A Critical Analysis of Energy Investment Decision Criteria Under Uncertainty: a Survey

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A critical analysis of energy investment decision criteria under uncertainty: a survey

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Abstract. Renewables investment is crucial in tackling a multitude of challenges and serving as a response to various issues such as economic uncertainties, escalating prices from the ongoing global energy crisis, energy security, and climate change threat. Renewable technologies, at different scales, have different economic profitability, necessitate capital investments, drive jobs creation, require materials and generate environmental implications. This paper provides a comprehensive approach to investment analysis methods when the focus is on implementation of a sustainable energy system. It discusses the central issue of the eventual coexistence between purely private objectives focused on profitability and the public perspective in which environmental and economic impacts must be considered in the decision-making process. This review evaluates both the advantages and disadvantages of the various investment analysis methods found in academic articles and documents from official institutions between 1994-2022.Traditionally, studies have primarily concentrated on investment rationality, employing methodologies rooted solely in financial optimization criteria. Nonetheless, a paradigm shift is evident. Beyond mere financial gains, an increasing emphasis is placed on an integrated approach that acknowledges socio-economic and environmental effects. Despite the challenge of its quantification, the focus on the public viewpoint and its influence on societal well-being is progressively gaining relevance.

Keywords: Renewable; Investment; Technologies; Decision-making

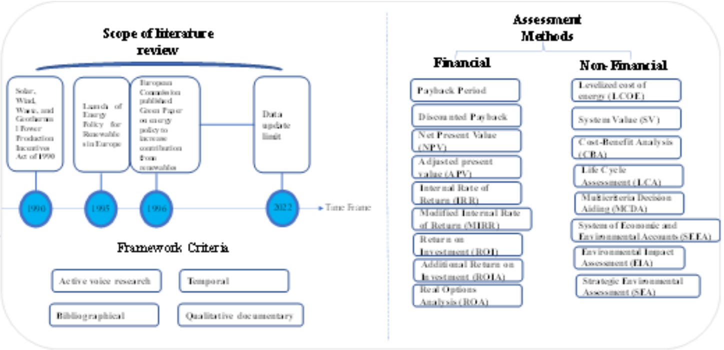
1 Introduction

The economic and environmental sustainability of the energy system is a key topic on the political agenda. As underlined by the International Monetary Fund (IMF) [1], it will be critical to invest heavily in mitigation and adaptation projects to address the challenges of climate change and vulnerability to shocks. The post-pandemic phase has created new investment opportunities aimed at a “green recovery” and sustainable development, with financing instruments supporting environmental projects and renewable energy sources (RES) [2]. Moreover, the escalating energy prices and the security issues caused by the war in Ukraine, further the relevance of transitioning to RES. Several RES technologies, at different scales, require capital investments, create jobs, and utilize the occupy-land [1], [3], [4]. These factors contribute to diverse economic and environmental consequences that may influence aspects such as economic growth, employment, human health, and equitable development [5]. While policy decision-makers should consider these aspects, private investors are primarily driven by profit. Therefore, the investor incentive instruments should incorporate public interests in decision-making. Collaboration with the public sector is necessary for this effort to reflect both private and public sector needs [1]. The key question is to ensure an optimal transition to RES that promotes sustainable economic development and maximizes well-being [6], [7]. This work aims to identify the most suitable methodologies for evaluating renewable energy projects to aid decision-making, focusing on sustainable energy systems. Rather than listing every available method, the review will discuss the advantages and drawbacks of various investment analysis methods found in academic articles and official institution documents. This survey aims to contribute to and improve the current literature by analysing the extent to which existing methods effectively address both the economic and environ-mental impacts and propose an integrated approach that can comprehensively support decision making. It aims to answer: which commonly used methodologies for evaluating renewable energy projects are better suited to support decision-making when the objective is to implement a sustainable energy system?

