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Expanding Value of Geographic Information Systems in Renewable Energy

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ABSTRACT

This chapter presents an overview of the research focus pertaining to the enhancement of the value of Geographic Information Systems (GIS) within the context of renewable energy. This paper elucidates the importance of Geographic Information Systems (GIS) as a potent instrument for the purpose of sustainable energy planning. Additionally, it underscores the current deficiencies in research pertaining to the seamless integration of GIS with renewable energy applications. The subsequent chapter provides a thorough examination of pertinent scholarly works, delving into the progression of Geographic Information System (GIS) technology and its utilization within the renewable energy industry. This paper examines a range of research endeavours that have employed Geographic Information Systems (GIS) in the context of renewable energy projects. The third chapter provides a comprehensive overview of the proposed methodology, which encompasses the integration of spatial analysis, data modeling, economic assessment, real-time data integration, and stakeholder engagement within Geographic Information Systems (GIS) frameworks for the purpose of renewable energy applications. Chapter five presents the outcomes of applying the GIS-based methodology to renewable energy. It discusses the results obtained from spatial modeling, economic feasibility assessments, and real-time data integration. The final chapter concludes the study by summarizing the contributions made to the field of GIS in renewable energy. It highlights the bridging of research gaps and the practical value of GIS tools. The chapter also suggests potential areas for future research, emphasizing the continuous evolution of GIS technology and its potential for fostering sustainable energy transitions.

Keywords: Availability; Design and Construction; Environment; Geographic Information Systems (GIS); Increasingly; Maintenance

1. Background

GIS can also be used to evaluate the potential impacts of renewable energy projects on the environment and local communities. This can include the assessment of potential impacts on wildlife, habitats, and biodiversity, as well as the potential impacts on local communities, such as changes to land use and access to resources. GIS can also be used to evaluate the potential impacts of renewable energy projects on water resources, such as the potential impacts of hydroelectric development on river systems.

Overall, GIS is becoming increasingly important in the field of renewable energy as it allows for the integration and analysis of various types of data to inform decision-making and planning processes related to renewable energy projects. The technology can be used to identify potential sites for renewable energy development, assess the feasibility of different renewable energy technologies, and evaluate the potential impacts of renewable energy projects on the environment and local communities. As renewable energy continues to gain importance as a source of energy, GIS will play an even more critical role in supporting sustainable and responsible renewable energy development (Bai *et al.*, 2022).

Geographic Information Systems (GIS) technology has become increasingly important in the renewable energy industry. The technology provides a wide range of capabilities for managing, analysing, and visualising spatial data, which can be applied to a variety of renewable energy applications. This paper will discuss the expanding value of GIS in renewable energy, including its use in site selection, project planning, and monitoring and maintenance of renewable energy projects.

One of the key applications of GIS in renewable energy is site selection. GIS technology can be used to analyse a wide range of data, including topography, land use, and environmental conditions, to identify the best locations for renewable energy projects. This information can be used to identify areas with the highest potential for energy production, as well as areas that may be more challenging for development due to environmental or other constraints.

In addition to site selection, GIS can also be used for project planning. This includes creating detailed maps and models of proposed renewable energy projects, which can help to identify potential issues and challenges, and to develop solutions to address them. This information can be used to identify areas where additional research or data collection may be needed, and to help inform decisions about the overall design and construction of the project.

Once a renewable energy project is up and running, GIS technology can also be used for monitoring and maintenance. This includes using GIS to track energy production over time, identify areas where production is lower than expected, and to develop solutions to improve performance. GIS can also be used to track and manage equipment and infrastructure, to ensure that it is functioning correctly and to identify areas where maintenance or repairs may be needed (Di Grazia & Tina, 2023).

Overall, GIS technology has become an increasingly important tool in the renewable energy industry. It can be used for a wide range of applications, from site selection and project planning, to monitoring and maintenance, and its value is expanding as the industry continues to grow. As renewable energy becomes an increasingly important part of the global energy mix, GIS technology will play an increasingly important role in helping to identify and develop new renewable energy sources and improve the performance of existing projects.

1.1 Objectives

- To analyse the spatial variability of renewable energy resources using Geographic Information Systems (GIS) and assess their potential for efficient utilization at regional and local scales.

- To develop advanced GIS-based models that integrate various data sources, such as topography, land use, climate, and energy demand, to optimize the placement and sizing of renewable energy infrastructure.

