REAL OPTIONS VALUATION OF SOLAR ENERGY PROJECTS: A SYSTEMATIC REVIEW

Furkan Suleyman Ustun[1], Gozde Bilgin[2] and Emre Caner Akcay[3]

[1&3] Department of Civil Engineering, Atilim University, Kizilcasar Mahallesi, Ankara, 06830, Turkey

[2] Department of Civil Engineering, Baskent University, Baglica Kampusu, Fatih Sultan Mahallesi, Ankara, 06790, Turkey

Energy plays an essential role in the development of countries, addressing the basic needs of people, and advancing technological progress. As the world's population and the energy demand in the industrial sector increase rapidly, the limited non-renewable energy resources prove insufficient to supply this demand. Consequently, both developed and developing countries are shifting towards renewable energy sources to meet their energy needs. As a result, the number of renewable energy projects in the world has been increasing day by day. Solar energy technology stands as an exemplar within the realm of renewable energy resources, playing a pivotal role in contributing to their overall share. Assessing the economic feasibility of solar energy projects is crucial to ensure their success. Traditional economic analysis methods often disregard managerial flexibility, leading to prefer the real options valuation for analysing the economic feasibility of solar energy projects. Therefore, the objective of this research is to review the application of the real options valuation for valuing solar energy projects in the existing literature. The findings of this study may provide a roadmap for future research efforts.

Keywords: economic feasibility; real options valuation; project; solar energy; sustainability

INTRODUCTION

Renewable energy is a leading approach in efforts to combat climate change and decrease dependency on limited fossil fuel resources (Gazheli and van den Bergh 2018). Among various renewable energy sources, solar energy is pivotal, leveraging the abundant and inexhaustible power of the sun to generate electricity (Fan *et al.,* 2020). Its significance is underscored by the dual challenges of rising electricity demand and the critical need to minimise carbon footprints (Li *et al.,* 2018). According to Gazheli and Di Corato (2013), especially ground-based solar photovoltaic (PV) installations offer a scalable and efficient way to meet energy demands while preserving agricultural lands for future use and balancing land use between energy and agriculture. Solar (PV) technology offers a clean, adaptable, and progressively affordable energy option by converting sunlight directly into electricity, making it essential for leading the worldwide shift toward a sustainable energy future (Kim *et al.,* 2020).

[1] furkanustunspace@gmail.com

Ustun, F S, Bilgin, G and Akcay, E C (2024) Real Options Valuation of Solar Energy Projects: A Systematic Review *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 40th Annual ARCOM Conference,* 2-4 September 2024, London, UK, Association of Researchers in Construction Management, 899-908.

The valuation of solar energy projects lies at the intersection of financial innovation and sustainable development (Pan *et al.,* 2019). Traditional investment appraisal methods struggle to handle the inherent uncertainties of these projects. The dynamic nature of technological advancements, policy frameworks, and market volatility necessitates a valuation approach that accounts for flexibility and strategic decision-making under uncertainty (Ma *et al.,* 2020). Real Options Valuation (ROV) plays a crucial role in this scenario, offering a structure to assess and leverage the built-in options found in solar energy investments (Lin *et al.,* 2013).

ROV offers a nuanced approach to investment decision-making, particularly under conditions of uncertainty, incorporating the strategic value of flexibility and the potential for adapting decisions based on new information. Unlike traditional valuation methods such as Net Present Value (NPV) and Discounted Cash Flow (DCF), which may not fully account for the unpredictability of cash flows and the strategic benefits of waiting for more information (Spertino *et al.,* 2013), ROV recognises the importance of options such as expand, wait, contract, or abandon. The Black-Scholes, Binomial, and Monte Carlo methods are the most popular ROV techniques due to their strong theoretical foundations, versatility in handling a wide range of valuation scenarios, and adaptability to both simple and complex options (Jeon *et al.,* 2015).

In recent developments within the renewable energy sector, particularly solar PV power generation, the application of ROV has emerged as a critical tool for enhancing the strategic valuation of investments under uncertainty. Di Bari (2020) illustrated the importance of tailoring the ROV approach to specific national and regional contexts, reflecting variances in policy support, market maturity, and solar irradiance. The adaptability of ROV to these diverse contexts underscores its flexibility and utility in facilitating informed and more accurate strategic investment decisions in the solar energy sector (Rocha *et al.,* 2023).