2 Methods

To achieve the objectives of this study, we performed a search on Scopus search, Google Scholar, Web of Science and official documents from the institutions with keywords combinations of “investment” and the names of the nine main financial methods of evaluating investments and other non-financial assessment methodologies, such as Levelized cost of energy (LCOE), System Value (SV), Cost-Benefit Analysis (CBA), Life Cycle Assessment (LCA), Multicriteria Decision Making Aid (MCDA), System of Economic and Environmental Accounts (SEEA), Environmental Impact Assessment (EIA) and, Strategic Environmental Assessment (SEA).The scope of the review is summarized in Fig. 1, which does not intend to provide an extensive list of all financial and non-financial methods literature by rather selecting the most relevant and highly cited papers for each method.

Fig. 1: The review scope of literature



Source: Own Authors

The review scope resulted in 211 academic articles and 66 official documents from government and private institutions published from 1994 to 2022. Among the seventeen methods, financial methods proved to be highly relevant in assessing investment in renewable energy projects. However, these methods mainly cater to purely private and neglect environmental and social objectives. Hence, non-financial methods should be more explored as a complement to financial methods.

3 Results

Encouraging renewable energies is crucial for a low-carbon energy matrix and energy policy. The appropriate investment indicator depends on the project´s goals. Cucchiella et al. [8] mention that while private investors aim to maximize profits, public decision-makers seek to maximize social welfare. Table 1 outlines the advantages and disadvantages of each method, to advantages, the criteria considered were: popularity, easy calculation, simplicity, geographical relevance, consideration of time horizon, timing of investment, time value of money, profitability measurement, incorporation of uncertainty, irreversibility, flexibility, and good environmental performance indicators. However, drawbacks include its complexity, scale problem, lack of integration between RES, failure to consider different levels of risk, absence of temporal and spatial aspects, and more general limitations.

Table 1. Strengths and weakness of the methodologies

Methods	Strength	Weakness	References	Technologies
Payback	easy calculation; easy comprehension	It does not take into account the time value of money ; It penalizes projects whose returns are long-term; It does not consider the cash flows after the payback period has been reached; It ignores all the costs and savings	[9]–[13]	Wind, Solar PV, Hydro

		that occur after the moment the payback is reached, and It does not differentiate between design alternatives with different design lifecycles and typically uses an arbitrary payback threshold.		
Discounted Payback	it takes into account the time value of money; easy comprehension.	It does not consider the cash flows after the payback period has been reached; it typically uses an arbitrary payback threshold.	[9], [10]	Wind, Solar PV, Hydro
Net Present Value (NPV)	It takes into account the time value of money ; The decision rule suggested by NPV calculations is straightforward; It is one of the most widely used methodologies in finance;	It NPV does not consider the irreversibility, uncertainty, and flexibility of managing an investment project.	[11], [13], [14]	Wind, Solar PV, Hydro
Adjusted NPV	Adjusted NPV combines investment and financing decisions, as it dissociates the adverse effect of financing from the project's NPV value if the project were financed by equity; The APV technique is especially useful in evaluating acquisition goals.	APV approach ignores the expected bankruptcy costs, the most significant cost of borrowing. It can run the risk of informing the overvalued value of the company with tax shields if it does not include in the calculation the distress costs and personal taxation, in order to avoid the tax shields of the debt in the income tax of the Cia.; It does not define the level of risk, because it calculates all regular returns and ignored the fluctuations in the investment process.	[15]–[17]	Wind, Solar PV, Hydro
Internal Rate of Return (IRR)	The decision rule suggested by IRR calculations are straightforward.	It IRR does not take into account the irreversibility, uncertainty, and flexibility of managing an investment project; The IRR generates a problem of scale since it is not possible to compare investment projects with different scales; It cannot be used with unconventional Cash Flow projects with more than one IRR.	[12], [13], [18], [19]	Wind, Solar PV, Hydro
IRR Modified (MIRR)	Used to improve IRR deficiencies; It assumes that cash flows are reinvested at the cost of capital.	It requires people to make multiple decisions about the cost of capital and the financing rate that generate additional estimates in the decision-making process, causing hesitation on the part of those who want to analyse the investment.	[13], [18], [20], [21]	Wind, Solar PV, Hydro

