Renewable energy project planning under Society 5.0 vision

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Abstract The rapid growth in renewable energy generation, driven by increased awareness of climate change and technological advances, is essential for achieving Society 5.0, which aims to improve human well-being through smart technology. However, assessing the social impact of renewable energy is complex. Previous studies have used changes in quality of life as an indicator, but no standardized method exists for measuring this. This work proposes the SQuaRE standard as a systematic framework for evaluating quality of life in the context of renewable energy, intending to provide a more consistent and reliable assessment. Additionally, the work suggests a comprehensive model that integrates economic, environmental, and quality-of-life objectives for planning renewable energy projects and aiding in the decision-making process. Effective implementation of this model requires multicriteria analysis, and various methods are available to evaluate the relevant criteria and trade-offs.

Key words Renewable energy, quality of life, SQuaRE standard, multicriteria analysis.

1. Introduction

The global increase in renewable energy (RE) generation has been remarkable in recent decades, driven by growing awareness of climate change, technological advancements, and supportive policies. This surge in RE, including solar, wind, hydro, and biomass, plays a crucial role in achieving Society 5.0, a vision of a future where technology enhances human well-being and societal development. Society 5.0 aims to create a super-smart society where the convergence of cyberspace and physical space leads to improved quality of life (QoL) and sustainable development.

However, measuring the social impact of RE generation presents a complex challenge. While renewable energy's environmental and economic benefits are well-documented, assessing how these benefits translate into improved quality of life for individuals and communities is more nuanced. QoL has emerged as a key social measure for evaluating these impacts, reflecting the multifaceted nature of human well-being.

Previous research into QoL measurement has produced a range of approaches, yet no consensus method has been established. Various studies have proposed different indicators for assessing QoL, reflecting the complexity of capturing its many dimensions. This lack of consensus highlights the need for a more systematic and standardized approach to evaluating the social impact of renewable energy projects.

In response to this need, the SQuaRE standard (ISO 25000) has been proposed in this work as a potential framework for systematic QoL evaluation. This standard provides a structured approach for assessing various quality attributes, offering a foundation for a more consistent evaluation of QoL in the context of RE. This framework could help address the current fragmentation in QoL measurement and provide a more reliable basis for understanding the social benefits of RE.

Building on this idea, a general model incorporating economic and environmental objectives and QoL measurements is proposed. This holistic model aims to provide a comprehensive view of planning RE projects. By integrating these multiple objectives, the model supports decision-making processes that consider the direct benefits of renewable energy and its broader social impacts.

To effectively implement this model, a multicriteria analysis is required. This analysis involves evaluating various criteria and trade-offs to ensure that decisions are balanced and informed. Different methods for multicriteria analysis can be applied, each offering unique strengths and considerations. By exploring these methods, stakeholders can select the most appropriate approach for their specific context, enhancing the effectiveness of renewable energy planning and decision-making.

2. Preliminaries

2.1 Renewable Energy

Renewable energy (RE) sources are naturally replenished and have a lower environmental impact than fossil fuels. The main types of RE sources include solar, wind, hydroelectric, geothermal, and biomass. In recent years, there has been a significant increase in the adoption and capacity of RE sources globally. This growth is driven by technological advances, decreasing costs, and growing concerns about climate change and environmental sustainability. Many countries have implemented policies and incentives to promote RE sources, leading to a shift from fossil fuels to cleaner energy sources.

The adoption of RES plays a significant role in advancing sustainable development by addressing multiple dimensions of sustainability. Environmentally, RE reduces carbon emissions, air pollution, and ecosystem degradation, contributing to climate change mitigation and biodiversity conservation. By harnessing abundant and clean energy sources, people can minimize their reliance on finite fossil fuels and transition towards a more sustainable and resilient energy system.

Moreover, renewable energy is closely linked to the Sustainable Development Goals (SDGs) outlined by the United Nations, particularly Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action). By expanding access to affordable and clean energy services, RES help eradicate energy poverty, improve health and well-being, and promote inclusive economic growth. Furthermore, by mitigating climate change and reducing our carbon footprint, renewable energy contributes to achieving the broader set of SDGs, including poverty reduction, food security, and sustainable cities and communities.

2.2 Society 5.0

Society 5.0 is a forward-thinking concept developed in Japan. It envisions a highly advanced society where digital transformation and cutting-edge technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, big data, and more are seamlessly integrated into every aspect of life. The goal is to create a society that balances economic progress with addressing social challenges, improving the quality of life, promoting inclusivity, and tackling issues like aging populations, environmental sustainability, and economic disparities. Society 5.0 shifts from previous societal stages and emphasizes the fusion of physical and digital realms to build a more connected, efficient, and adaptive world.

RE sources play a crucial role in achieving Society 5.0, aligning with its emphasis on sustainability and environmental responsibility. Shifting to renewable energy sources such as solar, wind, hydroelectric, and geothermal power is essential for reducing greenhouse gas emissions, addressing climate change, and reducing our reliance on finite fossil fuels. Clean energy isn't just a way to generate power but a fundamental building block supporting the entire technological ecosystem. It enables the sustainable operation of smart cities, intelligent transportation systems, and advanced manufacturing processes. The widespread use of RE promotes energy independence and resilience, reducing society's vulnerability to energy supply disruptions and geopolitical tensions.