In consideration of these factors, this study aims to provide a systematic review on Real Options Valuation (ROV) in the context of solar energy projects to gather insights from recent research and address existing research gaps. The primary objective is to investigate how ROV can promote the resilience and sustainability of investments in solar energy. This study intends to draw a holistic picture that combines financial innovation with sustainable development principles, thereby providing a contribution for more effective investment decision-making under conditions of uncertainty.

METHOD

This study delineates a scholarly synthesis concerning the utilisation of the ROV in the valuation of projects within the solar energy sector. Through an organised literature review, this investigation sought to gather methodological terminologies pertinent to ROV.

In the study, the scientific records were identified from three different databases: Scopus, Web of Science, and Science Direct. Web of Science is recognised for hosting high-impact journals across various subjects (Qiu and Chen, 2023). Scopus boasts a vast collection encompassing thousands of titles and provides robust tools for analysing research trends. Meanwhile, Science Direct offers a wide array of peer-reviewed articles (Ahmed *et al.,* 2021). The same search string ("real option approach" AND "solar energy" OR "photovoltaic" OR "PV") was used in each database to retrieve the related articles. Given the increased interest in renewable energy, especially over the last decade, the review focused on articles published between 2013 to 2023.

Furthermore, only publications written in English and published in peer-review journals and conferences were included. Peer review is included because experts rigorously evaluate the work, ensuring quality and credibility. This process makes research more reliable, prevents plagiarism and fraud, and helps with academic recognition and career advancement (Hasan *et al.,* 2018). Initially, a total of 476 records were identified as given in Figure 1, where in the final step 60 of them were listed as eligible for detailed analysis.