Return of Investment (ROI)	It is indicated when there is competition between markets and lack of financial resources available to make investments, allowing to compare several projects and selecting the most profitable project in different scenarios; Measure of profitability to generate a flow of future benefits with an expected return in a period of one year.	ROI ignores that the rate of return must equal or exceed the cost of capital; It is a metric that is not widely used in most evaluations.	[12], [22], [23]	Wind, Solar PV
ROI Adjusted (ROIA)	It is the best alternative for estimating gains in an investment project because the wealth generated by the project is presented in percentage form.		[13], [24]	Wind, Solar PV
Real Options Analysis (ROA)	It allows one to verify with greater precision the best time to be invested, considering the "timing" of the investment itself, in addition to the value of uncertainty; It takes into account aspects of uncertainty, irreversibility, and flexibility providing more information to investors regarding the risk and return of the project.	It is due to the complexity of the analysis and difficult interpretation, which is still considered a complex methodology.	[13], [25]–[28]	Wind, Solar PV
Levelized cost of energy (LCOE)	It is a measure, widely disseminated in the current literature; It is quite a popular methodology to assess the economic competitiveness of RES.	It ignores the cost of integration and the variability of energy systems with high penetration in variable renewable energy (VRE), failing in the precision of the results; The LCOE results for different technologies can be influenced by the location of the plant can influence; LCOE approach and other modified LCOE calculation methods put forth in various studies fall short in encompassing all the variables that impact investment decisions. This renders a direct comparison of LCOE between different technologies imprecise, especially when multiple-generation alternatives are available.	[6], [7], [28]	Wind, Solar PV

System Value (SV)	SV is that it allows you to directly compare the cost of building new VRE plants with their net impact on the system; It can vary according to geography and time horizon.	It ignores the broader socio-economic impact of RES technologies, such as net employment gains/losses and Gross Domestic Product (GDP).	[6], [7]	Wind, Solar PV
Cost-Benefit Analysis (CBA)	CBA is simpler for decision-makers; It is capable of removing market failures and indicating the lowest social cost or the highest net social benefit; CBA shows the economic weaknesses and strengths of investment and plays an important role in the decision-making of investment projects; It is easy communication in quantifying in monetary terms the impacts in time and space, allowing the comparison between projects; It can help prevent the implementation of projects that show negative impacts on social well-being, as well as make a political process more legitimate by measuring the economic impacts; It is capable of facilitating the efficient allocation of resources, giving an efficient alternative choice option for stakeholder.	Although the techniques for monetizing non-monetary and qualitative aspects are a strength of the CBA methodology, it tends to disregard or underestimate project impacts (e.g., environmental, and social).	[29]–[32]	Renewable energies
Life Cycle Analysis (LCA)	LCA typically focuses on products; It is possible to determine environmental performance indicators, including energy intensity and the energy payback time (EPBT) for energy technologies; LCA can be applied to assess the environmental performance of electricity generation from renewable	It is not expressed some temporal and spatial aspects (local or regional level) often important for decision-making by involved groups on the investment.	[33]–[36]	Renewable energies

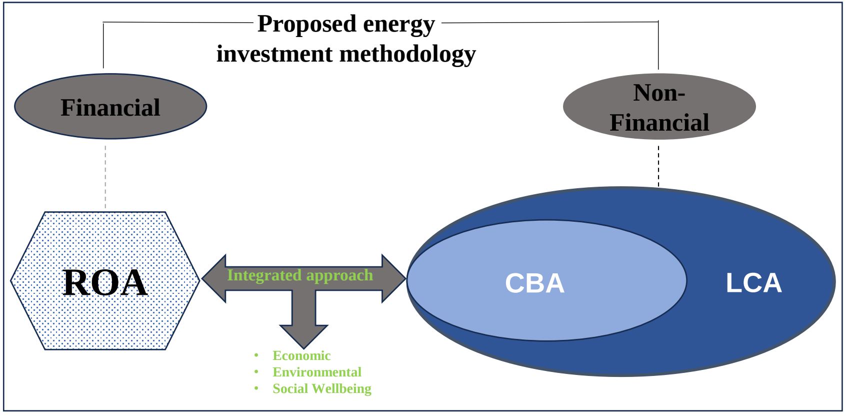
	energy technologies; LCA application is also a useful tool to quantify all impacts of the entire energy supply chain.			
Multicriteria Decision Aiding (MCDA)	MCDA techniques are popular in sustainable energy management to solutions with conflicting objectives and multiple problems; MCDA can inform the level of an alternative to reach the objectives and show the trade-offs; It improves understanding to resolve conflicts and it suggest solutions according to the preferences of individuals and stakeholders; MCDA is a reliable method to categorize renewable energy resources, technologies, and projects considering different objectives; It widely used in the assessment and comparison of the sustainability of different renewable energy technologies, being important information's for decision making.	MCDA brings biased results and can "contaminate" decision-making; MCDA is often known as an arbitrary and subjective process, with a certain negative effect on the part of the decision-making processes in the weighting of the criteria by not defining schemes and rules to achieve these criteria; The MCDA for processes whose objectives are conflicting, it is not indicated, because the search for congruence of objectives can generate doubts in the process itself; The more complex mathematical calculations make the MCDA process more difficult to understand for the parties involved and less technical.	[31], [35], [37], [38]	Renewable energies
System of Economic and Environmental Accounting (SEEA)	SEEA includes environmental considerations by analysing all environment-related flows and stocks, highlighting the costs associated with environmental conservation separately; It expands asset accounts to encompass economic and environmental assets, changes, and impacts on natural assets; In some countries, includes the monetary valuation of different environmental impacts by different valuation techniques; SEEA data are useful in the application of econometric models for impact studies of	They address only a part of the economic performance.	[33]	Renewable energies