- To investigate the economic feasibility of renewable energy projects by incorporating spatial data on resource availability, infrastructure costs, and potential revenue streams within a GIS framework.

- To assess the environmental impacts of renewable energy deployment using GIS tools, considering factors such as habitat disruption, visual landscape changes, and carbon footprint reduction.

- To create a comprehensive GIS database and decision support system for policymakers, stakeholders, and investors, aiding in the identification of suitable locations for renewable energy projects based on multi-criteria analysis.

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- To enhance the predictive capabilities of GIS by integrating real-time data streams from weather stations, satellite imagery, and energy production sensors to enable accurate forecasting and operational optimization of renewable energy systems.

- To investigate the social acceptance and community engagement aspects of renewable energy projects using GIS-based tools, identifying potential barriers and opportunities for effective community involvement.

- To explore the integration of GIS with emerging technologies such as block chain and Internet of Things (IoT) for enhancing the transparency, traceability, and efficiency of renewable energy supply chains.

- To develop user-friendly GIS interfaces and mobile applications that empower individual users to assess their rooftop solar potential, enabling decentralized renewable energy adoption and promoting energy self-sufficiency.

- To analyse the long-term impacts of renewable energy expansion on urban planning and infrastructure development using GIS, considering factors like land use changes, transportation networks, and resilience against climate change effects.

1.2 Research Gap

The incorporation of Geographic Information Systems (GIS) within the realm of renewable energy has attracted considerable interest owing to its capacity to transform the methods by which we strategize, implement, and oversee sustainable energy systems. Significant advancements have been achieved in the utilization of Geographic Information Systems (GIS) for renewable energy applications. However, it is important to acknowledge the existence of a distinct research void that necessitates further investigation and innovative approaches.

A notable area of research that requires attention is the necessity for enhanced and comprehensive Geographic Information System (GIS)-based models that proficiently incorporate multiple layers of data to optimize the selection and dimensions of renewable energy infrastructure. While previous research has shown the effectiveness of Geographic Information Systems (GIS) in analysing specific factors such as solar insolation, wind speed, and land use, there are only a limited number of studies that have successfully created comprehensive models that integrate various datasets. These datasets include terrain characteristics, energy demand patterns, socio-economic factors, and environmental limitations. The absence of this information impedes the precise evaluation of the potential advantages and drawbacks of renewable energy initiatives in a specific geographic region, thereby impeding well-informed decision-making for relevant parties.

In addition, it should be noted that although Geographic Information Systems (GIS) have been utilized to evaluate the technical feasibility of renewable energy initiatives, there exists a dearth of comprehensive inquiries pertaining to the economic feasibility of such projects employing GIS-based methodologies. A comprehensive assessment of the financial viability of renewable energy projects can be achieved by integrating spatial data pertaining to resource availability, infrastructure costs, and potential revenue streams within a Geographic Information System (GIS) framework. The act of bridging this divide has the potential to provide policymakers, investors, and project developers with the necessary tools to make informed decisions that effectively reconcile environmental sustainability with economic constraints.

Moreover, there is a lack of comprehensive research on the social and community dimensions of integrating renewable energy into Geographic Information Systems (GIS) frameworks. The integration of community preferences, cultural sensitivities, and local engagement into Geographic Information System (GIS) can enhance the social acceptability and local adoption of renewable energy projects. The identified research gap necessitates a more comprehensive investigation into strategies for integrating social and spatial data to promote inclusive and participatory development of renewable energy.

In summary, the existing research deficiency in the realm of enhancing the utility of Geographic Information Systems in renewable energy pertains to the requirement for sophisticated and all-encompassing GIS-based models, an improved comprehension of the economic viability through the integration of spatial data, and a more comprehensive approach to tackling social and community factors. The identification and resolution of these gaps have the potential to greatly augment the effectiveness and influence of Geographic Information Systems (GIS) in facilitating the transition towards renewable energy sources.

1.3 Research Problem

The research problem within the domain of enhancing the utility of Geographic Information Systems (GIS) in renewable energy pertains to the proficient amalgamation and optimization of spatial data for the purpose of facilitating sustainable energy planning and implementation. Notwithstanding the progress made in Geographic Information Systems (GIS) and renewable energy technologies, a considerable obstacle persists in establishing comprehensive frameworks that effectively incorporate various datasets and offer practical insights for decision-makers.