A key component of Society 5.0's vision for a technologically advanced and sustainable future is the shift to smart energy networks, also known as smart grids. These networks utilize digital technologies and IoT to optimize electricity production, distribution, and consumption. Smart grids allow for real-time monitoring and management of energy flows, leading to more efficient use of resources and better integration of RE sources [1], [2]. They can dynamically adjust to changes in demand and supply, support energy storage solutions, and enable decentralized energy systems like rooftop solar panels and electric vehicles. By enhancing grid reliability, reducing energy waste, and creating more flexible and resilient energy systems, smart energy networks are essential for powering the innovations and infrastructure of Society 5.0. They empower consumers to participate in energy management actively, make informed decisions, and contribute to a sustainable future [3]. All these advantages have led governments and companies to implement smart grid projects for small and large consumers. Still, once the project is completed, it isn't easy to measure environmental, technical, or social impacts [4], [5]. In the context of Society 5.0, the multidimensional nature of metrics to evaluate a smart grid has made it difficult to plan and operate present and future projects and, therefore, energy management and decision-making.

2.3 Social Impact

Determining the social impact of RE is essential for successfully planning and implementing energy projects. Social impacts include community acceptance, equitable access to benefits, and the potential for social change. Integrating these dimensions helps ensure that RE projects meet technical and environmental goals while positively contributing to the communities they serve.

Gaining community acceptance is a critical aspect of addressing social impacts. RE projects, such as wind turbines or solar farms, can significantly alter local landscapes, economies, and daily life. These changes may affect land use, property values, and local aesthetics. Engaging with the community early in the planning process through consultations and participatory decision-making can address concerns, dispel myths, and build trust. When communities feel heard and involved, they are more likely to support and participate in the project's development and maintenance, leading to smoother implementation and long-term success [6].

Equitable access to the benefits of RES projects is crucial, as these projects can provide significant economic advantages like job creation and lower energy costs. However, these benefits may not be evenly distributed without careful planning, potentially excluding unskilled or marginalized workers. Inclusive training programs and fair policies must ensure that all community members, including low-income households, share the financial benefits. Additionally, RE projects can promote local ownership and control, empowering communities and enhancing resilience. They can provide a stable income for reinvestment in regional infrastructure and inspire broader environmental awareness, encouraging sustainable practices.

A holistic approach to project development, incorporating social impact assessment alongside technical and economic considerations, is crucial for making informed decisions. Energy projects can have far-reaching effects on communities and the environment, so it is essential to consider the social implications. Analyzing the potential impact on residents and decision-makers ensures that energy project planning and development align with community needs and values. This comprehensive planning must include technical, economic, environmental, and social factors and involve multiple stakeholders [7].

In the context of sustainable development, power system planning has traditionally focused on minimizing financial costs within an economic framework [8]. However, given the diverse nature of RE, comprehensive planning must address multidimensional aspects. This includes exploring various scenarios to identify the most suitable combinations and sizes of energy sources according to stakeholders' needs and preferences [9]. An optimal design involves selecting, sizing, and efficiently operating components while balancing conflicting criteria [10]. A comprehensive assessment helps identify and select the alternative that best represents the social impact and interests of decision-makers, leading to more sustainable and socially responsible energy initiatives.

3. Measuring social impact

The analysis of the social aspect is complex as it encompasses various broad concepts such as empowerment, acceptance, and inclusion and is closely interrelated and influenced by economic and environmental development [11], [12].In the context of RES, there is a crucial connection between energy services and human well-being, which requires the expression of the key social aspects of this relationship, such as the participation and acceptance of end-users and the promotion of equity in access to reliable and quality energy. These can boost economic development and improve people's living standards through the diversification of productive activities and the creation of local employment [13]. Evaluating social aspects is challenging due to the difficulty of obtaining operational data [14]. However, many authors highlight the level of social acceptability, the potential for job creation, the health impact, and the professional development to assess the social implications of implementing RES.

Understanding the social impact of RES generation is complex due to its multifaceted and context-dependent nature. The benefits and drawbacks of RE projects can vary significantly across different communities and regions, influenced by local socioeconomic, cultural, and environmental conditions. As a result, no specific categories are defined to measure this impact. However, based on the literature, we propose four aspects to highlight the social benefits and encompass their impact on developing energy projects. While these aspects are not mutually exclusive and are related to economic and environmental factors, they could help in optimal planning and decision-making. A general overview of the four proposed aspects is shown in Table 1

Table 1 Overview of proposed aspects

Aspect	Description	Benefit	Challenge
Acceptance	The target community's perceived acceptability of RE. Factors such as land requirements, visual intrusion, noise, and safety concerns influence the community's perception of the project.	Build an honest and trustworthy relationship with the community, preventing possible failure risks due to end-user dissatisfaction.	Geographic, cultural, and economic factors make generalizing and applying findings universally difficult. Changes in demographics can affect previously obtained results and long-term studies.
Employment	Jobs generated due to research, planning, manufacture, installation, maintenance, economic activities, and new opportunities created using RE.	Boost economic development and improve living standards by diversifying productive activities and creating local employment.	Calculating the indirect jobs and determining new job opportunities or economic activities derived solely from RE is difficult to measure with certainty.
Health	Health benefits perceived from RE development. Factors such as air and water contamination, food and water insecurity, displacement, and increased risks of infectious diseases affect community health outcomes.	Increase life expectancy, quality of life, and social development.	RE's impact on health requires long-term studies and empirical evidence. Current approaches to health benefits are based on environmental and political factors.
Education	The level of community involvement in understanding the effects of RE. Increasing knowledge to innovate, implement sustainable technologies, and develop policies ensures the inclusion of individuals in RE generation projects.	Promoting environmental awareness and sustainable development. Encourage responsible behavior and reduce pollution. Increase interest in the development and usage of RE.	Measuring the level of involvement requires long-term studies and depends on cultural, economic, and political factors.