	fiscal and environmental policies.			
Environmental Impact Assessment (EIA)	EIA is typically used for projects; EIA is a procedural tool and can be used jointly with other analytical tools; EIA is used frequently to evaluate alternative locations to projects and emissions. Can be used as a broader sustainability evaluation including social-economic aspects; The use of the EIA as a tool for locating emissions is more indicated than the SEA.	Quality of the assessment reports; Lack of public participation and low levels of cooperation between policy makers, researchers and stakeholders; EIA relies heavily on technical data, data collection processes and measurements are not always accurate or may portray reality.	[33], [39]	Renewable energies
Strategic Environmental Assessment (SEA)	SEA is an evolution of EIA from the 1990s; SEA is a procedural tool and can be used jointly with other analytical tools; SEA is intended for policies, plans, and programs; SEA can be used as a broader sustainability assessment, including socio-economic aspects.	Approach in conditions that involve large uncertainty and little information; Although, strategic level, it may not provide more accurate information on the location of emissions and require traditional assessment methods, as EIA.	[33], [39]	Renewable energies

To effectively evaluate RES project, it is important to consider investment irreversibility, environmental uncertainty, and decision flexibilities. Each valuation method has its pros and cons and most of methods above do not take into account these factors [26].
To address these limitations, we propose an integrated approach (Figure 2) that combines monetary techniques with other non-monetary methods, such as environmental assessment and Cost-Benefit tools. This comprehensive approach seeks to bridge the gap and provide a more holistic evaluation of the socio-economic and environmental aspects of RES investments. Firstly, we propose the application of the ROA methodology on the financial side, as it considers uncertainty and decision flexibility. Although its mathematical calculations are complex ROA optimizes and postpones investment, adjusting project size, [13], [40]. Secondly, on the energy planning side, it is proposed the Life Cycle Assessment (LCA) and Cost-Benefit Analysis (CBA) are also suitable for energy planning, being dominant in Environmental Impact Analysis and Energy Policy and Management, respectively [35]. Browne & Ryan mention [38] that the CBA is useful for estimating costs and/or benefits associated with RES incentives, but it is limited in the quantification of impacts outside the market and in the monetization of total costs, and should be complemented with other environmental and socioeconomic indicators, namely the ones from LCA methodology (e.g., land-use, water consumption, materials use) or determined by econometric models (e.g., economic growth,

employment creation). This integration of ROA, CBA, environmental and socioeconomic indicators from LCA and econometric analysis, respectively, offers a comprehensive evaluation framework that empowers both private investors and policymakers to make informed and sustainable choices.