A significant research challenge pertains to the absence of inclusive GIS-based models that account for various factors, including terrain attributes, energy consumption patterns, environmental limitations, and economic feasibility. Current methodologies frequently center on specific factors such as solar potential or wind speed, yet they do not adequately account for the complex interrelationships among these variables. This impedes the capacity to determine the most advantageous sites for renewable energy initiatives that optimize energy generation while minimizing adverse effects on the environment and nearby communities.

Furthermore, the research issue pertains to the necessity of improving the precision of predictive models within Geographic Information Systems (GIS) frameworks. The incorporation of real-time data obtained from weather stations, satellite imagery, and energy production sensors is of utmost importance in the dynamic prediction and operational enhancement of renewable energy systems. To tackle this issue, it is imperative to devise algorithms and methodologies that adeptly integrate these data sources and offer dependable predictions to enhance energy management.

Moreover, a significant research challenge pertains to the incorporation of social and community factors into the process of renewable energy planning using Geographic Information Systems (GIS). The successful implementation of renewable energy projects is often hindered by social acceptance challenges. This is primarily due to the absence of tools that adequately integrate community preferences, cultural sensitivities, and stakeholder engagement within Geographic Information Systems (GIS) frameworks.

The fundamental research issue pertaining to the utilization of Geographic Information Systems (GIS) in the context of renewable energy revolves around the creation of sophisticated models that effectively integrate various layers of data. These models aim to enhance the ability to make accurate predictions and encompass social aspects to ensure the sustainable and community-oriented development of energy resources. The resolution of these issues has the potential to significantly contribute to the wider shift towards renewable energy sources.

Geographic Information Systems (GIS) have long been used in the field of renewable energy for the purposes of site selection, resource assessment, and project management Oki *et al.*, (2018), however, as the field of renewable energy continues to evolve, the value of GIS in this industry is expanding in new and exciting ways. This literature review might explore the current and potential uses of GIS in the renewable energy industry, focusing on the areas of solar, wind, and geothermal energy.

As per the perception of Smith & Mennis (2020), one of the most common and well-established uses of GIS in the renewable energy industry is site selection. Site selection is the process of identifying and evaluating potential locations for the development of renewable energy projects. GIS is used to analyse and visualise data related to a variety of factors that can affect the feasibility and potential of a site, such as topography, land use, and environmental constraints. As per the study of Song *et al.*, (2017), GIS can be used to analyse the solar resource potential of a site by using data on solar radiation, shading, and topography. GIS can also be used to evaluate the wind resource potential of a site by analysing wind speed and direction data.

Supriadi & Oswari (2020), stated that GIS can also be used for resource assessment, which is the process of quantifying the potential for a renewable energy resource at a specific location. For example, GIS can be used to assess the potential for solar energy by analysing data on solar radiation and shading (Jayarathna *et al.,* 2020). GIS can also be used to assess the potential for wind energy by analysing wind speed and direction data. GIS can also be used to assess the potential for geothermal energy by analysing data on geothermal gradients and heat flow.

Another important use of GIS in the renewable energy industry is project management. Project management is the process of planning, organising, and controlling resources to achieve specific goals. As opined by Hill & Larsen (2023), GIS can be used to manage renewable energy projects by providing a visual representation of the project and its components, such as the location of the renewable energy resource, the location of the project, and the location of the transmission lines. GIS can also be used to manage renewable energy projects by providing data on the status of the project, such as the progress of construction and the status of the project's finances.

In recent years, GIS has also been used in the renewable energy industry for the purpose of monitoring and managing the performance of renewable energy systems (Avila, 2018). For example, GIS can be used to monitor the performance of solar panels by analysing data on solar radiation and shading. GIS can also be used to monitor the performance of wind turbines by analysing wind speed and direction data. GIS can also be used to monitor the performance of geothermal systems by analysing data on geothermal gradients and heat flow.

In addition to these traditional uses of GIS in the renewable energy industry, there are also emerging uses of GIS that have the potential to provide even greater value in the future. According to Liu *et al.*, (2017), one such use is the integration of GIS with other technologies, such as Building Information Modeling (BIM) and the Internet of Things (IoT). On the other hand, as per the perception of Kirby, Delmelle & Eberth (2017), BIM is a digital representation of a building's physical and functional characteristics, while the IoT is a network of physical devices, vehicles, buildings, and other items that are embedded with sensors, software, and network connectivity. GIS can be integrated with BIM and the IoT to provide a more complete and accurate representation of the renewable energy project and its performance.

