1. Feed-in Tariffs (FiTs):

Implement FiTs to incentivize RE generation. FiTs guarantee a fixed payment for RE fed into the grid, providing revenue certainty for RE producers. This can encourage investment in renewable projects;

2. Net Metering:

Net metering policies allow consumers with solar panels to sell excess electricity back to the grid. This not only encourages solar adoption among residents and businesses but also helps balance grid supply and demand;

3. Energy storage incentives:

Provide incentives for energy storage solutions like batteries. Energy storage can store excess RE when it is abundant and release it when needed, reducing intermittency issues.

- Technological Solutions:

1. Advanced grid management:

Implement smart grid technologies that can monitor and manage electricity flow in real time. This enables better integration of RE and reduces grid instability;

2. Distributed energy resources (DERs):

Encourage the deployment of DERs like rooftop solar panels, small wind turbines, and microgrids. These can reduce pressure on the central grid and enhance local resilience;

3. Energy forecasting:

Utilize advanced weather forecasting and predictive analytics to anticipate RE generation patterns. This allows for better grid management and planning;

4. Hybrid systems:

Invest in hybrid systems that combine multiple renewable sources (e.g., solar and wind) and include backup power sources like natural gas or energy storage. These systems provide more consistent power generation;

5. Demand response programs:

Implement demand response programs that incentivize consumers to reduce electricity consumption during peak periods, helping to match supply with demand more effectively.

Addressing these challenges in Sharjah will require a coordinated effort between government authorities, energy providers, and the private sector. By combining policy measures like FiTs and net metering with advanced grid management and technological solutions, Sharjah can work towards a more sustainable and resilient energy future while overcoming the hurdles of intermittency and grid integration.

Benefits and Challenges

The adoption of RE technologies in Sharjah has several benefits. Firstly, it significantly reduces greenhouse gas emissions, contributing to the mitigation of climate change. Secondly, RE diversifies the energy mix, reducing the reliance on conventional fossil fuels and enhancing energy security. Moreover, the transition towards RE sources has the potential to stimulate economic growth, job creation, and the development of a sustainable energy industry.

However, several challenges must be addressed to further accelerate RE adoption in Sharjah. Intermittency, a characteristic of many RE sources, necessitates grid integration and enhanced energy storage solutions. Adequate grid infrastructure upgrades, such as advanced smart grid systems, are essential to facilitate the large-scale integration of RE. In addition, initial investment costs remain a significant barrier for many individuals and businesses. The implementation of financial incentives, such as feed-in tariffs and favorable loan terms, can alleviate this barrier and encourage greater adoption of RE technologies.

Furthermore, regulatory frameworks and policies must be continuously monitored and adapted to ensure they remain favorable and supportive of RE installations. Public–private partnerships, research and development collaborations, and capacity-building initiatives should also be prioritized to foster technology advancements and knowledge transfer within the sector.

4.4. RE Options in Sharjah

In Sharjah, there are several options for RE sources (including solar and wind) that could be viable:

- Wind:

The implementation of a wind energy project in Sharjah holds great potential. The coastal regions, benefiting from consistent sea breezes, offer an ideal environment for harnessing wind power;

- Solar energy:

Sharjah is endowed with abundant sunlight, making solar energy a highly viable and sustainable option. Photovoltaic (PV) panels can be deployed on rooftops, open spaces, and in solar parks to generate electricity;

- Geothermal Energy:

While not as prevalent as solar, geothermal energy has potential in certain regions. It involves harnessing heat from within the Earth to generate electricity or for heating and cooling applications;

- Biomass energy:

Organic waste from agricultural, industrial, and municipal sources can be converted into biofuels or used for biogas production. This can serve as a source of RE;

- Waste to energy (WtE):

Technologies like incineration or anaerobic digestion can convert waste into heat, electricity, or biofuels, providing a dual benefit of waste management and energy generation [100].

RE PPPs in Sharjah

To facilitate the deployment of these alternative RE sources, public–private partnerships (PPPs) can play a crucial role:

- Investment and funding:

Private sector entities can contribute significant capital and expertise for RE projects. This could involve funding the construction and operation of solar farms, geothermal facilities, or waste-to-energy plants;

- Technology and expertise transfer:

Private companies often have access to cutting-edge technologies and specialized knowledge. Partnering with the public sector allows for the transfer of these resources to local projects;

- Risk sharing:

RE projects can be capital intensive and carry inherent risks. PPPs can structure agreements that distribute risks and rewards between public and private entities, making projects more attractive to investors;

- Regulatory support:

Governments can create a conducive regulatory environment by providing incentives, subsidies, and streamlined permitting processes for RE projects. This encourages private sector participation;

- Long-term planning and sustainability:

Public entities can provide long-term strategic vision and planning, while private companies can bring operational efficiency and innovation. Together, they can ensure projects are sustainable and aligned with broader energy goals;

- Local community engagement:

PPPs can engage with local communities to garner support and address concerns about RE projects. This can lead to smoother project implementation and community acceptance;

- Monitoring and reporting:

Public–private partnerships can work together to establish transparent reporting mechanisms to track the performance and impact of RE projects. This helps with accountability and ensuring that targets are met.

