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## Risk Management in Renewable Energy Finance; Analyzing the Implication of Quantitative Risk Management Techniques Applied in Financing Renewable Energy Projects on Fostering Renewable Energy Growth and Its Integration into the US Energy Sector

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### ABSTRACT

*Risk management plays a critical role in the development of renewable energy projects in the United States. This paper analyzes the implications of quantitative risk management techniques applied in financing renewable energy projects on fostering renewable energy growth and its integration into the US energy sector. By examining the financial risks associated with renewable energy investments and the strategies to mitigate them, this study sheds light on how efficient risk management can enhance the attractiveness of renewable energy initiatives to investors and financial institutions. The paper also explores the role of government policies, market dynamics, and project selection criteria in shaping the risk landscape of renewable energy investments. Through a systematic review of literature and case studies, the paper demonstrates how quantitative risk management methodologies, such as probabilistic modeling, scenario analysis, sensitivity analysis, and Monte Carlo simulation, provide valuable insights for decision-making, resource allocation, and project resilience in the dynamic energy market. Overall, this research contributes to a deeper understanding of the importance of risk management in promoting the growth and sustainability of renewable energy in the United States.*

**Keywords:** *Risk management, Renewable energy finance, Quantitative techniques, United States, Energy sector, Financial risk, Probabilistic modeling, Scenario analysis, Monte Carlo simulation, Project selection.*

### I. INTRODUCTION

Robust risk management solutions are of utmost importance in the United States' renewable energy development setting. Renewable energy projects play a crucial role in the nation's ongoing shift towards a more sustainable energy future (Lee & Jin, 2014). Nevertheless, the inherent uncertainties linked to such initiatives require thorough evaluation of risks and implementation of strategies to minimize them, especially in the domain of financing. Renewable energy projects typically involve significant initial financial investments, which cover the stages of development, construction, and ongoing operations and maintenance (Mazzucato & Semieniuk, 2018). Within financing, this outcome in substantial financial risk for project developers, investors, and lenders alike. Efficient risk management

strategies work as a protective measure against any financial setbacks, instilling stakeholders with the trust and certainty required to allocate resources to these endeavors (Isah, et al., 2023).

According to Hain, et al. (2018), the viability of renewable energy projects depends not only on their technical feasibility but also on their economic feasibility. Through the early identification and mitigation of potential risks during the project's lifecycle, stakeholders can enhance the overall viability and appeal of these initiatives to investors and financial institutions (Ottinger, De Figueiredo, & Demange, 2013). Consequently, this promotes higher investor trust and enhances the probability of obtaining the required funds and financing agreements to advance initiatives. Obtaining funding continues to be a crucial element in the advancement and implementation of renewable energy initiatives around the United States (Cheuk & Zhong, 2015). However, lenders and investors tend to be cautious about taking risks, especially when it involves cutting-edge or nascent technologies. Effective risk management frameworks help reduce perceived risks, making negotiations easier and enabling project developers to get more attractive financing terms (Isah, et al., 2023).

In the view of Liu, et al. (2021), sustainable development involves not just ecological factors but also long-term viability and financial stability. Through proactive risk management during every stage of the project, stakeholders may protect against potential disruptions or setbacks that may jeopardize the long-term sustainability and profitability of renewable energy projects (Cheuk & Zhong, 2015). This adds to the overall objective of promoting a robust and environmentally friendly energy infrastructure throughout the United States. Renewable energy has become a fundamental part of the energy industry in the United States, serving as a crucial factor in expanding the variety of energy sources and decreasing dependence on fossil fuels (Hain, et al., 2018). The United States possesses ample renewable energy resources, such as solar, wind, hydropower, biomass, and geothermal energy, distributed across several geographical locations (Duma & Cabre, 2023).

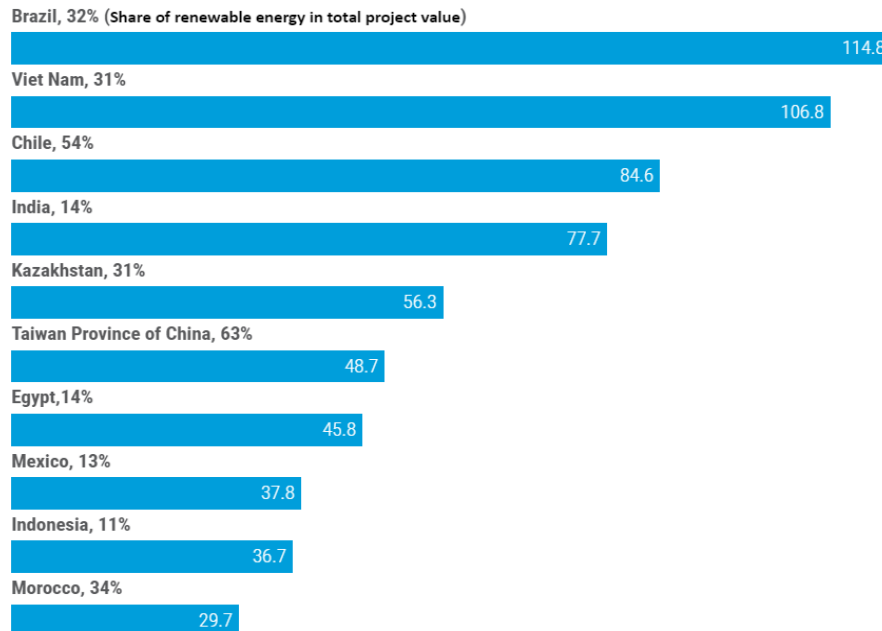
There has been notable progress in the implementation and use of renewable energy technologies throughout the nation. The rise of solar energy has experienced a rapid and significant increase, primarily due to the reduction in costs, advancements in technology, and the implementation of favorable legislation at the federal, state, and municipal levels (Hain, et al., 2018). The United States has emerged as one of the leading global producers of wind energy, contributing to the significant growth of wind power. The expansion of renewable energy in the United States has been additionally reinforced by an increasing recognition of environmental issues, endeavors to mitigate climate change, and the economic advantages linked to the growth of clean energy (Isah, et al., 2023). In addition, renewable energy projects have received significant investment and backing from both public and private sectors, leading to the creation of jobs, economic growth, and enhanced energy security.