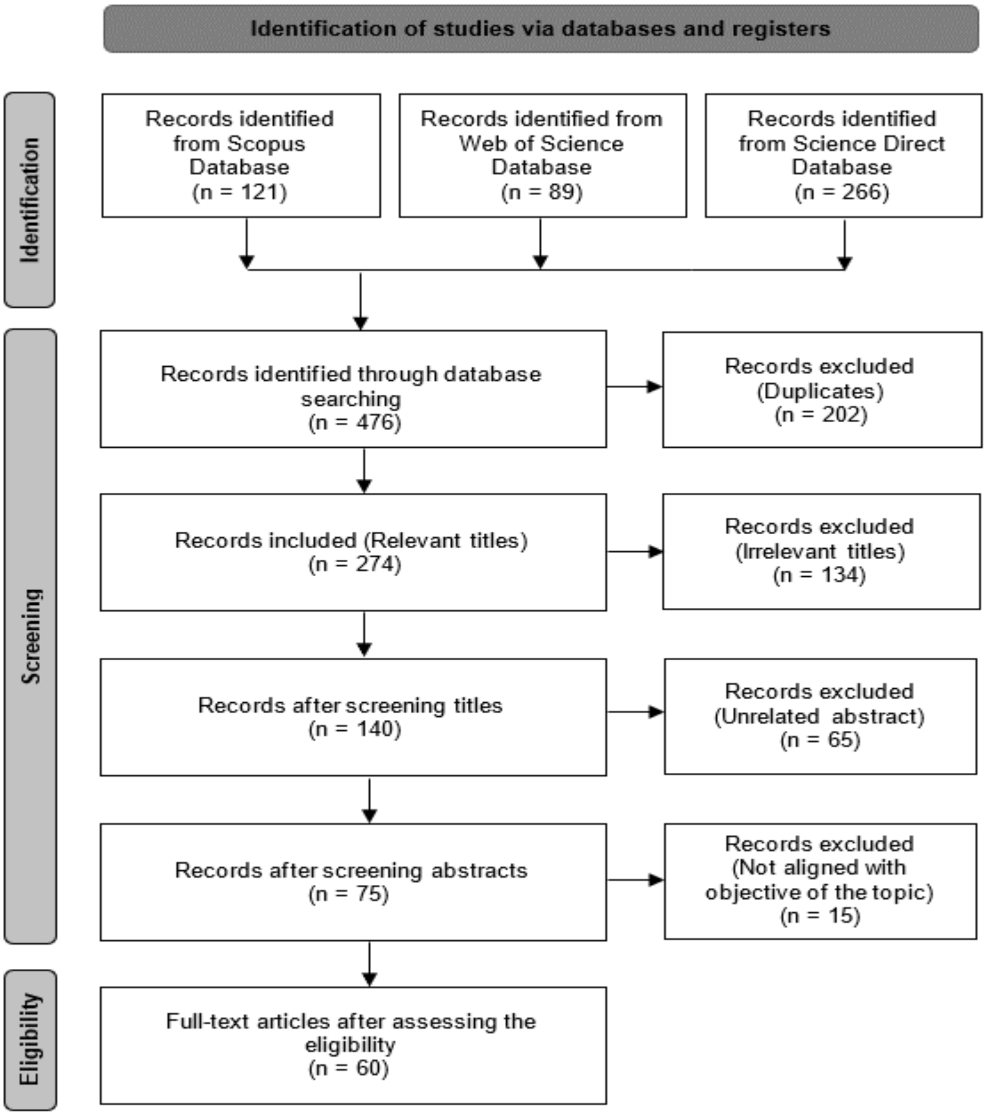

Figure 1: PRISMA Flow Diagram

The review was guided by the following research questions:

1. What are the types of options that ROV is used for in solar energy projects?
2. How have various studies utilised ROV to manage uncertainties in solar energy investments?
3. What are the current research trends and focal points concerning ROV in the existing literature?

DISCUSSION

Trend by Years, Country Focus and Keywords

Figure 2 shows the trend in annual publication volume, starting with just 3 publications in 2013. There is a noticeable increase in output, peaking at 8 publications in 2016. After this peak, the number declines slightly, with 5 publications each in 2017 and 2018, indicating stability. In 2019, the publications rise to 7, suggesting renewed activity. However, this growth isn't consistent, with 6 publications each in the next two years, possibly due to resource constraints. The chart ends with a rise to 5 publications in 2023. The data also shows a trend in publication output by country. Publications from developed countries increase significantly, peaking in 2022. Meanwhile, publications from developing countries gradually increase, indicating more research output or better access to publishing platforms.

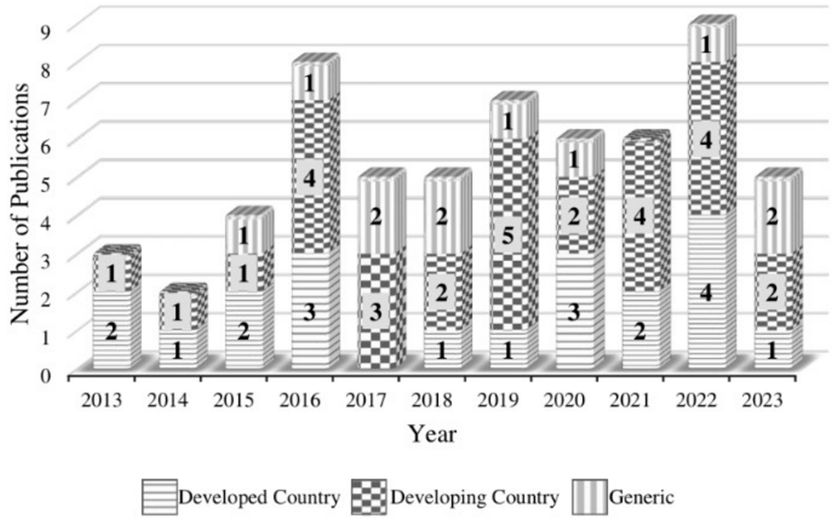

Figure 2: Number of Publications by Year

Figure 3 displays the statistical analysis organised by the countries where researchers have conducted studies. The chart distinctly highlights China leading the domain with a total of 17 publications as indicative of a potential concentration in research within this realm, which can be attributed to its massive investments in the renewable energy sector.

The singular "Generic" classification suggests a collection of publications that are not attributed to any specific country, which could potentially encompass international collaborations, organisations, or publications of undefined origin. The entity occupies the second position in the list, having contributed a compendium of 11 publications. Subsequently, the ranking continues with South Korea accounting for six publications, followed by the United States with five, and Italy with four, respectively. This underscores their status as principal contributors to research in this field. The figure illustrates a marginal predominance in research outputs from developed countries.