3.0.1 Acceptance

Despite the numerous benefits of RE, challenges such as technological limitations, regulatory barriers, fossil fuel industry interests, and public perception issues hinder their widespread acceptance. Addressing these challenges requires coordinated efforts from policymakers, industry stakeholders, and civil society to enhance education, awareness, and supportive policies. Community acceptance is crucial for the success of renewable energy projects, as factors like land use, visual impact, noise, and health concerns influence public perception [15]. Social acceptance is complex, involving socio-political, community, and market dimensions that interact and sometimes conflict [16], [17]. Researchers use a combination of surveys, questionnaires, focus groups, interviews, and participatory processes to gauge public attitudes, awareness, and support. These methods help understand diverse perspectives, build trust, and address concerns, ultimately improving social acceptance of renewable energy initiatives [18], [19].

3.0.2 Employment

RE offers diverse investment opportunities for businesses. Entrepreneurs can engage in activities like installing solar photovoltaic systems, developing wind farms, or producing bioenergy from organic waste. The intermittent nature of renewable energy sources necessitates energy storage solutions, creating opportunities for businesses specializing in battery storage, pumped hydro storage, and smart grid technologies.

The rise of electric vehicles (EVs) and renewable energy-powered hydrogen fuel cells presents additional business prospects in the transportation sector. As EVs become more popular, businesses in EV manufacturing, charging infrastructure, and sustainable mobility services are poised to benefit. The growth of green finance has also spurred investment in renewable energy projects, with financial institutions offering capital through green bonds, investment funds, and crowdfunding platforms.

Renewable energy projects contribute significantly to job creation and economic development, generating direct jobs in manufacturing, installation, and maintenance and indirect and induced jobs throughout the supply chain and local economy [20]. Accurate measurement of these employment impacts involves surveys for direct jobs and top-down analysis for direct and indirect effects, considering sector interdependencies [21].

3.0.3 Health

RE sources significantly reduce air pollution compared to fossil fuels, which release harmful pollutants like sulfur dioxide and nitrogen oxides that contribute to respiratory diseases [22]–[25]. Wind, solar, and hydroelectric power produce minimal air pollutants, leading to cleaner air and improved respiratory health. Additionally, RE generates fewer greenhouse gas emissions, helping mitigate climate change and its indirect effects on human health, such as food and water insecurity and increased disease risks. Unlike fossil fuels, which can cause water pollution through oil spills and chemicals, renewable technologies like solar and wind use minimal water, helping preserve water quality. While the link between energy and health is recognized, most studies are qualitative and case-specific, highlighting the need for more empirical global evidence to understand this relationship fully [24].

3.0.4 Education

Research and innovation are pivotal in advancing RE technologies and enhancing education quality [26]. Investments by academic institutions, government agencies, and private enterprises drive improvements in the efficiency, reliability, and affordability of renewable energy systems. Interdisciplinary research contributes to technological breakthroughs and sustainable energy solutions.

Education is vital for promoting environmental awareness and sustainable development. Integrating environmental education into curricula helps individuals understand their impact on the planet, encouraging environmentally responsible behavior [27], [28]. Educational programs focusing on sustainability prepare future generations with the skills needed to innovate and implement sustainable technologies.

Indicators such as curriculum integration, student involvement, and job preparation are used to measure the impact of RE on education. Quantitative and qualitative methods like surveys, interviews, and focus groups help assess the effects on students, educators, and educational institutions, reflecting academic development and sector-related opportunities [29].

3.1 Social impact and Quality of Life

Measuring the social impact of RE is challenging due to the complexity and variability of social factors, the need for long-term studies, and limited data availability. One major difficulty is the availability and consistency of data over time. Long-term studies are crucial to accurately capture the evolving social dynamics RE projects' influence. To understand the broader social implications, these studies must track changes in various indicators such as employment rates, income levels, health outcomes, and educational opportunities. However, gathering such data can be challenging due to resource constraints, varying data collection methodologies, and the need for sustained funding and institutional support.

To address these limitations, various studies use quality of life (QoL) as a social measure to evaluate the wide-ranging impacts of different interventions, such as RE projects. Researchers often use QoL indicators like community satisfaction, health outcomes, and economic stability to assess how these interventions affect individuals and communities [30]–[33]. For instance, studies might analyze how residents' perceptions and overall well-being change to measure community acceptance of RE projects [34], [35]. Health-focused research might look at improvements in public health indicators and reduced illness rates resulting from cleaner energy sources. Economic studies often examine how income levels affect financial security and overall quality of life [30], [36], [37]. Incorporating a variety of QoL measures enables researchers to understand the social effects of interventions and ensure that the benefits are distributed fairly and aligned with community needs. Therefore, this study follows the same approach and focuses on measuring quality of life as a means to gauge the social impact of RE across all aspects.