Notwithstanding these progressions, obstacles endure in fully actualizing the promise of renewable energy in the United States. These encompass the problems of irregularity linked to specific renewable technologies, difficulties in incorporating them into the power grid, obstacles imposed by regulations, and the necessity of ongoing investment in infrastructure and research (Owens, 2002). However, the prospects for renewable energy in the United States continue to be positive, as there are ongoing initiatives to increase the capacity of renewable energy, improve the flexibility of the power grid, and expedite the shift towards a low-carbon energy future. The United States is well-positioned to utilize its abundant renewable energy resources to satisfy increasing energy needs in a sustainable manner and address the effects of climate change through strategic planning, innovation, and collaboration (Duma & Cabre, 2023).

Quantitative risk management strategies provide a methodical approach to evaluating and measuring the many risks associated with investments in renewable energy. These strategies utilize mathematical models and statistical studies to assess risks that encompass technology uncertainty, regulatory changes, market volatility, and financial restrictions. These risk strategies are highly significant regarding financing renewable energy projects, as they support the basis of renewable energy finance, enabling well-informed decision-making and ways to reduce risk. By doing exhaustive risk identification and assessment, stakeholders can gain a deeper understanding of the inherent risks associated with certain projects. This, in turn, enables them to allocate resources more efficiently and manage potential risks more wisely.

Moreover, the strategies are crucial in determining the cost of financing for renewable energy projects. Integrating risk-adjusted return needs into financial models enables investors and financiers to synchronize the cost of capital with the project's risk profile, guaranteeing that investment decisions are proportionate to the level of risk involved. Duma & Cabre (2023) were of the opinion that a detailed technique for estimating costs becomes possible to determine the pricing of renewable energy assets with greater precision. This, in turn, makes these assets more appealing to investors and encourages the influx of capital into the field. Owens (2002) asserted that the application of risk management allows for developing resilient financial models and perform scenario evaluations that replicate potential project outcomes in various risk scenarios. These assessments offer essential insights into how the project is affected by important risk factors, enabling assessing the potential consequences of negative events and create proactive strategies to reduce risks (Lee & Jin, 2014).

The unpredictability of critical project characteristics like energy output and market pricing is evaluated using probabilistic modelling, which is one method that uses probability distributions (Strielkowski, et al., 2021). Simultaneously, stakeholders can use scenario analysis to help identify risks and formulate adaptive strategies by exploring the consequences of various future scenarios, such as changes in policy or technical breakthroughs (Nuriyev, Mammadov, & Mammadov, 2019). In addition to these methods, sensitivity analysis can help decision-makers identify areas of increased risk or opportunity by assessing how project results are affected by changes in input factors. It is worth mentioning that Monte Carlo simulation shows great promise as a technique for estimating risk-adjusted financial measures and for gaining insight into the spectrum of possible project outcomes through the generation of numerous scenario scenarios (Lu, et al., 2020). Finally, stakeholders utilize Value-at-Risk (VaR) analysis to measure the potential negative impact of investment portfolios, which helps them establish risk tolerances and develop effective risk management plans. Stakeholders in renewable energy financing can benefit from these quantitative tools when used together; they help with decision-making, resource allocation, and project resilience in a dynamic energy market (Mazzucato & Semieniuk, 2018).



**Figure 1: Top 10 developing economies by international investment in renewable energy**  
Source: UNCTAD’s World Investment Report 2023

## II. LITERATURE REVIEW

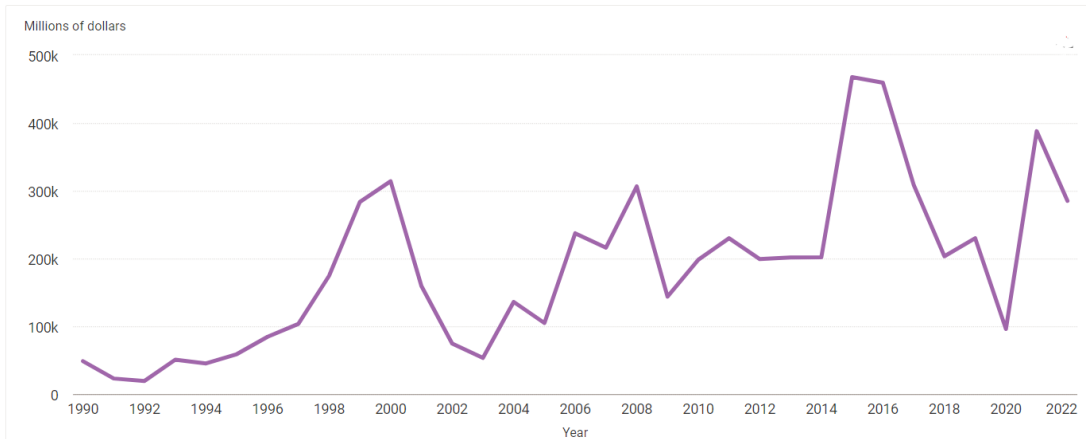
According to (Lee & Jin, 2014), risk management’s goal is to reduce the likelihood that an organisation or project will fail to accomplish its goals by systematically identifying, assessing, and mitigating any risks that may arise. Studies have emphasized the critical importance of alleviating risks across various sectors. This investigation seeks to provide insights into proactive strategies to address uncertainties relating to financial investment in the energy sector, focusing on United States.

### The Cost of Capital in Renewable Energy

Renewable energy project viability and finance hinge on a thorough understanding of the cost of capital (Duma & Cabre, 2023). The cost of capital for renewable energy projects can be affected by their specific difficulties, in contrast to conventional energy projects that typically have preexisting infrastructure and reliable income sources. The perceptions of investors and the dynamics of risk-return are affected by these obstacles, which include technical uncertainties, regulatory complexity, and market concerns (Lee & Jin, 2014). When calculating the cost of capital for renewable energy projects, Mazzucato & Semieniuk (2018) emphasizes the significance of risk-adjusted returns. Renewable energy technology investments are notoriously risky due to their long-term nature and the inherent uncertainty in the market. As a result, investors usually demand larger returns to offset these concerns (Lee & Jin, 2014). The cost of capital assessment process is greatly aided by quantitative risk management approaches, which are essential for evaluating and quantifying these risks. Financial decisions should be based on an accurate assessment of the project’s risk profile, which can be achieved by using tools like sensitivity analysis, Monte Carlo simulation, and probabilistic modelling (Hain, et al., 2018).