Figure 4 presents a bibliometric network visualisation of the 60 studies and depicts the interconnectedness of ROV-related keywords. Constructed using VOSviewer, the graphic encapsulates the central tenet of 'real options', where principal theme is intricately linked to a spectrum of associated concepts, including 'renewable energy', 'uncertainty', 'energy storage', and 'investment under uncertainty'.

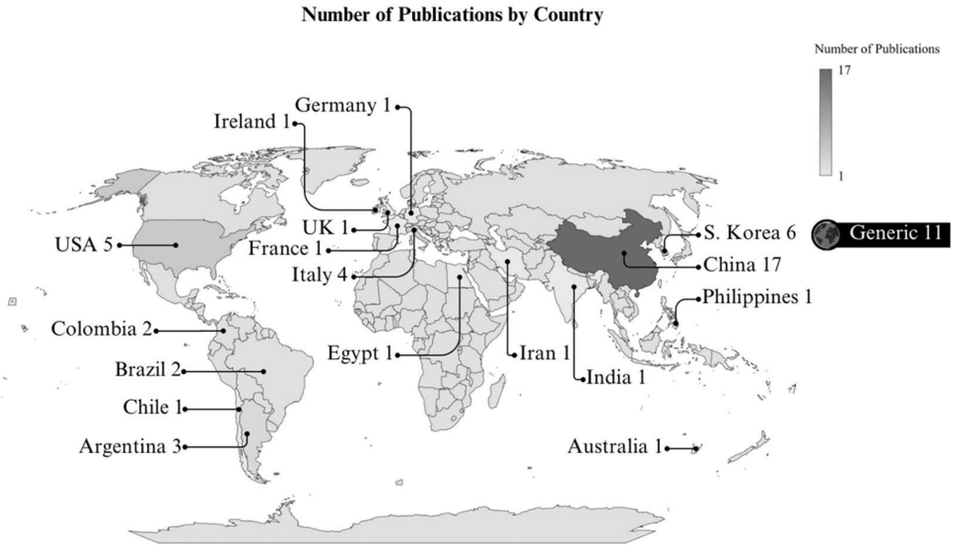

Figure 3: Number of Publications by Country

Such associations underscore the emphasis on strategic decision-making within the ambit of renewable energy investment, considering the inherent uncertainties. The configuration of nodes and interconnecting lines serves to illustrate the multidisciplinary confluence where ROV theory converges with energy policy, environmental considerations, and technological advancements, providing a panoramic view of the research landscape in this field.