4. Renewable energy impac in Quality of life

QoL refers to the overall well-being of individuals and societies, encompassing various factors that contribute to their happiness, health, and satisfaction with life. It includes physical health, mental and emotional well-being, social connections, economic status, environmental quality, and personal fulfillment. A high quality of life indicates that individuals have access to resources and conditions that promote their overall welfare, enabling them to lead meaningful and fulfilling lives. This concept is subjective and can vary depending on cultural, social, and personal perspectives. Still, it reflects how individuals perceive their lives as satisfactory and fulfilling.

RE has emerged as a pivotal factor in shaping contemporary societies' QoL. As nations seek sustainable alternatives to fossil fuels, adopting RE has garnered significant attention for its environmental benefits and profound socio-economic impacts. Integrating RE contributes to societal well-being by fostering cleaner environments and reducing dependency on finite resources. This shift towards sustainable energy sources mitigates greenhouse gas emissions and promotes healthier living conditions, particularly in urban areas with substantial air quality improvements.

Moreover, the socio-economic benefits of RE extend beyond environmental stewardship. Communities adopting RE often experience enhanced economic opportunities, ranging from job creation in the renewable energy sector to increased energy independence and affordability. Studies have shown that households and communities leveraging solar, wind, and other forms of renewable energy report improved economic stability, higher satisfaction levels, and expanded access to modern amenities.

However, the impact of RE on QoL is not without its challenges. Issues such as intermittency in energy supply, technical compatibility with existing infrastructure, and localized environmental impacts require careful consideration and strategic planning. Addressing these challenges effectively is crucial to maximizing the benefits of RE adoption while minimizing potential drawbacks.

Research on RE and QoL yields mixed results across diverse contexts. In Poland, solar collector households reported enhanced subjective well-being, positively impacting QoL. Similarly, Brazil's Marajó Island communities experienced increased satisfaction, income gains, and improved appliance access after adopting alternative energy sources [38]. A study in Greece revealed that respondents were well-informed about RE types and perceived their benefits as critical factors influencing usage and QoL [33]. However, a multi-country European study indicated low awareness among households regarding RE and concerns about potential health impacts despite expectations of environmental benefits [34].

Energy consumption is intricately linked to quality of life, with higher consumption generally correlating with improved living standards in developing countries [39]. Conversely, developed nations are reducing energy use through efficiency measures while maintaining high QoL standards. The relationship between RE technologies and QoL is complex, with potential health concerns arising from certain implementations [40]. Assessing the socioeconomic impacts of renewable energy projects is crucial for enhancing social acceptance, an aspect often overshadowed by environmental and economic considerations [41]. Moreover, renewable energy integration can positively or negatively impact power quality, dependent upon factors such as penetration level, system configuration, and technology type [42].

In urban settings, RE usage can significantly contribute to an improved QoL, with perceived benefits playing a pivotal role in shaping public opinion [33]. However, challenges like voltage sags in electrical grids due to wind and solar power integration highlight potential power quality issues [43]. Local impacts from renewable energy facilities, such as wind turbines and biomass plants, can influence subjective well-being over time, with varying effects depending on the type of technology [44]. While RE implementation holds promise for enhancing the QoL in rural electrification initiatives, logistical hurdles related to transportation and daily activities persist [45]. These studies underscore the multifaceted implications of RE adoption, emphasizing the necessity for comprehensive planning and assessment in RE deployment.

4.1 QoL and the SQuaRE standard

The SQuaRE standard is a comprehensive framework for defining and evaluating software quality requirements. This standard outlines a structured approach for measuring and ensuring quality across various aspects of software systems, including functionality, reliability, usability, efficiency, maintainability, and portability. It offers guidelines for establishing quality metrics and evaluation criteria, helping organizations manage and enhance the performance of their software products. It aims to provide consistency and clarity in assessing software quality, thereby supporting better decision-making and improved software development processes.

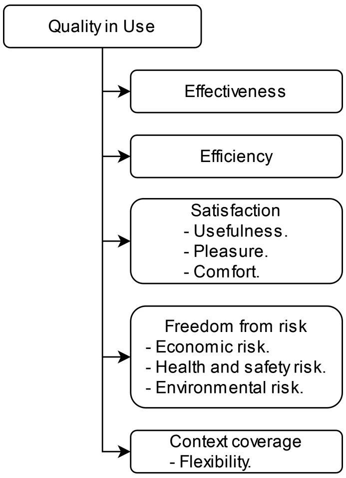
The standard significantly enhances decision-making in software quality management by providing a structured approach for defining and evaluating quality requirements. It helps organizations articulate clear, measurable quality criteria for their software products, allowing stakeholders to make informed decisions regarding design, development, and prioritization. This clarity ensures that the software aligns with user needs and expectations.

Furthermore, the standard establishes a comprehensive evaluation framework with predefined metrics and criteria. This allows decision-makers to assess whether the software meets the established quality standards and pinpoint improvement areas. A consistent approach across projects supports comparative analysis and benchmarking, enabling better strategic choices for resource allocation, project management, and quality assurance.