Capital expenditures on renewable energy projects are also heavily impacted by legislative incentives and regulatory frameworks (Lu, et al., 2020). By reducing revenue risk and providing predictable streams of income, renewable energy certificates, feed-in tariffs, tax

incentives, and government subsidies can enhance project economics and lower financing costs. But the converse is also true: investors' risk perceptions can rise, and their required returns might rise in response to policy uncertainties and regulatory changes. According to Nuriyev, et al. (2019), lowering the cost of capital and attracting investment capital to the renewable energy sector are both made possible by stable and transparent legislative frameworks.



**Figure 2: Energy Investment in the United States 1990-2022**

Source: UNCTAD's World Investment Report 2023

The cost of finance for renewable energy projects is also heavily influenced by market factors such as interest rates, inflation forecasts, and liquidity conditions (Cheuk & Zhong, 2015). Investment confidence and risk appetite are affected by market fluctuations, which in turn affect the cost and availability of funding for renewable energy projects. Lee & Jin (2014) showed that renewable energy projects can benefit from improved economics and lower cost of capital when market conditions are favorable, including when interest rates are low, and liquidity is abundant.

### **Renewable Energy Policy Overview in the United States**

Changes in renewable energy legislation in the US over the last several decades are indicative of the country's maturing understanding of the significance of making the switch to green power (Liu, et al., 2021). Investment conditions, project economics, and the nationwide deployment of renewable energy sources are all significantly impacted by renewable energy regulations at the national, state, and regional levels. To encourage the creation and implementation of renewable energy projects, federal renewable energy laws have changed over time (Cabre, 2023). Two important programs that offer tax breaks for renewable energy generation and investment are the Production Tax Credit (PTC) and the Investment Tax Credit (ITC). Investment in renewable energy projects, especially solar and wind power, has been greatly facilitated by these incentives (Isah, et al., 2023).

Renewable Portfolio Standard (RPS) and Clean Power Plan (CPP) are two federal programs that work towards the same goals of reducing power sector emissions of greenhouse gases and increasing the usage of renewable energy (Mazzucato & Semieniuk, 2018). Demand for renewable energy is being driven by state-level RPS mandates, which influence market dynamics, despite the fact that the CPP has been subject to regulatory revisions and legal challenges in recent years (Strielkowski, et al., 2021). The many policy tools at the disposal of states allow them to shape renewable energy markets. Renewable Portfolio Standards (RPS) are in place in numerous states and require utilities to get a specific amount of power from renewable sources. The expansion of renewable energy sources in areas rich in such resources has been propelled in large part by these criteria, which differ from state to state.

To further encourage the development of renewable energy sources, several states provide financial incentives such as rebates, subsidies, and incentives depending on performance (Liu, Xu, Wei, Hatab, & Lan, 2021). The expansion of distributed renewable energy generation has been aided by net metering rules, which permit consumers to resell surplus power produced by renewable sources to the grid. Communities and municipalities are also taking novel steps to encourage the use of renewable energy sources, complementing regulations at the federal and state levels. Among these efforts, local stakeholders are empowered to engage in the transition to clean energy through community solar programs, municipal aggregation programs, and green procurement policies (Duma & Cabre, 2023). A mix of federal incentives, state mandates, and local initiatives has made renewable energy policy in the US make great strides. Despite ongoing policy uncertainties and regulatory hurdles, renewable energy adoption is set to continue expanding, highlighting the need for supporting policy frameworks to achieve a sustainable energy future.

### **Project Selection in Renewable Energy**

The economics, sustainability, and success of renewable energy projects are all affected by the project selection process, making it an essential part of renewable energy development. Resource availability, site suitability, technological considerations, financial feasibility,

and regulatory restraints are some of the aspects that are considered while finding and evaluating possible project opportunities (Cheuk & Zhong, 2015). A thorough evaluation of the renewable energy resources available at possible project locations is one of the first things to do before selecting a project. Solar irradiance and shading analyses are critical for solar projects, whereas wind resource assessments and topographical analyses are necessary for wind projects. When deciding if a site is suitable for renewable energy production, other aspects to examine include water availability, geography, and land use (Owens, 2002).

An additional critical factor in project development is the selection of renewable energy technology. Project needs, available resources, and market conditions determine the relative merits of various technologies, including solar photovoltaic (PV), wind turbines, biomass, hydroelectric, and geothermal (Lee & Jin, 2014). To choose the best technology for a specific project, it is necessary to assess each option's technical viability, scalability, and cost-effectiveness. Project selection is heavily influenced by financial factors. Developers carefully evaluate each project's economic feasibility and return on investment. Evaluating the project's economics under many scenarios requires financial modeling, cost-benefit analysis, and sensitivity analysis. To evaluate and lessen the impact of market, regulatory, and financial risks, quantitative risk management tools like Monte Carlo simulation and probabilistic modeling are employed (Ottinger, et al., 2013).

When developing renewable energy projects, it is crucial to navigate the regulatory landscape. Project developers working on renewable energy projects have a responsibility to research and adhere to all applicable federal, state, and municipal rules and regulations, such as those pertaining to environmental permits, land use zoning, grid connectivity, and incentive programs (Prasad, et al., 2022). In overcoming regulatory hurdles and acquire required clearances and permits, it is essential to engage with relevant agencies, stakeholders, and local communities at an early stage of project development. When developing renewable energy projects, it is essential to engage the community and consult stakeholders (Kumar, Majid, & Rajesh, 2020). Building trust, addressing concerns, and fostering support for renewable energy projects can be achieved through engaging with local communities, landowners, indigenous organizations, and other stakeholders. To gather input and incorporate stakeholder comments into project design and implementation, developers frequently engage in outreach efforts, public meetings, and participatory decision-making procedures (Hain, et al., 2018).

#### **Risk Management for Renewable Energy Investment**

When investing in renewable energy projects, it is crucial to use effective risk management strategies to reduce uncertainty and maximize project viability. Research in this area highlights the significance of methodically recognizing, evaluating, and controlling risks connected to renewable energy projects. These risks include a wide range of elements, such as changes in regulations, technological uncertainties, market volatility, and financial limitations (Kumar, Majid, & Rajesh, 2020).

Market fluctuations, unclear regulations, and risks unique to individual projects are all components of the financial risk landscape surrounding investments in renewable energy. For renewable energy projects to be economically viable and sustainable, Lin and Zou (2017) emphasized the significance of efficiently managing financial risks. To do this, it is necessary to undertake thorough financial feasibility studies, evaluate cash flow estimates, and put risk mitigation measures in place, such as hedging systems, to safeguard against energy market price variations. Furthermore, Hirth et al. (2018) highlighted the importance of maximizing returns on investments by optimizing capital structure and obtaining financing on advantageous conditions.