Fig. 2. The scheme of the suggested energy investment methodology



Source: Own Authors

4 Discussion

This study was driven by the fact that despite many investment analysis techniques reported and recommended by researchers, there is a limited understanding of how they have been applied especially in practice. Conventional valuation measures (Net Present Value-NPV, Payback, and Internal Rate of Return-IRR), are insufficient to support investment decisions by themselves [13]. The Payback period, along with other metrics, can thus provide a more comprehensive analysis. Real options (ROA) models are more adequated to apply in investments in renewable energies, because it allows not only to reflect the investment options of private investors, but also to better understand their reaction to the incentives defined by policymakers. ROA considers uncertainty, and decision flexibility [13], [40]. To Pienaar [41], the APV (Adjusted Present Value) considers investment and financing decisions. It dissociates the negative effect of financing on a project´s NPV if it is funded by equity. IRR can be problematic for unconventional cash flows and multiple rates of return. Modified Internal Rate of Return (MIRR) uses multiple rates, in comparing alternative projects. But MIRR also leads uncertainty in decision-making when it relies on the cost of capital and financing rates [21]. Return of Investment (ROI) compares projects and selects the most profitable one [22]. It ignores returns equal to or over the cost of capital (Mäkeläinen, 1998). To (Pletsch, 2020), additional Return of Investment (ROIA) is useful for estimating a project´s gains, it presents income in percentage. Furthermore, the U.S. Energy Information Administration (EIA) report [28]noted that the Levelized of Cost of Energy (LCOE) method or its modifications [3], [9], [22] are insufficient to capture relevant investment decisions when multiple generations are available. Comparisons of LCOE between technologies ignore the temporal heterogeneity of electricity demand, the variability of the Variable renewable energy (VRE), and the integration between RES. Although, it is quite a popular methodology to assess the economic competitiveness of RES [6], [7]. However, the NPV and IRR have an advantage over the LCOE as they not only consider private expenses in the levelized costs and revenues from the sale of generated energy and potential concession. The System value (SV) varies by geography and time horizon, but it does not account for the socioeconomic impact of RES technologies, like employment and Gross domestic Product (GDP), crucial metrics for policymakers [7]. The use of the MCDA tool together with SEA, considering that the first one is more complete for the assesses and compares the sustainability of different renewable energy technologies [37] and second one, it is a tool for evaluating potential environmental impacts of strategic decisions because SEA is a useful tool from cover spatial impacts (local or regional) from the project with specific environmental impacts. Additionally, SEA also has public involvement as part of the decision-making process [39]. To Strantizali et al [35] , the LCA, CBA, and MCDA are suitable for energy planning, being LCA and CBA are dominant in Energy Policy and Management and Environmental Impact Analysis, respectively. While, LCA although the integration of this tool with environmental protection is excellent and useful, it fails when it does not express some important temporal and spatial aspects for investment decision-making that can be compensated by SEA. SEA is a useful tool from cover spatial impacts (local or regional) from the pro-ject with specific environmental impacts [36]. The CBA is an analytical tool that shows the economic weaknesses and strengths of investment and plays an important role in the decision-making of investment projects. being capable of facilitating the efficient allocation of resources, giving an efficient alternative choice option for those involved [32]. However, although the techniques for monetizing non-monetary and qualitative aspects are a strength of the CBA methodology, it tends to disregard or underestimate project impacts (e.g. environmental and social) [31]. MCDA tool compares the sustainability of various renewable energy technology options [37]CBA as complementary tool of MCDA in assessing the environmental and socioeconomic impact [41], because although CBA is limited in the quantification of impacts outside the market and in the monetization of total costs, CBA is useful for estimating costs and/or benefits associated with policies [8].

5 Conclusion

Until recently studies focused solely on investment rationality and relied on methodologies that primarily optimized financial criteria as the decision-making tool. However, nowadays, alongside profit considerations, there is a growing concern in other aspects, especially those related to impacts on the economy, the environment and on social well-being. The review of methods for assessing RES investment has revealed the strengths and limitations of various approaches. To facilitate informed decision-making for both private investors and policymakers, an integrated approach. On the financial side, the application of Real Options Analysis (ROA) is essential as it considers uncertainty and decision flexibility inherent to RES investment. Despite the complexity of the calculations, studies have highlighted its importance [12], [39] On the non-financial side, approach combines the strengths of Life Cycle Assessment (LCA), which provides a comprehensive understanding of the environmental impact of RES projects, with socioeconomic indicators derived from econometric analysis, enabling a robust assessment of socioeconomic implications. Moreover, incorporating Cost-Benefit Analysis (CBA) complements the framework by quantifying costs and benefits. Such a comprehensive evaluation enables stakeholders to consider not only financial factors but also the broader environmental implications, thereby supporting sustainable and socially responsible investment decisions in the renewable energy sector. It was not found in the literature an integrated methodology that addresses all the pillars of sustainability, i.e., economic, social environmental. Thus, it is suggested that future work can carry out this suggested integrated approach, using renewable power sector investments in the Portugal as a case study.