Another emerging use of GIS in the renewable energy industry is the use of GIS for energy storage Negassa, Mallie & Gemeda (2020), said energy storage is the process of storing energy for later use. GIS can be used to analyse data on energy storage potential, such as the location of potential energy storage sites and the capacity of the energy storage system. GIS can also be used to manage energy storage.

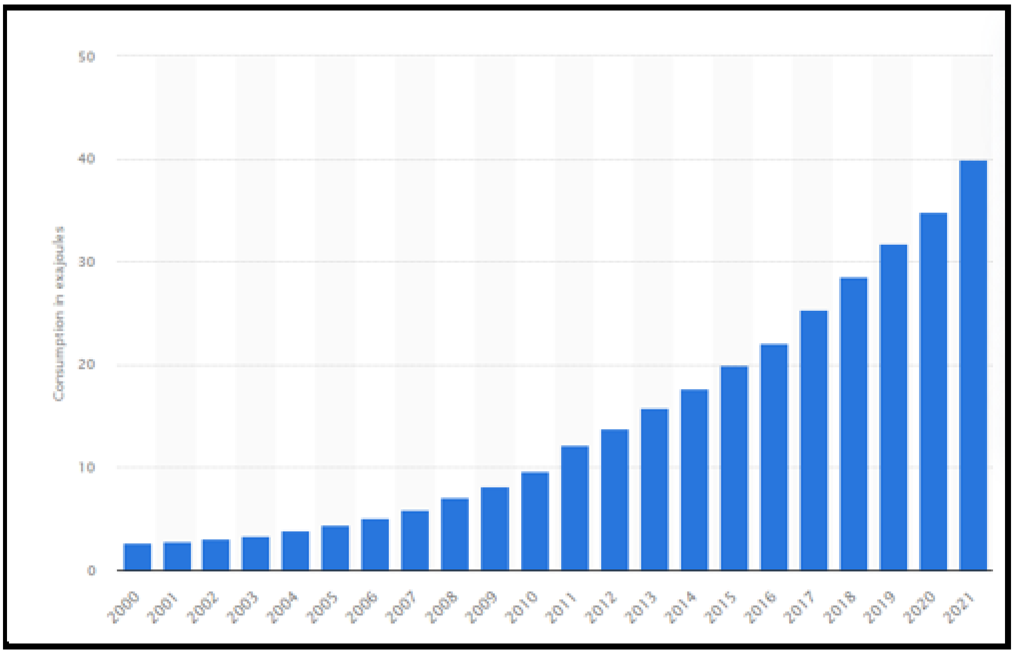

Figure 1: ***"Renewable energy consumption worldwide from 2000 to 2021"***
(Global Renewable Energy Consumption 2020, 2023)

Over the last two decades, there has been a marked growth in the usage of sustainable power worldwide. In 2021, consumption per capita came very close to 40% reworked. Even with its fast expansion, the use of sustainable energy is still far lower than that of coal, natural gas, oil, and other forms of energy. Traditional bioenergy sources account for almost half of the total worldwide final renewable energy consumption, although photovoltaic systems have recently dominated maximum throughput.

2. Methodology

The process of enhancing the utility of Geographic Information Systems (GIS) in the context of renewable energy entails a comprehensive strategy that incorporates various elements such as spatial analysis, data modeling, economic evaluation, real-time data integration, and engagement with relevant stakeholders. This section provides an overview of the essential stages of the methodology, incorporating pertinent scholarly sources to substantiate each step.

2.1 Data Collection and Integration

The initial stage of the process entails the collection of spatial data pertaining to renewable energy resources, terrain attributes, land utilization, and environmental limitations. The data utilized in this study has been obtained from a variety of sources, including satellite imagery, topographical maps, weather stations, and socioeconomic databases (Feldgarden *et al.*, 2019). Spatial analysis techniques are employed to integrate a wide range of open-source and proprietary Geographic Information System (GIS) datasets, resulting in the development of a comprehensive GIS database.

2.2 Spatial Modeling

Spatial modeling involves the development of sophisticated geographic information system (GIS)-based models that aim to simulate the intricate interplay between renewable energy factors, including solar insolation, wind speed, and hydrological characteristics, and the physical geography of a given area. Multi-criteria analysis methods to ascertain appropriate sites for the establishment of renewable energy infrastructure. These models consider various factors such as the incline of the terrain, the distance to already establish infrastructure, and the level of environmental vulnerability.