Government rules and regulations influence the dynamics of the market and the economics of a project, making them major obstacles for investments in renewable energy. Sovacool (2016) cites research showing that investors may feel uneasy and see a drop-in project income due to changes in renewable energy support schemes, subsidy programs, and targets. To lessen the blow that policy shifts could deal to a project's bottom line, prudent risk managers keep a careful eye on new regulations, communicate with lawmakers, and spread their investments around. Issues with technology, such as the potential for equipment failure, performance unpredictability, and technological obsolescence, provide inherent risks to renewable energy projects. Argyroudis and Daskalakis (2018) found that to manage technological risks in renewable energy investments, technology evaluation and due diligence were crucial. To improve asset performance and reduce operational disruptions, it is necessary to evaluate the dependability and efficiency of renewable energy technologies, conduct site-specific assessments, and establish maintenance protocols. These measures are done throughout the project lifecycle.

Concerns about the environment and society could discourage funding for renewable energy projects, especially those with large-scale effects on local ecosystems or populations. Environmental and social impact assessments (ESIAs) are crucial for identifying hazards and ensuring compliance with social and environmental standards and regulations, as highlighted by Jenkins et al. (2016). Enhancing project acceptance and sustainability can be achieved through effective risk management techniques that engage stakeholders, address community concerns, and implement measures to prevent adverse environmental and social impacts. The profitability and viability of renewable energy projects can be affected by market risks, such as disruptions in the supply chain, competitive pressures, and changes in energy demand. Market intelligence and scenario analysis are useful tools for gauging market risks and making informed investment

decisions, according to Neufeld and Axsen (2016). To thrive in the ever-changing renewable energy markets, investors need to keep an eye on market trends, look for new possibilities, and spread their best.

### **Risk Management Methodology in Renewable Energy Project**

Renewable energy projects have a few hazards, such as technology uncertainty, regulatory complexity, market dynamics, and financial limits, all of which must be identified, assessed, and mitigated using strong risk management procedures (Liu, et al., 2021). Renewable energy project risk management relies heavily on quantitative risk management procedures, which provide organized ways to assess and lessen hazards. Uncertainties in energy resource availability, technology performance, and market prices are often quantified with probabilistic modelling. Stakeholders can evaluate the chances of different project outcomes and devise methods to mitigate risk by integrating probability distributions into financial models (Cheuk & Zhong, 2015).

To round out probabilistic modelling, scenario analysis considers several future scenarios and how they could affect the project's finances and performance. Stakeholders have the option to consider many scenarios when evaluating the project's viability and financial returns. These scenarios can include changes in governmental frameworks, technological costs, and market conditions (Prasad, et al., 2022). By determining which factors have the most impact on project economics and providing direction for decision-making, sensitivity analysis improves risk assessment even further.

Stakeholders in renewable energy projects can use Monte Carlo simulation, another potent technique in risk management, to create thousands of simulated scenarios using probabilistic inputs. Stakeholders may make better decisions and create stronger risk management plans with the use of Monte Carlo simulation, which helps by modelling various scenarios and revealing insights into the distribution of project outcomes and their corresponding probability (Lee & Jin, 2014).

Renewable energy projects use both quantitative and qualitative risk assessment tools to enhance their risk analysis. Finding and assessing project risks using expert opinion and standard industry norms is what qualitative risk assessment is all about. A few tools are available to help stakeholders communicate and reach a consensus on project risks, including risk matrices, risk registers, and stakeholder workshops (Strielkowski, et al., 2021).

In renewable energy projects, risk management goes beyond only financial concerns; it also considers operational, social, environmental, and technical hazards. Complete engineering and design procedures are necessary to reduce technical hazards like equipment breakdown and performance deterioration. Proactive risk management techniques are necessary because operational risks, such as problems with maintenance or interruptions in the supply chain, can affect the performance and profitability of a project (Duma & Cabre, 2023).

Stakeholder involvement and risk mitigation strategies are necessary to successfully handle environmental and social hazards, which include things like community resistance, land use conflicts, and regulatory compliance. Proactively identifying and managing social and environmental hazards requires early engagement with stakeholders, including local people and indigenous organizations (Hain, et al., 2018).

Significant risks in developing renewable energy projects include policy and regulatory uncertainties, which impact investor confidence and the economics of the projects. Project revenues and financial returns are very sensitive to shifts in government policies, subsidies, and incentives; so, stable and predictable policy frameworks are crucial (Liu, et al., 2021).

Project revenues and finance costs can be affected by market risks such commodity price volatility, interest rate changes, and currency exchange rate concerns. To limit this exposure, risk management measures like hedging and diversification are necessary (Cheuk & Zhong, 2015). Project resilience and profitability can be enhanced with appropriate risk management approaches, which are crucial for navigating the intricacies of renewable energy project development. To help renewable energy investments, expand and remain sustainable, stakeholders should use a holistic approach to risk management that incorporates both quantitative and qualitative risk management methodologies. This will allow them to detect, assess, and reduce risks across multiple dimensions (Kumar, Majid, & Rajesh, 2020).

### **Systematic Approach to Managing Risk in Energy Sector**

From inception to completion, this methodology takes a methodical approach to controlling uncertainty at every stage of a project's lifecycle. The first stage of risk management is to identify the risks that may have an impact on the project (Kunya & Yusuf, 2023). This necessitates a review of both internal and external elements, including technological hurdles, changes in regulations, market dynamics, and ecological concerns. Methods for identifying potential dangers in the renewable energy industry include holding workshops, conducting expert interviews, and holding brainstorming sessions.

The next step in risk management is to evaluate each identified risk according to how likely it is to occur and how much of an influence it could have on the project's goals. In order to rank the risks and establish their importance, we use quantitative and qualitative risk assessment methods. Risks can be quantitatively assessed using tools like sensitivity analysis and Monte Carlo simulation, or qualitatively assessed using tools like risk matrices and expert judgement, according to factors like severity and urgency (Cabre, 2023). After identifying potential dangers, the next step is to devise plans to lessen their occurrence or severity. To do this, it may be necessary to take contractual, financial, operational, or technical steps to mitigate certain risks. Robust quality control procedures, for instance, can lessen the impact of technical risks like equipment failure, while hedging and insurance can lessen the impact of financial risks like revenue unpredictability (Lee & Jin, 2014). For risk mitigation techniques to be effective, parties such as investors, developers, contractors, and regulatory agencies must work together.