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References

[1] K. Georgieva and T. Adrian, “IMF Blog:Public sector must play major role in catalyzing private climate finance.” https://www.imf.org/en/Blogs/Articles/2022/08/18/public-sector-must-play-major-role-in-catalyzing-private-climate-finance (accessed Jun. 13, 2023).

[2] J. Tian, L. Yu, R. Xue, S. Zhuang, and Y. Shan, “Global low-carbon energy transition in the post-COVID-19 era,” Elsevier Ltd, 2022. doi: 10.1016/j.apenergy.2021.118205.

[3] P. Crossley, *The Economic Justification for Regulating Renewable Energy*. London: Cambridge University Press, 2019. doi: 10.4337/9781783478330.

[4] M. Cárdenas Rodríguez, I. Haščič, N. Johnstone, J. Silva, and A. Ferey, “Renewable Energy Policies and Private Sector Investment: Evidence from Financial Microdata,” 2015. doi: 10.1007/s10640-014-9820-x.

[5] J. J. Buonocore *et al.*, “Health and climate benefits of different energy-efficiency and renewable energy choices,” 2015. doi: 10.1038/NCLIMATE2771.

[6] S. Muller, E. Taibi, J. C. Smith, D. Fraile, and T. K. Vrana, “System Integration Costs – a Useful Concept that is Complicated to Quantify ?,” 2018.

[7] and K. S. Mueller, Simon, Paolo Frankl, “Next Generation Wind and Solar Power,” *Next Generation Wind and Solar Power*, 2016, doi: 10.1787/9789264268715-en.

[8] F. Cucchiella, I. D’Adamo, and M. Gastaldi, “Financial analysis for investment and policy decisions in the renewable energy sector,” 2015. doi: 10.1007/s10098-014-0839-z.

[9] S. K. Fuller and S. R. Petersen, *LCCosting Manual for the Federal Energy Management Program*, no. 135. 1996.

[10] A. L. Bruni, R. Famá, J. De, and O. Siqueira, “Análise Do Risco Na Avaliação De Projetos De Investimento: Uma Aplicação Do Método De Monte Carlo,” 1998.

[11] J. Ross, Westerfield, *Princípios de Administração Financeira*, 2a Edition. Atlas, 2002.

[12] L. Santos, I. Soares, C. Mendes, and P. Ferreira, “Real Options versus Traditional Methods to assess Renewable Energy Projects,” *Renew Energy*, vol. 68, pp. 588–594, 2014.

[13] G. G. Dranka, J. Cunha, J. D. de Lima, and P. Ferreira, “Economic evaluation methodologies for renewable energy projects,” 2020. doi: 10.3934/ENERGY.2020.2.339.

[14] Y. O. H. Tsukamoto, J. Sugimoto, R. Yokoyama, and Y. Zhou, “Economic Evaluation and Scenario Analysis of Wind Generations Based on Environment Factors,” 2006.

[15] E. F. Brigham and P. R. Daves, *Intermediate financial management*, vol. 21, no. 3. 1989. doi: 10.1016/0890-8389(89)90100-5.

[16] L. Booth, “Finding Value Where None Exists: Pitfalls in Using Adjusted Present Value,” 2002. doi: 10.1111/j.1745-6622.2002.tb00344.x.

[17] F. Gu, Z. Jiang, and J. Su, “Application of Features and Neural Network to Enhance the Performance of Deep Reinforcement Learning in Portfolio Management,” 2021. doi: 10.1109/ICBDA51983.2021.9403044.