Previous studies have explored various aspects of measuring QoL, such as health, economic stability, and environmental factors, but there remains a lack of consensus on a unified approach. The diversity in measurement methods and criteria has led to fragmented and sometimes inconsistent results across different research efforts. To address this issue, this work suggests adopting the SQuaRE standard (ISO 25000), which provides a comprehensive framework for systematic and standardized quality evaluation. By using the SQuaRE standard, this approach aims to unify the assessment of the impact of RE in QoL across various contexts and studies.

Drawing from the standard, this work adapts the concept of QoL analogously to the quality in use of software, which is categorized into five key sections: effectiveness, efficiency, satisfaction, freedom from risk, and context coverage [46] as shown in Figure 4.1. This structured approach provides a comprehensive framework for assessing QoL systematically.

Fig. 1 SQuaRE standard (ISO/IEC25000) [46]



4.1.1 Effectiveness

This measures how well the software achieves its intended purpose. It involves assessing whether the software enables users to achieve their goals and complete their tasks accurately and efficiently. In the context of QoL, effectiveness assesses whether the interventions or improvements lead to the desired outcomes, such as better health, increased well-being, or enhanced functionality.

Increasing QoL through renewable energy offers significant benefits across several areas. It enhances public health by reducing pollution and related diseases. Economically, it creates jobs and lowers energy costs, boosting local economies. Renewable energy ensures more reliable power and supports social and educational advancements by improving connectivity and resource access. Environmentally, it preserves natural landscapes and supports recreational activities. Additionally, it fosters community development by powering cultural and social facilities, promoting cohesion and artistic preservation.

RE brings numerous interconnected benefits for human development and well-being in isolated communities. It enables the establishment of essential services like lighting, heating, and refrigeration, which are crucial for healthcare, education, water purification, and sanitation. It also enhances health by reducing reliance on polluting alternatives, improving air quality, and reducing respiratory illnesses. Reliable electricity supports modern communication, enabling quicker emergency responses and fostering a safer environment. It enhances social connectivity through mobile phones and the internet, strengthening community networks, providing access to information, and supporting economic activities such as online transactions and e-commerce.

4.1.2 Efficiency

This refers to the performance of the software in terms of resource usage. It involves evaluating whether the software provides the desired functionality with optimal use of resources such as time, memory, and processing power. Efficiency in QoL measures how effectively resources are utilized to improve well-being, balancing the input (such as time, effort, and space required) against the benefits achieved.

RE projects often necessitate significant space depending on the technology used; for instance, solar farms require extensive areas for solar panels, and wind farms need substantial land or offshore space for turbines, with adequate spacing to optimize efficiency. The timeline for these projects can be relatively short compared to traditional energy projects, as solar and wind installations can be completed quickly once a suitable site is identified. However, considerable time must be invested in site assessments, environmental impact studies, and obtaining necessary permits and approvals. This preparatory work ensures regulatory compliance and minimizes adverse environmental and community impacts.

4.1.3 Satisfaction

This aspect evaluates how users feel about the software. It involves assessing user satisfaction regarding usability, comfort, and overall experience with the software. In terms of QoL, this reflects how pleased individuals are with the improvements or changes made, encompassing their personal experiences and perceptions of the benefits.

Satisfaction derived from RE sources presents a range of benefits and challenges that merit consideration. On the positive side, renewable energy significantly reduces greenhouse gas emissions compared to fossil fuels, thereby playing a crucial role in mitigating climate change. Moreover, it enhances energy security by reducing dependence on imported fuels and offers economic opportunities through job creation in the renewable energy sector. Additionally, renewable sources like wind, solar, and hydroelectric power are sustainable in the long term, ensuring energy availability without depletion.

However, there are challenges associated with renewable energy. One major issue is intermittency, where solar and wind power generation can vary due to weather conditions, necessitating backup power sources or effective energy storage solutions. Another concern is the initial high costs of setting up renewable energy systems such as solar panels and wind turbines, although these costs generally amortize over the system's lifespan. Moreover, large-scale renewable projects may require significant land areas, potentially impacting ecosystems and local communities. Finally, ongoing technological advancements are essential to address limitations in storage and transmission, which are critical for maximizing the efficiency and reliability of renewable energy sources.

Renewable energy projects, particularly large-scale installations like wind farms and solar arrays, can have varying impacts on local communities and landscapes. The impact of renewable energy projects on land value can be mixed. In some cases, properties near renewable energy installations may experience a decrease in value due to concerns about visual impact, noise, or perceived changes in the local environment. However, studies have shown that well-planned renewable energy projects can sometimes increase property values by attracting investment and promoting a green image for the community.

On a medium scale, renewable energy projects can stimulate local economies by creating new business opportunities. These include construction and maintenance jobs for installing and servicing renewable energy infrastructure and opportunities in research, development, and manufacturing of renewable technologies. Local businesses may also benefit from increased economic activity associated with hosting renewable energy projects, such as accommodation, catering, and retail services for workers and visitors.

Renewable energy installations, especially wind turbines, can generate noise that may affect nearby residents. This noise can vary depending on turbine design and distance from residential areas. Visual intrusion is another concern, as large wind farms or solar arrays can alter the scenic landscape, potentially impacting aesthetic values and local tourism. Some tourists may be attracted to destinations that promote sustainable energy practices, viewing renewable installations as innovative and environmentally responsible. However, others may perceive large-scale wind farms or solar fields as detracting from natural beauty and tranquility, potentially affecting tourism revenues in areas valued for their scenic appeal.