Continuous monitoring and control of risks is essential throughout a project's lifetime since risk management is an iterative process. Evaluating the efficacy of mitigation strategies, keeping tabs on newly identified hazards, and keeping tabs on changes to risk variables are all part of this process. To make sure new risks are found and dealt with quickly, the risk register should be reviewed and updated on a regular basis (Liu, et al., 2021). Project stakeholders can make well-informed decisions and take preventative measures when there are systems in place for reporting and communicating risks.

Documenting and sharing lessons learnt from risk management efforts at project completion helps guide future projects and promotes continuous improvement. Project teams can learn about their risk management practices' strengths, shortcomings, and opportunities for growth through this feedback loop. Future renewable energy projects will benefit from improved risk management because of ongoing efforts to update risk management frameworks, refine risk assessment methodology, and incorporate emerging best practices (Kunya & Yusuf, 2023).

## **Theoretical Review**

### **Modern Portfolio Theory**

Harry Markowitz's 1952 introduction of Modern Portfolio Theory (MPT) offered a systematic framework for optimizing investment portfolios, which shook up the field of investment theory. To achieve better risk-adjusted returns, MPT essentially stresses the significance of diversification and risk management (Beyhaghi & Hawley, 2013). According to the notion, investors may get more out of their money while taking on less risk if they diversify their holdings across a wide range of asset classes with varying degrees of risk and return. The efficient frontier, the collection of portfolios that provide the best expected return relative to the risk level, or the lowest risk relative to the expected return, is fundamental to maximum probability theory (MPT). Optimal risk-return trade-offs can be achieved by building portfolios along the efficient frontier, hence maximizing portfolio efficiency (Qiang, Wang, & Wu, 2022).

Optimization of portfolios and methods for mitigating risk can be greatly enhanced by studying Modern Portfolio Theory. Several factors, such as changes in policy, technology advancements, and market dynamics, provide inherent risks to renewable energy projects (Liu Y. , 2022). Renewable energy finance stakeholders can build diversified portfolios spanning solar, wind, and hydropower projects, each with their own unique risk profile, by utilizing MPT principles. To optimize portfolio allocations according to the efficient frontier, quantitative risk management methods like Monte Carlo simulation and probabilistic modelling can be employed to evaluate the risk-return properties of specific projects (Beyhaghi & Hawley, 2013). Investments in renewable energy projects and other uncorrelated assets can help diversify a portfolio and lower its overall risk, according to MPT. To maximize portfolio efficiency and achieve sustainable long-term returns, stakeholders can improve their ability to handle the intricacies of renewable energy finance and investment by integrating MPT concepts into risk management plans.

### **Real Option Theory**

The theory was originally created in the late 1970s by Stewart Myers and Robert C. Merton. Extending the scope of conventional financial analysis, Real Options Theory considers the importance of being adaptable and making strategic decisions in the face of uncertainty (Benaroch, Lichtenstein, & Robinson, 2006). Real Options Theory assesses the value of investment projects and other real assets in uncertain and dynamic markets using the concepts of option pricing. Rather than being final, investment decisions are strategic choices that allow one to react to uncertain market conditions. This is something that the theory acknowledges. According to Real Options Theory, investment projects have attributes similar to options, giving decision-makers the ability to use different strategies, such as postponing, expanding, or cancelling projects, depending on how the market is doing and how risky they feel it is (Savchuk, 2023). When it comes to making strategic decisions and developing plans to control risk, Real Options Theory provides invaluable insights. A number of factors, such as changes in policy, innovations in technology, and the dynamics of the market, pose substantial risks to renewable energy projects. The framework provided by Real Options Theory allows one to assess the worth of decision-making flexibility, such as the ability to postpone project construction until market circumstances improve or the option to increase project capacity in reaction to surges in demand. The benefit of strategic flexibility can be evaluated and factored into investment decision-making processes when stakeholders view renewable energy projects as genuine possibilities. For projects to be more resilient and generate more value in the ever-changing energy market, Real Options Theory says that managers should be able to shift gears quickly

and easily in response to market shifts. To help stakeholders in renewable energy finance and investment better handle uncertainty and make well-informed decisions that maximize project value and long-term returns, Real Options Theory can be included into risk management techniques.

### **Empirical Review**

Liu, et al. (2021) examined the nexus between green financing, renewable energy, and energy efficiency, highlighting potential global spending increases in renewable energy through energy efficiency projects. The study's findings reveal a significant potential increase in global expenditures on renewable energy through energy efficiency projects, with a projected rise of 24%.

Lee & Jin (2014) explored the evolution of renewable energy policy and its alignment with investors' risk-return perspectives. It identifies major risks—market, credit, operational, liquidity, and political—impacting renewable energy projects. By reviewing risk management tools tailored to policy-related uncertainties, stakeholders are empowered to make informed decisions, fostering future investment in renewable energy.

Hain, et al. (2018) examined managing stochastic production risks in Germany's dynamic electricity market, a prominent renewable energy hub. It finds unhedged portfolios risky, existing derivatives inadequate. New exotic weather contracts show potential but lack liquidity. Price-related derivatives are anticipated to evolve into more effective hedging instruments amid growing renewable energy influence on market prices.

Cabre (2023) explored risk interventions in renewable energy investments, emphasizing developers' perspectives. It addresses barriers in project finance and development, particularly in Sub-Saharan Africa. The study reviews risk's role, cost of capital, and investment selection, while evaluating the effectiveness of risk mitigation and transfer instruments in utility-scale investments.