[18] G. Dalton *et al.*, “Economic and socio-economic assessment methods for ocean renewable energy: Public and private perspectives,” *Renewable and Sustainable Energy Reviews*, vol. 45, pp. 850–878, 2015.

[19] D. L. Talavera, P. Pérez-Higueras, F. Almonacid, and E. F. Fernández, “A worldwide assessment of economic feasibility of HCPV power plants: Profitability and competitiveness,” 2017. doi: 10.1016/j.energy.2016.12.093.

[20] B. Balyeat and J. Cagle, “MIRR : The Means to an End ? Reinforcing Optimal Investment Decisions Using the NPV Rule,” 2015.

[21] H. Kierulff, “MIRR: A better measure,” 2008. doi: 10.1016/j.bushor.2008.02.005.

[22] J. et al Ross, Westerfield, *Administração financeira : versão brasileira de corporate finance*. 2015.

[23] E. Mäkeläinen, “Economic Value Added AS A management tool,” HSEBA-Helsinki, 1998.

[24] G. B. Pletsch, “Modelo Multicritério para seleção e avaliação econômica de tecnologias de separação de resíduos lácteos,” 2020.

[25] A. K. Dixit and R. S. Pindyck, “A New View of Investment,” in *Investment under Uncertainty*, 2019, pp. 3–25. doi: 10.2307/j.ctt7sncv.4.

[26] V. Delapedra-Silva, P. Ferreira, J. Cunha, and H. Kimura, “Methods for Financial Assessment of Renewable Energy Projects: A Review,” *Processes*, vol. 10, 2022.

[27] B. Fernandes, J. Cunha, and P. Ferreira, “Real Options Theory in Comparison To Other Project Evaluation Techniques,” 2011.

[28] EIA, “Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013,” 2022.

[29] C. Böhringer, A. Keller, and E. van der Werf, “Are green hopes too rosy? Employment and welfare impacts of renewable energy promotion,” Elsevier B.V., 2013. doi: 10.1016/j.eneco.2012.08.029.

[30] B. Hillebrand, H. G. Buttermann, J. M. Behringer, and M. Bleuel, “The expansion of renewable energies and employment effects in Germany,” 2006. doi: 10.1016/j.enpol.2005.06.017.

[31] F. Marleau Donais, I. Abi-Zeid, E. O. D. Waygood, and R. Lavoie, “A review of cost–benefit analysis and multicriteria decision analysis from the perspective of sustainable transport in project evaluation,” 2019. doi: 10.1007/s40070-019-00098-1.

[32] European Commission, *Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020,* no. December. 2014. doi: 10.2776/97516.

[33] G. Finnveden and Å. Moberg, “Environmental systems analysis tools - An overview,” 2005. doi: 10.1016/j.jclepro.2004.06.004.

[34] Varun, I. K. Bhat, and R. Prakash, “LCA of renewable energy for electricity generation systems-A review,” 2009. doi: 10.1016/j.rser.2008.08.004.

[35] E. Strantzali and K. Aravossis, “Decision making in renewable energy investments: A review,” *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 885–898, 2016, doi: 10.1016/j.rser.2015.11.021.

[36] M. Herrchen and W. Klein, “Use of the life-cycle assessment (LCA) toolbox for an environmental evaluation of production processes,” 2000. doi: 10.1351/pac200072071247.

[37] M. Troldborg, S. Heslop, and R. L. Hough, “Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties,” Elsevier, 2014. doi: 10.1016/j.rser.2014.07.160.

[38] D. Browne and L. Ryan, “Comparative analysis of evaluation techniques for transport policies,” Elsevier Inc., 2011. doi: 10.1016/j.eiar.2010.11.001.

[39] B. Ness, E. Urbel-Piirsalu, S. Anderberg, and L. Olsson, “Categorising tools for sustainability assessment,” 2007. doi: 10.1016/j.ecolecon.2006.07.023.

[40] K. Kim, H. Park, and H. Kim, “Real options analysis for renewable energy investment decisions in developing countries,” *Renewable and Sustainable Energy Reviews*, vol. 75, no. October 2015, pp. 918–926, 2017.

[41] A. Pienaar, *Investment appraisal: A critical review of the adjusted present value (APV) method from a South African perspective*, vol. 6. 1998.