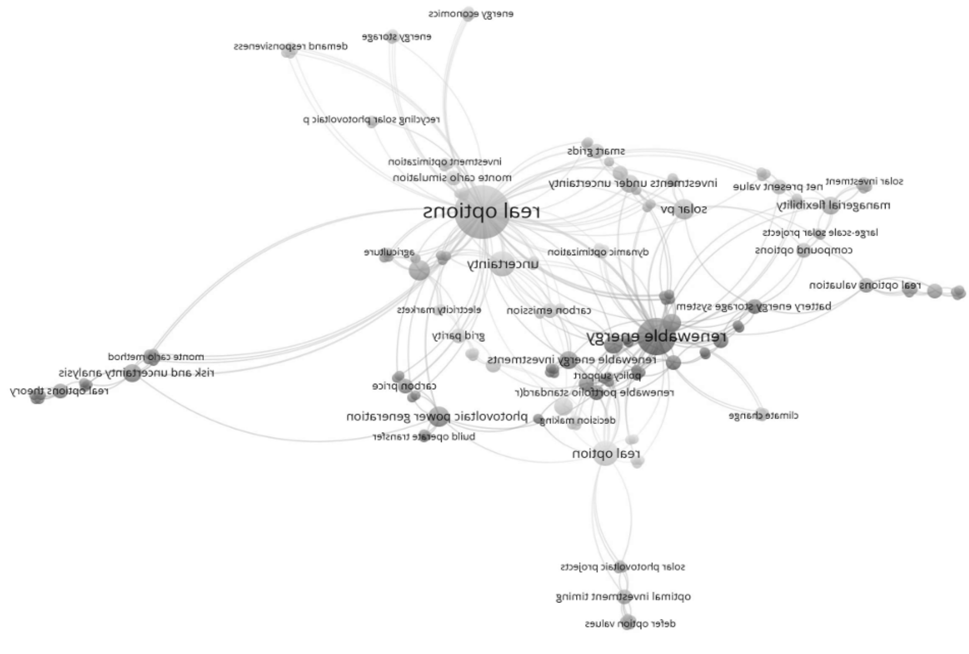

Figure 4: Keywords

Journal Focus

Figure 5 illustrates the distribution of publications by various journals in the field of ROV in solar energy investments. 'Renewable and Sustainable Energy Reviews' has the most significant contribution, with 10 publications (16.66%), highlighting its importance in this research area. Other journals contribute between 1.66% and 8.33%. 'Energy Economics,' 'Energy,' and 'Applied Energy' each have 5 publications (8.33%), indicating their significant roles. 'Renewable

Energy' and 'Energies' each have 4 publications (6.66%). The 'IEEE Conference' accounts for 3 publications (5%), showing the importance of conferences in sharing research. The remaining contributions come from various specialised fields, each contributing 1.66% or more. This diverse range reflects the need for insights from multiple disciplines to address the complex issues of sustainability and energy.