### **III. METHODOLOGY**

The study employed quantitative research design. More specifically, time series analysis was conducted based on the model specified to achieve the objectives of the study. Secondary data was collected on total energy consumption, per capita energy consumption, solar generation, wind generation, hydro generation, and other renewables. The adoption of time series techniques will enable the study to account for the temporal nature of the data and assess trends and seasonality in energy consumption and renewable energy generation. The data covers the period of 1990 to 2022, obtained from World Bank's World Development Indicators. Additionally, a multiple regression model was specified as follows;

#### **Model 1**

$$EC = \beta_0 + \beta_1SG + \beta_2WG + \beta_3HG + \beta_4OR + \varepsilon$$

Where;

EC = Total Energy Consumption

SG = Solar Generation

WG = Wind Generation

HG = Hydro Generation

OR = Other Renewable Energy Generation

$\varepsilon$  = Error term

$\beta_0$  = Intercept

$\beta_1$  to  $\beta_4$  = Slopes of the coefficients of SG, WG, HG, OR

This model aims to assess how changes in solar, wind, hydro generation, and other renewable energy impact overall energy consumption over time. The coefficients ( $\beta_1, \beta_2, \beta_3, \beta_4$ ) indicate the strength and direction of the relationships between each renewable energy source and energy consumption.

#### **Model 2**

$$PC = \beta_0 + \beta_1SG + \beta_2WG + \beta_3HG + \beta_4OR + \varepsilon$$

Where;

PC = Per capita Energy Consumption

SG = Solar Generation

WG = Wind Generation

HG = Hydro Generation

OR = Other Renewable Energy Generation

$\varepsilon$  = Error term

$\beta_0$  = Intercept

$\beta_1$  to  $\beta_4$  = Slopes of the coefficients of SG, WG, HG, OR



This model aims to assess how changes in solar, wind, hydro generation, and other renewable energy impact per capita energy consumption over time. The coefficients ( $\beta_1, \beta_2, \beta_3, \beta_4$ ) indicate the strength and direction of the relationships between each renewable energy source and energy consumption.

**IV. RESULTS**

**Table 1: Descriptive Analysis of the Variables**

Variable	Mean	Std. Dev.	Min	Max	Obs
EC	25518.73	1251.17	22576.31	27063.79	33
PC	86108.11	6151.78	73236.14	93999.86	33
SG	28.96	53.72	0.37	206.17	33
WG	103.61	129.91	2.82	439.20	33
HG	277.46	30.51	210.24	355.97	33
OR	72.12	6.91	57.46	84.07	33

*Source: Author’s Computation, 2024:*

*Explanatory Notes: EC is Total Energy Consumption, PC is Per capita Energy Consumption, OR, Other Renewables Energy Generation, SG is Solar Energy Generation, WG is Wind Energy Generation, HG is Hydro Energy Generation.*

Table 1 presents the summary statistics of the variables. It could be seen that the average overall energy consumption is 25,518.73 terawatt-hour with a standard deviation of 1,251.17, which indicates minimal differences in the values of overall energy consumption over time. The minimum value of overall energy consumption is 22,576.31 terawatt-hour, while the maximum is 27,063.79 terawatt-hour. Per capita energy consumption in the United States is 86108.11 kilowatt-hour with a standard deviation of 6151.78, which suggest that the values do not deviates widely from the mean. The minimum value of per capita energy consumption is 73,236.14 kilowatt-hour, while the maximum value is 93,999.86 kilowatt-hour.

Solar energy generation has an average value of 28.96 terawatt-hour with a standard deviation of 53.72, indicating a wide difference in solar generated over time within the period considered. The minimum value of solar energy generation is 0.37 terawatt-hour, while the maximum is 206.17 terawatt-hour. Wind energy generation has an average value of 103.61 terawatt-hour with a standard deviation of 129.91, which implies that the values spread across the years under consideration. The minimum value of wind energy generation is 2.82 terawatt-hour, while the maximum value is 439.20 terawatt-hour. Hydro energy generation has an average value of 277.46 terawatt-hour with a standard deviation of 30.51, indicating a minimal spread in the values of hydro energy over the years. The minimum value of hydro energy generation is 210.24 terawatt-hour, while the maximum value is 355.97 terawatt-hour. Other renewable energy generated has an average value of 72.12 terawatt-hour with a standard deviation of 6.91, which suggests a minimal difference in the values of other renewable energies. The minimum value is 57.46 terawatt-hour, while the maximum value is 84.07 terawatt-hour.

**Table 2: Correlation Analysis**

Variable	EC	PC	SG	WG	HG	OR
EC	1.000					
PC	-0.158 (0.377)	1.000				
SG	0.572 (0.000)	-0.467 (0.000)	1.000			
WG	0.219 (0.218)	-0.414 (0.000)	0.408 (0.019)	1.000		
HG	0.275 (0.122)	-0.598 (0.000)	0.656 (0.000)	0.637 (0.000)	1.000	
OR	-0.181 (0.311)	0.255 (0.152)	-0.308 (0.081)	-0.136 (0.449)	-0.178 (0.321)	1.000

*Source: Author’s Computation, 2024:*

*Explanatory Notes: EC is Total Energy Consumption, PC is Per capita Energy Consumption, OR, Other Renewables Energy Generation, SG is Solar Energy Generation, WG is Wind Energy Generation, HG is Hydro Energy Generation.*

Table 2 presents the pairwise correlation results, indicating the relationship that exists between a pair of variables. The correlation coefficients for all pairs are less than 0.8, indicating that including these variables in regression analysis will not generate spurious results. That implies that there is no problem of severe multicollinearity among the variables.

**Table 3: Variance Inflation Factor (VIF)**

Variable	VIF	1/VIF
Solar Generation	2.49	0.40
Wind Generation	5.41	0.18
Hydro Generation	1.26	0.79
Other Renewable Energies	5.65	0.17
Mean VIF	3.71	

*Source: Author's Computation, 2024*

Table presents the variance inflator factor (VIF) results testing for multicollinearity among the independent variables. The decision rule for VIF is to accept that there is low-level of multicollinearity if the VIF values are less than 10 or reject if the values are greater than 10. The values in Table 3 are less than 10, which further suggest that there is no problem of severe multicollinearity among the variables.

**Table 4 Estimation of Model 1 (Overall Energy Consumption)**

Variables	Coeff.	Std. Err	T-Stat	p-value
Solar Energy Generation	0.0021	0.0005	3.99	0.000
Wind Energy Generation	-0.0011	0.0002	-4.14	0.000
Hydro Energy Generation	0.0001	0.0002	0.81	0.426
Other Renewable Energies	0.0113	0.0019	5.71	0.000
Constant	9.3318	0.1608	58.02	0.000
R-Squared	0.5866			
Adjusted R-Squared	0.5276			
F-Stat (p-value)	9.93 (0.000)			

*Source: Author's Computation, 2024*

The table above presents the result of the regression analysis investigating how renewable energy generations influence overall consumption of energy in the United States. The result indicates that solar energy and other renewable energy generated have positive influence on overall consumption, while wind energy generated has negative effect on overall consumption of energy. More specifically, a unit increase solar energy generated will bring about 0.0021 terawatt-hour increase overall energy consumption in the United States. Accordingly, a unit increase in other renewable energy generated will lead to increase in overall energy consumption in the United States by 0.0113 terawatt-hour. On the other hand, a unit increase in wind energy generated will bring about reduction in the overall energy consumption in the United States by 0.0011 terawatt-hour.