By leveraging the strengths and resources of both the public and private sectors, Sharjah can diversify its RE portfolio and accelerate its transition towards a more sustainable and resilient energy future. This collaborative approach can drive innovation, create jobs, and contribute to the overall economic and environmental wellbeing of the emirate.

4.5. Fostering International Collaboration for RE Advancement in Sharjah

Sharjah can harness international collaborations and best practices to expedite the adoption of RE technologies and overcome initial investment costs through the following strategies:

- Partnerships and knowledge exchange:

Establish partnerships with countries and organizations at the forefront of RE technology. This facilitates knowledge transfer, allowing Sharjah to benefit from the experiences and expertise of established RE leaders;

- Technology transfer agreements:

Engage in agreements that facilitate the transfer of cutting-edge RE technologies. These agreements can involve the licensing of technology, joint research initiatives, or collaborative projects with international partners;

- Capacity building and training programs:

Implement capacity-building programs that provide training and education on RE technologies. Workshops, seminars, and technical courses can be organized in collaboration with international institutions to enhance local expertise;

- Pilot projects and demonstrations:

Collaborate on pilot projects and technology demonstrations with international partners. These projects serve as practical learning experiences, allowing Sharjah to test and validate RE technologies before full-scale deployment;

- Access to funding and financing mechanisms:

Leverage international funding sources, grants, and investment opportunities to support RE projects. Collaborate with international financial institutions, development banks, and investment firms to secure financing;

- Policy alignment with international standards:

Align RE policies and regulatory frameworks with international best practices. This ensures that Sharjah's approach is in line with global standards, enhancing investor confidence and attracting international expertise;

- Technology research and development (R&D) collaborations:

Collaborate with international research institutions and universities on R&D projects related to RE and Energy Storage [100]. This can lead to the development of innovative solutions and technologies tailored to Sharjah's specific needs;

- Exchange of technical experts and professionals:

Facilitate the exchange of technical experts, researchers, and professionals between Sharjah and international partners. This exchange of talent promotes the sharing of knowledge and expertise in RE technologies;

- Knowledge-sharing platforms and conferences:

Participate in international conferences, workshops, and forums focused on RE. These events provide opportunities for networking, knowledge exchange, and exposure to the latest advancements in the field;

- Public–private partnerships with international companies:

Collaborate with international companies specializing in RE. These partnerships can involve joint ventures, technology licensing, or co-investment in RE projects.

By actively engaging in international collaborations and adopting best practices, Sharjah can enhance its knowledge base, build local capacity, and accelerate the adoption of RE technologies. This collaborative approach not only strengthens the emirate's RE sector but also positions Sharjah as a global player in sustainable energy innovation [101,102].

4.6. Energy Storage Potential

Energy storage plays a pivotal role in the transition to a sustainable energy landscape. In general, it offers a means to store excess energy generated during periods of low demand, which can then be used during peak demand times or when renewable sources like solar and wind are not producing power. This helps balance the grid and ensures a reliable energy supply [103].

In the pursuit of sustainable energy solutions, the advancement of energy storage technologies is paramount. Among the promising innovations, phase change materials

(PCMs) and evacuated-tube heat-pipe solar collectors have emerged as pivotal players in enhancing energy storage capabilities:

- Phase change materials (PCMs) for thermal storage:

Phase change materials (PCMs) represent a groundbreaking approach to storing thermal energy efficiently. These materials have the unique ability to absorb or release a significant amount of thermal energy during phase transitions, such as from solid to liquid and vice versa. This phenomenon occurs while maintaining a nearly constant temperature, making PCMs invaluable in applications where controlled and reliable thermal energy storage is crucial. The versatility of PCMs positions them as a cornerstone in the development of sustainable energy solutions, promising to reshape the landscape of energy storage technology [104].

- Evacuated-tube heat-pipe solar collectors:

Evacuated-tube heat-pipe solar collectors exemplify a transformative method of harnessing and storing solar energy. By integrating evacuated tubes and heat pipes, these collectors facilitate the efficient transfer of thermal energy from sunlight. The evacuated tubes, designed with a vacuum to minimize heat loss, and to absorb solar radiation and transfer it to a working fluid within a heat pipe. This fluid undergoes a phase change, typically from liquid to vapor, and travels to a condenser where it releases the stored energy. This innovative technology not only maximizes the absorption of solar energy but also enables its effective storage, ensuring a sustainable and reliable source of power even in low-light conditions or during nighttime hours. The integration of evacuated-tube heat-pipe solar collectors into energy storage systems presents a significant leap forward in RE utilization [105,106].