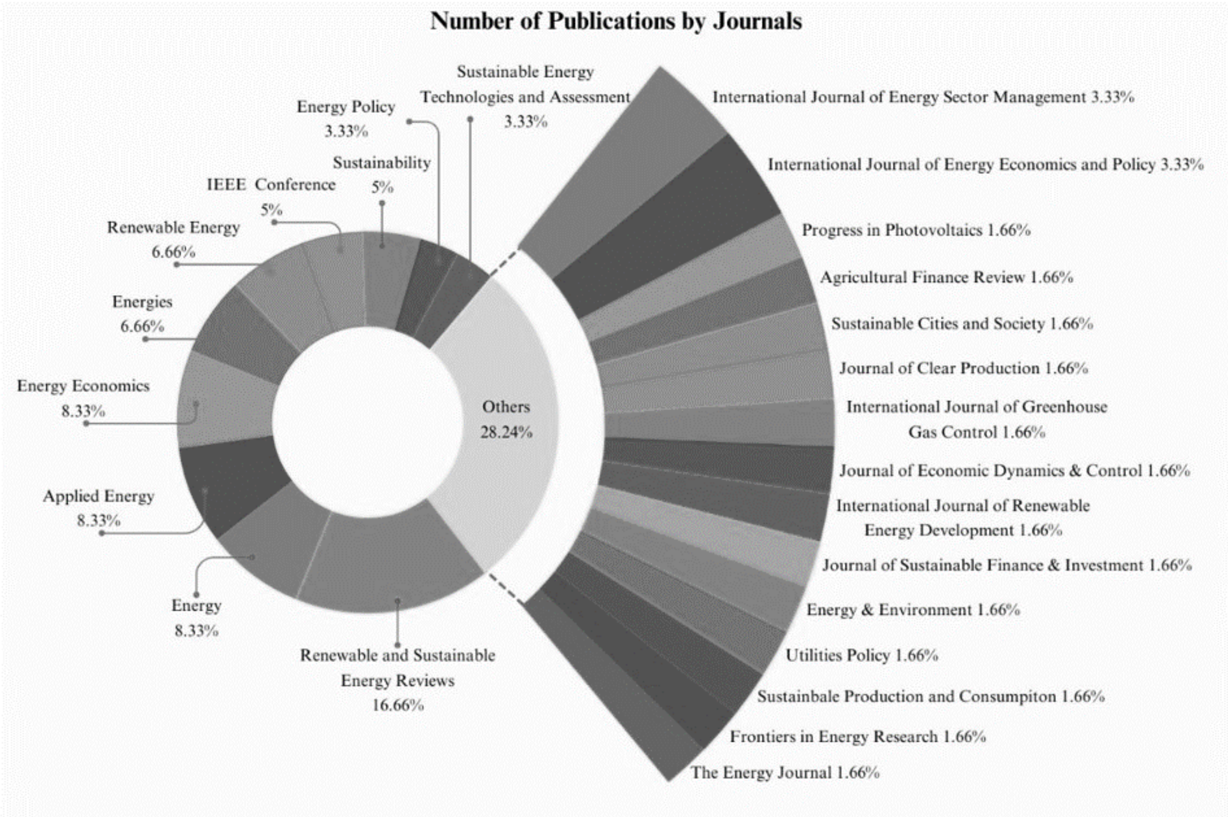

Figure 5: Distribution by Journals

Real Options Valuation Method

Figure 6 presents the proportional usage of three distinct valuation methods: Black Scholes, Monte Carlo, and Binomial. The Black Scholes model which has 11 studies constitutes 18% of the chart, indicating its relative usage frequency. The Monte Carlo method accounts for a substantial majority at 55% (33 studies), suggesting it is the preferred technique among the depicted options. Lastly, the Binomial model comprises 27% of the pie chart with number of 16 studies. The prominence of the Monte Carlo method attributable to its versatility and robustness in handling a wide array of financial instruments and risk assessment scenarios. The Monte Carlo method exhibits considerable superiority relative to prescriptive analytical models like Black-Scholes and the conventional Binomial Tree approaches due to its several advantages: It has ability in simulating a range of underlying assets, incorporating cash flows from diversified origins, and lastly, accommodating various forms of uncertainty characterised by distinct stochastic processes (Penizzotto *et al.,* 2019). The Black Scholes model, while foundational in option pricing theory, appears less utilised, which could be a consequence of its underlying assumptions, such as constant volatility, which are often violated in real markets. The Binomial model's intermediate position reflects its utility in educational contexts or in scenarios where discrete time steps are appropriate for option valuation.

There are several parameters used in Real Options Valuation (ROV) methods. According to Mun (2002), “Option Types” and “Uncertainty Sources” are crucial for understanding the decision-making process as a series of dynamic options. These parameters describe the generic types of options that exist in corporate investment strategies. Option types provide different strategic choices available to management, while uncertainty factors drive the need for these options, enabling dynamic and flexible decision-making in response to changing conditions. This combination is essential for accurately evaluating and managing investments in uncertain environments (Mun, 2002). Therefore, these two parameters were considered integral to this study.

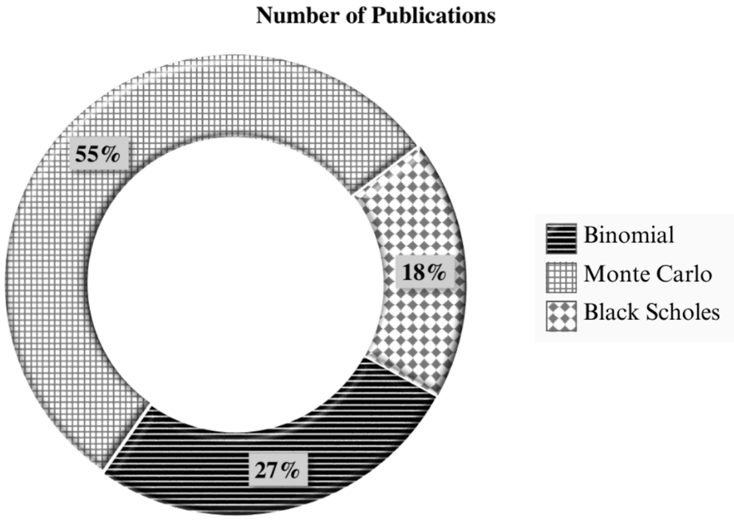

Figure 6: Valuation Methods

Option Types

AS PRESENTED IN Figure 7, the 'Defer' option is the most common with a count of 36, suggesting a preference for delaying decisions to wait for better conditions or more information.

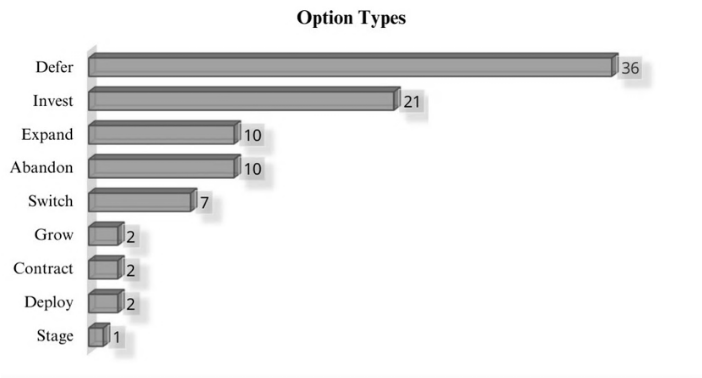

Figure 7: Option Types

The 'Invest' option follows with 21 instances, indicating a substantial but lesser commitment to new or expanding ventures. Both 'Expand' and 'Abandon' options have a count of 10, showing equal tendencies toward growth or withdrawing from initiatives. The 'Switch' option appears seven times, suggesting some flexibility in strategy changes. 'Grow', 'Contract', and 'Deploy' each have a count of two, indicating they are rarely used. Finally, the 'Stage' option, with a count of one, is the least common, showing a rare use of a phased approach.