The R-squared of 0.5866 suggests that solar, wind, hydro, and other renewable energies are able to explain 58.6% variation in overall energy consumption. The F-statistics of 9.93 with an associated p-value of 0.0000 indicates that all the independent variables are jointly significant in predicting overall energy consumption in the United States. Hence, it was concluded that the model is good fitted.

**Table 5 Estimation of Model 1 (Per Capita Energy Consumption)**

Variables	Coeff.	Std. Err	T-Stat	p-value
Solar Energy Generation	0.0018	0.0002	6.89	0.000
Wind Energy Generation	-0.0012	0.0001	-9.64	0.000
Hydro Energy Generation	0.0002	0.0001	2.00	0.055
Other Renewable Energies	0.0024	0.0009	2.44	0.021
Constant	11.2057	0.0809	138.51	0.000
R-Squared	0.9495			
Adjusted R-Squared	0.9423			
F-Stat (p-value)	131.66 (0.000)			

*Source: Author's Computation, 2024*

Table 5 presents the regression result indicating the effect of renewable energy generated on the per capita energy consumption in the United States. The findings revealed that solar, wind, and other renewable energy have significant effect on per capita energy consumption. However, the result indicated that hydro energy does not have significant effect on per capital energy consumption. This conclusion was reached based on their respective p-values. The statistically significant positive coefficient of solar energy generation implies that a unit increase in solar energy generated will lead to a 0.0018 kilowatt-hour increase in per capital energy consumption. Accordingly, other renewable energy generated with a positive and significant coefficient implies that a unit increase in other renewable energy generated will bring about increase in per capital energy consumption by 0.0024 kilowatt-hour. However, the negative significant coefficient of wind energy generation implies that a unit increase in wind energy generated will lead to 0.0012 decrease in per capita energy consumption in the United States.

The R-squared of 0.9495 suggests that solar, wind, hydro, and other renewable energies are able to explain 94.9% variation in per capita energy consumption. The F-statistics of 131.66 with an associated p-value of 0.0000 indicates that all the independent variables are

jointly significant in predicting per capita energy consumption in the United States. Hence, it was concluded that the model is good fitted.

## **V. DISCUSSION AND CONCLUSION**

The findings revealed that the significant determinant of energy consumption in the United States are solar, wind, and other renewable energies, including biomass and geothermal. Given this outcome from the empirical analysis financing in the energy sector on renewable energies can focus on solar, wind and other renewable energies that were found to influence consumption. Increasing solar energy generation may lead to an uptick in overall energy consumption due to a phenomenon known as the rebound effect. As solar energy becomes more accessible and affordable, consumers may be inclined to increase their energy usage, offsetting some of the gains made in energy efficiency. While this surge in energy consumption presents opportunities for revenue generation in energy projects, it also introduces financial risks. This may lead to incorporating smart technology and demand-side management practices that contribute to optimizing energy usage, which further mitigate financial risks associated with potential increased in consumption. The increase in wind energy generation can potentially lead to a decrease in overall energy consumption due to several factors. First, as wind energy becomes a larger contributor to the energy mix, it displaces energy generated from fossil fuel sources, which tend to be less efficient and more polluting. Additionally, the variability of wind energy production encourages grid operators and consumers to adopt more efficient energy storage solutions and demand-response programs, leading to better management of energy consumption. From a financial risk perspective, managing this decrease in energy consumption entails careful planning and adaptation.

The findings showed the importance of renewable energy to overall energy consumption in the United States. While it is an opportunity for investors, it is essential to understand patterns associated with renewable energy generation and changes in consumer behavior towards renewable energy.

### **Recommendations**

Project financiers must carefully evaluate and mitigate these risks by ensuring robust demand forecasting, implementing pricing strategies that encourage energy efficiency, and diversifying energy sources to minimize dependence on solar alone. Project financiers must anticipate potential shifts in demand patterns, assess the impact on revenue streams, and diversify investments across a mix of renewable energy sources and ancillary services to mitigate any adverse effects on project profitability. Furthermore, ensuring regulatory support and fostering market mechanisms that incentivize efficient energy usage can contribute to risk mitigation strategies in the evolving landscape of wind energy generation.

## **VI. REFERENCES**

- Benaroch, M., Lichtenstein, Y., & Robinson, K. (2006). Real Options in Information Technology Risk Management: An Empirical Validation of Risk-Option Relationships. *MIS Quarterly*, 30(4), 827-864.
- Beyhaghi, M., & Hawley, J. F. (2013). Modern portfolio theory and risk management: assumptions and unintended consequences. *Journal of Sustainable Finance & Investment*, 3(1), 17-37.
- Cabre, M. M. (2023). Risk Mitigation and Transfer For Renewable Energy Investments. *Stockholm Environment Institute*, 1-26.
- Cheuk, W. L., & Zhong, J. (2015). Financing and risk management of renewable energy projects with a hybrid bond. *Journal of Renewable Energy*, 75(1), 779-787.
- Duma, D., & Cabre, M. M. (2023). Risk Mitigation and Transfer for Renewable Energy Investments. *Stockholm Environment Institute*, 3(7), 1-26.
- Hain, M., Schermeyer, H., Uhrig-Hamburg, M., & Fichtner, W. (2018). Managing renewable energy production risk. *Journal of Banking and Finance*, 97(1), 1-19.
- Isah, A., Dioha, M. O., Debnath, R., Abraham-Dukuma, M. C., & Butu, H. M. (2023). Financing renewable energy: policy insights from Brazil and Nigeria. *Journal of Energy, Sustainability, and Society*, 2(1), 13.
- Kumar, J., Majid, M. A., & Rajesh, C. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. *Energy, Sustainability, and Society*, 2(1), 10.
- Kunya, I. O., & Yusuf, M. (2023). Risk Management Practices and Performance of Renewable Energy Projects in Nairobi County. *World Journal of Innovative Research*, 14(4), 41-49.
- Lee, C. W., & Jin, Z. (2014). Risk Management Methods Applied to Renewable and Sustainable Energy: A Review. *The Open Electrical & Electronic Engineering Journal*, 3(1), 1-12.
- Liu, Y. (2022). Application of Modern Portfolio Theory in Stock Market. *International Conference on Financial Innovation and Economic Development*, 211, 1-6.