4.1.4 Freedom from risk

This aspect focuses on ensuring that the software does not cause harm to users, data, or the environment. It involves evaluating how well the software handles errors, security issues, and other risks. For QoL, it assesses how well the interventions minimize adverse effects or possible harms, ensuring that improvements do not introduce new risks.

Adopting renewable energy sources can significantly enhance QoL by reducing various risks associated with conventional energy. Renewable energies like solar, wind, and hydro generate minimal emissions, decreasing air and water pollution and reducing health risks such as respiratory and cardiovascular diseases. This improvement in environmental quality leads to better overall public health and lowers the burden on healthcare systems. Additionally, renewable energy reduces the risk of energy supply disruptions and price volatility associated with fossil fuels, providing more stable and reliable energy access. By minimizing environmental impact and offering consistent energy, renewable energy contributes to a healthier, safer, and more resilient living environment, thereby significantly improving quality of life.

On the other hand, intermittency in sources like solar and wind may cause fluctuations in energy supply, potentially leading to reliability issues. However, advances in storage and grid management are improving reliability. Integrating renewable energy requires significant infrastructure upgrades, which can involve disruptions and costs but ultimately result in a more sustainable and resilient energy system. The production and disposal of renewable technologies can have environmental impacts, though these are generally lower than fossil fuels and can be managed through recycling and sustainable practices. Large-scale installations might alter land use and landscapes, leading to local concerns, but careful planning can mitigate these effects. Additionally, the shift from fossil fuels to renewables may displace workers, causing economic hardship, which can be alleviated through job retraining and economic diversification.

4.1.5 Context coverage

This evaluates how comprehensively the software addresses different users' and contexts' needs and conditions. In QoL terms, it looks at whether the improvements are inclusive and adaptable to various situations and populations, ensuring broad and relevant benefits.

RE is a flexible and adaptable solution for powering diverse areas, including remote and off-grid locations. Solar panels, wind turbines, and hydroelectric systems can be used to meet specific needs, reducing operating costs and increasing energy independence. It is scalable and has lower maintenance costs than fossil fuel-based power plants, making it beneficial for remote areas. Additionally, it produces minimal greenhouse gas emissions, contributing to environmental sustainability and climate change mitigation.

However, planning RE projects comes with challenges. Resource variability is a key consideration, as renewable sources like wind and solar depend on local environmental conditions, requiring careful planning to ensure a reliable energy supply. Initial costs for infrastructure can be significant, and accessing the necessary technical expertise in remote areas can be challenging. Developing infrastructure for energy generation and distribution involves logistical considerations, and navigating regulatory requirements adds another layer of complexity.

When applying these principles to a new area, it's essential to assess local resources to determine the most suitable technology. Financial planning should address initial costs and explore funding options while engaging technical experts to ensure the project team can handle local challenges. Infrastructure development must account for logistical issues, and adherence to local regulations is crucial for successful project implementation. By carefully considering these aspects, renewable energy projects can be effectively tailored to meet the needs of both remote and urban areas, providing sustainable and reliable energy solutions across diverse environments.

5. Planning renewable energy projects

Planning, in general terms, is defined as a decision-making process aimed at achieving future objectives, taking into account both the present situation and the internal and external factors that may influence the success of a project. In any system or organization, efficient resource utilization, reduced process uncertainty, and choosing suitable alternatives following a systematic approach to plan development and implementation are crucial for achieving the established objectives [7]. This definition of planning can be applied to the development of the electricity system to promote renewable energy projects.

Power system planning has traditionally been approached as an investment decision, where the lowest financial cost is reasonably sought. This is usually contemplated in a financial analysis framework that includes a cost model summarizing the economic need of the system [8]. However, in the context of sustainable development and given the heterogeneous nature of renewable energy, comprehensive planning must address various multidimensional aspects through a broad analysis that includes technical, economic, environmental, and social factors and the participation of multiple stakeholders [7].

In planning any system, achieving an optimal design in terms of selection, sizing, and efficient operation of the components involved [47]. In the case of renewable energy, by adopting an optimization strategy, various scenarios can be explored to identify the most suitable combinations and sizes of energy sources in line with a set of relevant criteria according to the needs and preferences of the stakeholders [9]. This idea should link all the social criteria evaluated throughout the planning process. It is important to note that some of these criteria may conflict. Therefore, the optimization approach in planning should seek those alternatives that offer an appropriate balance or compromise between criteria [10]. It is essential to perform a comprehensive assessment to identify and select the alternative that best represents the social impact and the interests of the decision makers [48].

5.1 General model

We propose a general model shown in Figure 5.1 for planning renewable energy projects designed to assist decision-makers in selecting the optimal combination of renewable energy technologies. This model integrates various factors to guide the selection process, ensuring that the chosen energy mix aligns with economic, environmental, and QoL objectives.

The model evaluates potential renewable energy technologies—such as solar, wind, hydro, and others—based on economic, environmental, and QoL criteria (Objectives). Economic considerations include cost-effectiveness, return on investment, and long-term financial sustainability. Environmental factors assess the impact on natural resources, emissions reduction, and ecological preservation.