Uncertainty Sources

During the review, it was observed that most studies used more than one uncertainty factor. In Figure 8, the tallest bar, "Electricity Price," with a value of 38, suggests this is the biggest source of uncertainty due to market volatility and regulatory changes. The second highest, "Technological Uncertainties," with a value of 23, indicates significant uncertainty from factors like solar panel efficiency and technological advancements. Other bars show "Financial Uncertainties" (8), "CO2 Price" (18), "Coal Price" (3), and "Subsidy Payments" (4), highlighting the impact of environmental policies, fuel prices, and financial conditions, though to a lesser extent. "NRE Cost" (3), "Battery Cost" (5), and "Managerial Flexibility" (2) indicate some uncertainty from non-renewable energy costs, energy storage, and organisational factors. The final bars, "PV Uncertainties" (15), "Agricultural Demand" (2), "Power Demand" (1), and "Investment Cost / Feed-in Tariff (FIT)" (8), suggest moderate uncertainty from photovoltaic systems, agricultural competition, power demand, and investment costs or policies. Overall, the graph shows electricity prices and technological uncertainties as the most significant factors affecting the solar energy sector's profitability and feasibility.

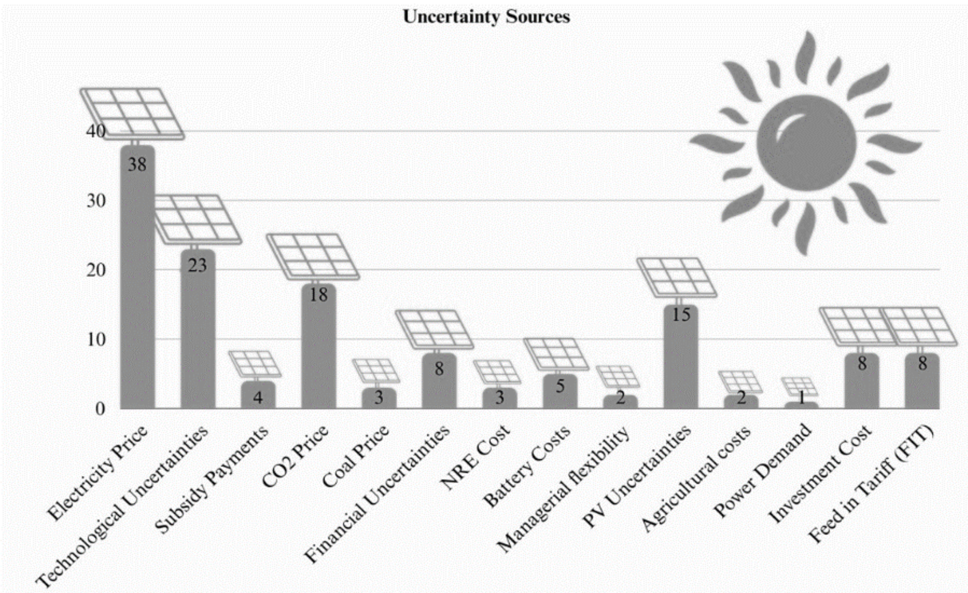

Figure 8: Uncertainty Factors

CONCLUSION

This research examines the application of Real Options Valuation (ROV) in valuing solar energy projects, highlighting its advantages over traditional economic analysis methods. The study provides a review of the current literature, noting the increasing trend in publications related to ROV in solar energy projects, with an emphasis on geographical diversity and varied methodologies employed. The findings underscore the predominant use of the MCS due to its robustness and versatility in handling complex financial instruments and uncertainties. This is complemented by an analysis of different real option types, among which the option to defer is prominently utilised, reflecting the strategic preference for waiting for more favourable conditions or additional information before making investment commitments. Furthermore, the research identifies the main sources of uncertainty that impact the valuation and management of solar energy projects, including market volatility, regulatory changes, technological advancements, and environmental factors. This highlights the necessity for comprehensive risk modelling and robust financial planning in the deployment of renewable energy technologies.