Liu, Z., Xu, J., Wei, Y., Hatab, A. A., & Lan, J. (2021). Nexus Between Green Financing, Renewable Energy Generation, and Energy Efficiency: Empirical Insights Through DEA Techniques. *Environmental Science and Pollution Research*, 30, 61290-61303.

Lu, Y., Khan, Z. A., Alvarez-Alvarado, M. S., Zhang, Y., Huang, Z., & Imran, M. (2020). A Critical Review of Sustainable Energy Policies for the Promotion of Renewable Energy Sources. *Journal of Sustainability*, 12(12), 5078.

Mazzucato, M., & Semieniuk, G. (2018). Financing Renewable Energy: Who is Financing What and Why it Matters. *Technological Forecasting and Social Change*, 127(1), 8-22.

Nuriyev, M. N., Mammadov, J., & Mammadov, J. (2019). Renewable Energy Sources Development Risk Analysis and Evaluation: the Case of Azerbaijan. *European Journal of Economics and Business Studies*, 5(3), 11-20.

Ottinger, R. L., De Figueiredo, D. S., & Demange, L. H. (2013). Case study of renewable energy in Brazil. *Renewable Energy Law and Development*. 107-134.

Owens, G. (2002). Economic & Financial Evaluation of Renewable Energy Projects. *Institute of International Education*, 1(4), 1-60.

Prasad, A., Loukoianova, E., Feng, A. X., & Oman, W. (2022). Mobilizing Private Climate Financing in Emerging Market and Developing Economies. *International Monetary Fund*, 1(7), 1-41.

Qiang, S., Wang, M., & Wu, W. (2022). Contemporary Theoretical Models of Portfolio Risk. *International Seminar on Education*, 687, 3095-3101.

Savchuk, V. (2023). Real Options Technique as a Tool of Strategic Risk Management. *International Institute of Business*,.

Strielkowski, W., Civin, L., Tarkhanova, E., Tvaronaviciene, M., & Petrenko, Y. (2021). Renewable Energy in the Sustainable Development of Electrical Power Sector: A Review. *Journal of Energies*, 14(24), 8240.

**Appendix**

Variable	Obs	Mean	Std. Dev.	Min	Max
Energy_ConsumptionTWh	33	25518.73	1251.174	22576.31	27063.79
PerCapitaEnergyUseKWh	33	86108.11	6151.781	73236.14	93999.86
Otherrenewablesincludinggeothermal	33	72.11646	6.909765	57.45932	84.07023
SolargenerationTWh	33	28.96285	53.72154	.370795	206.1717
WindgenerationTWh	33	103.6134	129.9072	2.816768	439.2037
HydrogenerationTWh	33	277.4654	30.51376	210.24	355.9731

. pwcorr Energy\_ConsumptionTWh PerCapitaEnergyUseKWh Otherrenewablesincludinggeothermal SolargenerationTWh WindgenerationTWh HydrogenerationTWh, sig

	Energy_ConsumptionTWh	PerCapitaEnergyUseKWh	Otherrenewablesincludinggeothermal	SolargenerationTWh	WindgenerationTWh	HydrogenerationTWh
Energy_ConsumptionTWh	1.0000					
PerCapitaEnergyUseKWh	-0.1587	1.0000				
Otherrenewablesincludinggeothermal	0.3776		1.0000			
SolargenerationTWh	0.5715	-0.4672	0.0005	1.0000		
WindgenerationTWh	0.0005	0.0000			1.0000	
HydrogenerationTWh	0.2199	-0.4143	0.4078	0.0185		1.0000
	0.2188	0.0000	0.0185			
	0.2745	-0.5976	0.6560	0.6369	1.0000	
	0.1221	0.0000	0.0000	0.0000		1.0000
	-0.1818	0.2551	-0.3078	-0.1363	-0.1783	1.0000

```
| 0.3114 0.1519 0.0814 0.4493 0.3208
|
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```
. estat vif
```

Variable	VIF	1/VIF
lnor	5.65	0.176856
lnwg	5.41	0.184685
lnsg	2.49	0.401761
lnhg	1.26	0.792304
Mean VIF	3.71	

```
. reg lnpc SolargenerationTWh WindgenerationTWh HydrogenerationTWh Otherrenewablesin
> cludinggeot
```

Source	SS	df	MS	Number of obs	=	33
Model	.160273969	4	.040068492	F(4, 28)	=	131.66
Residual	.008521118	28	.000304326	Prob > F	=	0.0000
Total	.168795086	32	.005274846	R-squared	=	0.9495
				Adj R-squared	=	0.9423
				Root MSE	=	.01744

lnpc	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
Solargeneration~h	.0018569	.0002693	6.89	0.000	.0013052 .0024087
WindgenerationTWh	-.0012995	.0001348	-9.64	0.000	-.0015757 -.0010233
Hydrogeneration~h	.0002164	.0001082	2.00	0.055	-5.25e-06 .000438
Otherrenewables~t	.0024395	.0009997	2.44	0.021	.0003918 .0044872
_cons	11.20573	.0809023	138.51	0.000	11.04001 11.37145

```
. reg lnec SolargenerationTWh WindgenerationTWh HydrogenerationTWh Otherrenewablesin
> cludinggeot
```

Source	SS	df	MS	Number of obs	=	33
Model	.047792669	4	.011948167	F(4, 28)	=	9.93
Residual	.033675314	28	.00120269	Prob > F	=	0.0000
Total	.081467983	32	.002545874	R-squared	=	0.5866
				Adj R-squared	=	0.5276
				Root MSE	=	.03468

lnec	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
Solargeneration~h	.0021384	.0005355	3.99	0.000	.0010416 .0032353
WindgenerationTWh	-.0011093	.000268	-4.14	0.000	-.0016583 -.0005603
Hydrogeneration~h	.0001736	.0002151	0.81	0.426	-.0002669 .0006142
Otherrenewables~t	.0113551	.0019873	5.71	0.000	.0072843 .0154258
_cons	9.331897	.1608305	58.02	0.000	9.002451 9.661344