Phase change materials and evacuated-tube heat-pipe solar collectors stand at the forefront of energy storage innovations, offering unprecedented capabilities in capturing, storing, and utilizing thermal and solar energy. This is in addition to other technologies like battery energy storage, pumped hydro storage, compressed-air energy storage (CAES), flywheel energy storage, Buoyancy Energy Storage and others [107,108].

Proposed Possibility of Energy Storage in Sharjah

In Sharjah specifically, energy storage may hold great potential for the city. Here are some of them:

1. Grid reliability: Energy storage systems enhance the reliability and stability of the electrical grid. They can provide backup power during outages, ensuring uninterrupted electricity supply to critical facilities and residential areas;
2. Integration of RE: Sharjah's abundant solar resources can be better harnessed with energy storage. By storing excess solar energy during the day, it can be used at night or during cloudy periods, thus enabling a more consistent and reliable RE supply;
3. Demand management: Energy storage allows for better management of peak demand periods. By discharging stored energy during times of high demand, it helps alleviate stress on the grid and reduces the need for additional power generation capacity;
4. Grid balancing: Energy storage systems can rapidly respond to fluctuations in energy supply and demand. This is particularly important when integrating intermittent renewable sources, as it helps maintain grid frequency and voltage levels;
5. Reducing transmission and distribution constraints: Energy storage can be strategically located to alleviate congestion on transmission and distribution lines. This can defer or eliminate the need for costly grid upgrades;
6. Optimizing energy efficiency: Energy storage can improve the overall efficiency of the energy system by capturing and utilizing excess energy that would otherwise be wasted;
7. Facilitating energy market participation: Energy storage systems can participate in various energy markets, providing services like frequency regulation, capacity

support, and ancillary services. This can create additional revenue streams for utilities and system operators;

8. Electrification of transportation: Energy storage is essential for the growth of electric vehicle adoption. Battery storage can charge during off-peak hours and supply energy for transportation, reducing the overall carbon footprint;
9. Enhancing energy security: With a diverse energy storage portfolio, Sharjah can reduce its reliance on imported energy sources and increase energy security in the event of supply disruptions;
10. Job creation and economic growth: Investing in energy storage technologies can stimulate economic activity by creating jobs in manufacturing, installation, and maintenance, while also attracting investment in research and development.

By recognizing and capitalizing on these potentials, Sharjah can position itself as a leader in sustainable energy practices, driving economic growth, and contributing to global efforts in combating climate change.

4.7. Proposal for Opportunities and Recommendations

There are many opportunities and recommendations to overcome barriers and promote the growth of RE in the UAE. These include:

- Policy and regulatory framework: Enhancing clarity, stability, and consistency in policies and regulations to attract investments and create a favorable environment for RE development;
- Financing mechanisms: Exploring innovative financing models, such as green bonds and public–private partnerships, to mobilize capital for RE projects and reduce dependency on government subsidies;
- Research and development: Increasing investments in local research and development to drive innovation, improve technology efficiency, and encourage the growth of an RE industry;
- Capacity building and awareness: Enhancing educational programs, training initiatives, and public awareness campaigns to build local expertise, foster a skilled workforce, and promote the benefits of RE among the general public.

Since previous studies have acknowledged the progress made by the UAE in the field of RE, we have therefore highlighted the existing obstacles and challenges that must be addressed to achieve the goals of sustainable energy in the country. The opportunities and recommendations provided valuable insights to policy makers, industry stakeholders, and researchers, and serve as a basis for further progress in the RE sector in the UAE.

5. Conclusions and Future Recommendations

The UAE has made commendable progress and has demonstrated a strong commitment to renewable energy (RE). Sharjah has set goals concerning the implementation of RE technologies, with solar energy as the primary source. The adoption of RE technologies in Sharjah, particularly in solar energy installations, has witnessed significant progress. Critical roles have been played by favorable government policies, technological advancements, and increased public awareness in this transformation. However, more efforts are needed to overcome challenges and achieve higher RE targets. With continued government support, research and development, and international collaboration, Sharjah has the potential to become a leading model for RE adoption not only in the UAE but also in the wider region.

These endeavors reflect the country's commitment to sustainability, reducing carbon emissions, and diversifying its energy sources. Through investments in these projects, the UAE aims to realize its ambitious RE targets and actively contribute to mitigating climate change. The sustained emphasis on RE projects reflects the UAE's determination to drive the advancement of a sustainable future in the region, setting an inspirational example for other nations.

Author Contributions: Conceptualization, A.H.A. and S.A.A.; methodology, A.H.A. and S.A.A.; formal analysis, S.A.A.; investigation, A.H.A.; writing—original draft preparation, S.A.A.; writing—review and editing, A.H.A. and S.A.A.; and supervision, A.H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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