However, this study has several limitations. Firstly, the screening process and the selection of indicators in analysis can introduce some level of subjectivity. Additionally, study examines various databases with differing coverage of journals and disciplines. It provides a limited perspective since the quantitative measures used in this study do not offer deep insights into the true extent, quality, or impact of the research.

In conclusion, this paper contributes to the body of knowledge on the application of the ROV in the solar energy sector. It may provide a roadmap for future research efforts through practical insights for investors, policymakers, and practitioners in making informed and strategic investment decisions in the context of solar energy projects. Further research is encouraged to address the existing challenges and to refine the methodologies for integrating environmental and social considerations into the ROV framework, ultimately contributing to the broader objectives of sustainable finance and energy security.

REFERENCES

Ahmed, R, Philbin, S P and Cheema, F E (2021) Systematic literature review of project manager's leadership competencies, *Engineering, Construction and Architectural Management*, **28**, 1-30.

Di Bari, A A (2020) Real options approach to valuate solar energy investment with public authority incentives: The Italian case, *Energies*, **13**, 4181.

Fan, J L, Wei, S, Zhang, X and Yang, L (2020) A comparison of the regional investment benefits of CCS retrofitting of coal-fired power plants and renewable power generation projects in China, *International Journal of Greenhouse Gas Control*, **92**.

Gazheli, A and Di Corato, L (2013) Land-use change and solar energy production: A real option approach, *Agricultural Finance Review*, **73**(3), 507-525.

Gazheli, A and van den Bergh, J (2018) Real options analysis of investment in solar vs wind energy: Diversification strategies under uncertain prices and costs, *Renewable and Sustainable Energy Reviews*, **82**(3), 2693-2704.

Hasan, A, Baroudi, B, Elmualim, A and Rameezdeen, R (2018) Factors affecting construction productivity: A 30-year systematic review, *Engineering, Construction and Architectural Management*, **25**, 916-937.

Jeon, C, Lee, J and Shin, J (2015) Optimal subsidy estimation method using system dynamics and the real option model: Photovoltaic technology case, *Applied Energy*, **142**, 33-43.

Kim, B, Kim, C, Han, S, Bae, J and Jung, J (2020) Is it a good time to develop commercial photovoltaic systems on farmland? An American-style option with crop price risk, *Renewable and Sustainable Energy Reviews*, **125**.

Li, Y, Yang, W, Tian, L and Yang, J (2018) An evaluation of investment in a PV power generation project in the gobi desert using a real options model, *Energies*, **11**, 257.

Lin, B and Wesseh Jr, P K (2013) Valuing Chinese feed-in tariffs program for solar power generation: A real options analysis, *Renewable and Sustainable Energy Reviews*, **28**, 474-482.

Ma, Y, Swandi, K, Chapman, A C and Verbic, G (2020) Multi-stage compound real options valuation in residential PV-Battery investment, *Energy*, **191**.

Mun, J (2002) *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions*, Chichester: John Wiley and Sons.

Pan, Y, Yao, X, Wang, X and Zhu, L (2019) Policy uncertainties: What investment choice for solar panel producers? *Energy Economics*, **78**, 454-467.

Penizzotto, F, Pringles, R and Olsina, F (2019) Real options valuation of photovoltaic power investments in existing buildings, *Renewable and Sustainable Energy Reviews*, **114**.

Qiu, Y and Chen, H (2023) A systematic review of the knowledge domain of institutional theory in construction project management, *Engineering, Construction and Architectural Management*, **30**, 2523-2544.

Rocha, Q S, Munis, R A, da Silva, R B G, Aguilar, E W Z and Simões, D (2023) Photovoltaic solar energy in forest nurseries: A strategic decision based on real options analysis, *Sustainability*, **15**, 3960.

Spertino, F, Di Leo, P and Cocina, V (2013) Economic analysis of investment in the rooftop photovoltaic systems: A long-term research in the two main markets, *Renewable and Sustainable Energy Reviews*, **28,** 531-540.