QoL objectives are a critical component of this model, focusing on improving the overall well-being of communities.

By balancing these diverse objectives, the model provides a holistic renewable energy project planning framework. It helps decision-makers navigate the complex landscape of renewable energy options, ensuring that the selected technologies meet financial and environmental goals and significantly improve the QoL for the affected communities. This integrated approach supports developing sustainable, resilient, and socially beneficial energy solutions.

5.2 Measuring the objectives

5.2.1 Economic objective

When planning a RE project, assessing short-term, medium-term, and long-term costs is essential to ensure that resource use and management do not compromise economic interests. This objective aims to compare the costs of different options and determine their economic viability. When determining the costs of a RE project, it is important to consider its characteristics such as capacity, composition (generation and storage), and how these factors influence construction, acquisition, replacement of assets, and operation and maintenance expenses. Access to capital is vital for any electrification effort from an economic standpoint [49], [50].

Possible measurements for this objective are:

- Capital cost [51], [52].
- Operation and maintenance costs [52], [53].
- Levelized cost of energy [54], [55].

5.2.2 Environmental objective

When planning a RE project, it is essential to consider the environmental impact. Factors such as pollutant gases and particulate matter emissions, material flows resulting from energy conversion processes (such as water, chemicals, and waste), and land use must be evaluated and analyzed [56]. These considerations can help formulate strategies to reduce the potentially negative impact of microgrid deployment and operation on the environment by prioritizing technologies with a lower pollution index. Possible measurements for this objective are:

- Emissions of CO2 [55], [57].
- Land requirements [57].

5.2.3 QoL objective

As mentioned, QoL can be divided into five areas: effectiveness, efficiency, satisfaction, freedom from risk, and context coverage. Evaluating these QoL categories requires a mix of quantitative and qualitative approaches. Quantitative measures provide objective data, such as numerical scores or statistical analyses, to assess performance metrics. On the other hand, qualitative measures capture subjective experiences, opinions, and perceptions, offering insights into the personal and social aspects of QoL.

The Internet of Things (IoT) can play a significant role in this context. IoT enables real-time energy generation and consumption tracking through smart meters and energy management systems by integrating smart sensors, devices, and data analytics. This provides insights into performance metrics such as energy output, efficiency, and operational status, helping to evaluate whether RE systems are utilized effectively to meet their generation targets. Predictive maintenance algorithms can ensure optimal performance.

Community feedback and satisfaction with RE can be assessed using IoT-enabled surveys and sentiment analysis tools. Smart community hubs and mobile applications collect real-time feedback on residents' experiences, while environmental sensors monitor factors like noise levels and air quality changes. Analyzing this data helps understand community perceptions and identify areas for improvement.

Health impacts can be evaluated through IoT-based environmental monitoring systems, tracking decreases in pollutants and changes in air quality. Wearable health devices provide data on respiratory health and overall wellness, correlating with shifts in energy sources. This helps determine RE's effects on public health.

Furthermore, IoT technology enhances the flexibility and adaptability of renewable energy resources by enabling dynamic management through smart grids and energy storage systems. Real-time monitoring and control can adjust energy distribution based on demand, availability, and weather conditions, ensuring efficient integration of renewable sources into the energy mix. Data from IoT systems can also optimize hybrid energy systems, combining different renewable sources to improve reliability and flexibility.

5.3 Multicriteria analysis

When faced with decision-making scenarios involving multiple criteria or objectives, a simple evaluation may not suffice. The complexity of such decisions often necessitates a deeper analysis to ensure that all relevant factors are considered and balanced appropriately. This is where advanced decision-making methods come into play, offering structured approaches to handle complexity and make informed choices.

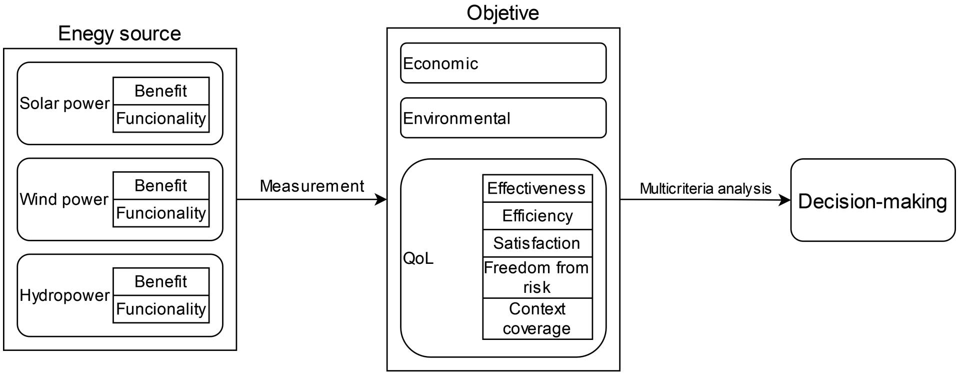
In power system planning, decision-making has traditionally concentrated on exploring the relationships between energy and economics [58]. However, there is an increasing need to integrate environmental and social considerations into the analysis, leading to a more comprehensive approach focused on sustainability. This shift has resulted in the growing use of Multi-Criteria Decision Analysis (MCDA) methods, which allow for the structured handling of multiple criteria and facilitate the involvement of various stakeholders with diverse perspectives. Detailed reviews of MCDA methods used in power system applications cover energy policy analysis, power system planning, project evaluation, and environmental impact analysis [14], [58].