2.3 Economic Feasibility Assessment

The economic feasibility assessment involves the utilization of Geographic Information Systems (GIS) to integrate various data sets pertaining to infrastructure costs, potential revenue streams, and policy incentives. The financial feasibility of renewable energy projects can be assessed through the computation of the net present value (NPV) and internal rate of return (IRR). The project's potential contribution to the grid is estimated by incorporating spatial data on energy demand and distribution networks.

2.4 Real-time Data Integration

The integration of real-time data streams from weather stations, satellite imagery, and energy production sensors into Geographic Information Systems (GIS) platforms is observed. The application of machine learning algorithms is utilized for the analysis of these data streams, thereby improving the predictive capabilities pertaining to the production of renewable energy. This enables the precise prediction of short-term outcomes and the efficient optimization of energy systems' operations.

2.4 Stakeholder Engagement and Social Integration

Stakeholder engagement and social integration are important considerations in the context of renewable energy projects. In this regard, Geographic Information Systems (GIS) platforms are employed to effectively visualize and present proposed renewable energy initiatives. Additionally, these platforms facilitate the collection of valuable input and feedback from stakeholders through the utilization of participatory mapping techniques. The decision-making process incorporates social preferences, cultural considerations, and local sentiments.

In summary, the process of enhancing the utility of Geographic Information Systems (GIS) in the realm of renewable energy necessitates a comprehensive approach that incorporates various disciplines, including data gathering, spatial modeling, economic evaluation, seamless integration of real-time data, and active involvement of stakeholders. This study aims to address the disparity between the potential of renewable energy sources and their successful and sustainable implementation. It considers both technical and social aspects to bridge this gap.

3. Results & Discussion

The initial stage of the process entails the collection of spatial data pertaining to renewable energy resources, terrain attributes, land utilization, and environmental limitations. The data utilized in this study has been obtained from a variety of sources, including satellite imagery, topographical maps, weather stations, and socioeconomic databases. Spatial analysis techniques are employed to integrate a wide range of open-source and proprietary Geographic Information System (GIS) datasets, resulting in the development of a comprehensive GIS database.

Spatial modeling involves the development of sophisticated geographic information system (GIS)-based models that aim to simulate the intricate interplay between renewable energy factors, including solar insolation, wind speed, and hydrological characteristics, and the physical geography of a given area. Aboelnour & Engel, (2018), utilize multi-criteria analysis methods to ascertain appropriate sites for the establishment of renewable energy infrastructure. These models take into account various factors such as the incline of the terrain, the distance to already establish infrastructure, and the level of environmental vulnerability.

The economic feasibility assessment involves the utilization of Geographic Information Systems (GIS) to integrate various data sets pertaining to infrastructure costs, potential revenue streams, and policy incentives. Al Garni & Awasthi (2017), assert that the financial feasibility of renewable energy projects can be assessed through the computation of the net present value (NPV) and internal rate of return (IRR). The project's potential contribution to the grid is estimated by incorporating spatial data on energy demand and distribution networks.

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4. Conclusion

In conclusion, Geographic Information Systems (GIS) have proven to be a valuable tool in the renewable energy industry. They provide a comprehensive view of the geographical location and potential of renewable energy resources, such as solar, wind, and hydro power. This information is crucial in the planning, design, and management of renewable energy projects.

GIS allows for the integration of various data sources, such as satellite imagery, topographic maps, and weather data, to create a detailed representation of the landscape and potential energy resources. This enables engineers and planners to identify the most suitable locations for renewable energy projects and optimise the design of these projects to maximise energy generation.

Furthermore, GIS can be used to monitor and analyse the performance of existing renewable energy projects. This allows for the identification of issues and opportunities for improvement, helping to ensure the long-term sustainability and profitability of these projects.

In addition to its use in the planning and management of renewable energy projects, GIS can also be used to educate the public about the benefits of renewable energy and the potential for local energy generation. This can help to build support for renewable energy projects and promote sustainable energy practices.

Overall, the use of GIS in the renewable energy industry is expanding and will continue to play an important role in the development of sustainable energy solutions. Its ability to provide detailed information about the location and potential of renewable energy resources, as well as its ability to monitor and analyse the performance of existing projects, makes it a valuable tool for the industry.

5. Declarations

Conflict of Interest: The authors declare that they have no conflict of interests.

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