Energy system planning frequently involves evaluating and selecting energy resources at specific locations using MCDA methods. For instance, the ELECTRE III method was adapted to assess renewable energy resources in Turkey [59], considering uncertainty with discrimination thresholds and identifying wind energy as a major option. Other studies employ different MCDA methods for evaluating energy sources, such as the AHP method used to analyze combinations for a microgrid [60], highlighting the grid-solar combination's suitability, or the TOPSIS method used to recommend a solar-wind-biogas combination for a village in Iran [61].

The hybridization of MCDA methods enhances the evaluation and selection of energy resources by combining various techniques to weight criteria and rank alternatives. For example, a hybrid SWARA/ARAS method ranks onshore wind energy highly [62], while a combination of Shannon entropy and AHP assesses solar, wind, and hydropower as suitable options for India [63]. Another study integrates AHP, BWM, FUCOM, and TOPSIS methods to evaluate hybrid renewable energy systems and emphasizes the role of government policies and economic conditions [55]. Similarly, the Shannon-AHP entropy method is used to assess energy alternatives for a microgrid, considering economic, reliability, structural, and environmental factors [64].

Beyond evaluating energy resources, research often combines MCDA methods with optimization strategies and software tools like HOMER. For instance, a methodological framework for rural microgrid planning in India utilizes AHP-TOPSIS and HOMER for sizing energy resources [65]. Other frameworks minimize costs and CO2 emissions using SPEA2 and TOPSIS [66], analyze electrification alternatives in Pakistan using HOMER and fuzzy AHP/TOPSIS [57], and optimize distributed power systems in Nigeria with HOMER and TOPSIS [67]. MCDA methods have also been applied in diverse contexts, including energy policy formulation [68], sustainability as-

Fig. 2 Proposed general model



sessments [69], and RE development [70], [71].

Incorporating these methods into the decision-making process ensures a thorough evaluation of multiple criteria, enabling more balanced and effective choices. Each method offers a different perspective and set of advantages, making them valuable tools for tackling complex decisions where multiple objectives must be weighed and reconciled.

5.4 Future work

Future research will focus on creating a thorough case study using the proposed model. This study will investigate how the model can be practically applied by analyzing existing data to assess the impact of renewable energy generation on QoL. Additionally, the research would showcase the practicality of using IoT technologies to measure the social benefits of RE and its effect on QoL.

Additionally, future work will include a comprehensive analysis of renewable energy sources considering the economic and environmental impacts and the QoL indicators. By integrating these dimensions, the research could provide a holistic view of the benefits and challenges of different RE options.

Another important direction for future research is to evaluate and determine which multicriteria decision-making method is most suitable for planning RE projects following the proposed model. This work would involve comparing various multicriteria approaches to identify the one that best aligns with the model's objectives and provides the most effective framework for evaluating and prioritizing RE projects.

6. Conclusions

In the context of Society 5.0, the importance of RE cannot be overstated. As an advanced societal paradigm, Society 5.0 seeks to harmonize economic advancement with resolving societal issues through a system that integrates cyberspace and physical space. RE plays a crucial role in this vision, offering a sustainable solution to meet energy demands while minimizing environmental impacts. The transition towards renewable generation is not merely a technological shift but also a fundamental change in how society functions, aiming to create a more resilient and sustainable future.

However, measuring the social impact of RE poses significant challenges, particularly in areas such as community acceptance, employment, health, and education. Community acceptance can vary widely depending on factors like cultural attitudes, economic incentives, and the perceived fairness of project implementation. Additionally, RE projects often promise job creation, but the quality and permanence of these jobs can differ, influencing local economic conditions. The health benefits of reducing pollution and the potential educational opportunities associated with new technologies further complicate the assessment of social impacts. Despite these complexities, these factors are critical for understanding the broader consequences of RE projects.

Previous works have often utilized QoL as an indicator to measure the social impact. However, there is a lack of consensus on how to approach this measurement, leading to various methodologies and frameworks being employed. This diversity in approaches reflects the multifaceted nature of QoL, encompassing economic, social, and environmental dimensions. The absence of a standardized method has made it difficult to compare results across different studies and contexts.

The SQuaRE standard offers a promising alternative to unify these disparate studies under a general framework. This international standard provides a structured approach to evaluating software product quality, and its principles can be adapted to assess the impacts of RE on the QoL of the people. By offering a common language and set of criteria, the standard could facilitate a more systematic and comparable assessment, thereby enhancing the usability of research findings.

Incorporating QoL and economic and environmental factors into a general model for decision-making in RE projects is highly beneficial. Such a model can provide a holistic view of the potential impacts, helping stakeholders make more informed decisions. However, the complexity of balancing these factors necessitates using multicriteria analysis methods. These methods can help weigh different factors according to their relative importance, allowing for a more nuanced understanding of the trade-offs involved in renewable energy projects.

Future work is needed to demonstrate the effectiveness of this model in real-world scenarios. A comprehensive case study would provide valuable insights into the practical application of this framework, highlighting its strengths and areas for improvement. Such an endeavor would validate the proposed model and contribute to the ongoing efforts to optimize the social, economic, and environmental outcomes of RE projects.

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