

Probabilistic Risk Modeling in a Decoupled NPV Framework for Photovoltaic Investments

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1. Introduction

The unbroken and extensive use of fossil energy sources over the last decades has led to a tremendous climate change that will affect future generations. The risks of the massive environmental damage, additionally evolving from growing expected energy demand, are one of the greatest global issues of our time. There has been increasing effort to keep global temperature rise at the lowest possible by exploiting renewable energy resources. However, world-wide coverage of power generating capacity from renewable energy is still insufficient to satisfy current and future consumption. Nevertheless, investments in renewable energy is on the rise reaching an all time high at nearly 286 billion USD in 2015 globally (McCrone et al. 2016). With continuously decreasing costs for solar *photovoltaic* (PV), this technology seems promising in further contributing clean resources to global electricity production and a sustainable future.

On this account, *information systems* (IS) research increasingly engaged in renewable energy research. By means of further contribution to renewable energy provided by IS, Watson, Boudreau, and Chen (2010) have called for more awareness of research on Green IS. Following this, a *decision support system* (DSS) based on a novel investment valuation approach is presented within this thesis. Investors being active in the renewable energy market are exposed to several risks. The most common method is the discounted cash flow approach where the discount rate accounting for the time value of money is selected heuristically when valuing risky project investments (P. A. Ryan and G. P. Ryan 2002). However, as pointed out by Robichek and Myers (1966) the time value of money and risk are two different and independent parameters. Lumping those into one variable may lead to valuation errors and thus to misguided investment decisions.

For providing accurate and unbiased methodological support, Espinoza and Morris (2013) has proposed a novel approach termed the *decoupled net present value* (DNPV) where the risk is decoupled from the time value of money. All risks whatsoever are considered as additional costs to the project, on which basis the cash flows can be discounted with the risk-free rate. This framework and its related concepts are implemented in a MATLAB based DSS within this thesis, allowing for the valuation of PV investments.

The developed DSS is a comprehensive and multi-objective tool incorporating systematic and unsystematic risk and gives guidance on the financial and risk performance of such investment. On this account, probabilistic risk modeling techniques are utilized for quantifying the price of risk. Furthermore, *Monte Carlo simulations* (MCS) are used for reproducing PDFs allowing to take risk correlations of PV investments into account.

The capabilities of the DNPV approach and the developed DSS for valuing solar renewable investments are demonstrated and discussed by valuing a fictive PV farm in Northern Chile. This area of South America, featuring some of the highest solar resources worldwide offers extraordinary potential for highly profitable solar ventures (Salazar et al. 2015). Furthermore, the target of the Chilean government to cover 20% (around 21 TWh) of demanded energy with non-conventional renewable technologies by 2025 requires further huge investments (Garcia-Heller, Espinasa, and Paredes 2016). The application of the DSS indicates that solar renewable energy investments in Northern Chile can be highly reasonable. The DSS allows for guidance on investment decisions in the solar renewable market making a contribution to a sustainable future and therefore serves the aims of Green IS (Dedrick 2010).

Based on a systematic literature review on the current state of research, which results are presented in section 2, this thesis is organized as follows: Section 3 describes the conventional discounted cash flow approach reviewing the *net present value* (NPV). On this basis, the enhanced and novel DNPV approach of Espinoza and Morris (2013) and its related including several key figures is examined. By means of pricing risk transfer, the concept of SIPs is presented within that section. Furthermore, section 4 investigates how to quantify the price of risk presenting three different approaches: heuristic, probability based and stochastic methods. In section 5 the underlying cash flow model of the DSS is derived and its system architecture outlined. In addition, the project characteristics of the fictive PV farm in Northern Chile are set and the application of the DSS is demonstrated. Sensitivity analysis to determine the lowest feasible electricity price for the project are performed subsequently. The limitations and corresponding recommendations of the DNPV and the DSS with its applied methods are discussed in section 6. Finally, along with recommendations for future research conclusions are discussed in section 7.

7. Conclusion and Outlook

Within this thesis a Green IS giving decision support on potential actions making contribution to future environmental sustainability is developed. The characteristics of a Green IS are fulfilled by the DSS as it gives guidance on PV farm investment decisions that support the expansion of solar renewable energy (Dedrick 2010).

In the DSS a novel investment valuation approach considering project-specific risk structures is implemented, the DNPV. This approach acts on the suggestion to decouple the time value of money and risk. By considering all risks that can not be mitigated as additional costs to the project, the expected cash flows are rendered synthetically riskless and can be discounted with the risk-free rate. Thus, the DNPV avoids the hurdle of choosing a risk-adjusted discount rate a priori and heuristically that may not be consistent with the project's risk profile. That being the case may lead to misguided investment decisions. On this account, the DNPV methodology provides assistant on structured analysis of investment risks. Furthermore, the cost of risk (i.e., synthetic insurance premium) is determined on the basis of the project's risk profile.

Due to its underlying and widely accepted DCF concept, the DNPV is easily communicable to not only decision makers, which may have additional technical expertise, but also to institutional investors as they are familiar with this financial valuation methodology. Nevertheless, for a precise and project-specific valuation at least probability based methods should be applied. However, this requires broad technical expertise and sophisticated financial modeling skills.

The capabilities of the DSS, facilitating financial and risk performance metrics for a sounder investment support, are demonstrated in a case study. Northern Chile featuring some of the highest solar resources worldwide offers extraordinary potential for highly profitable solar ventures. The application of the DSS and its incorporated valuation methods has proven that establishing large solar energy producing farms in this region seems highly profitable. On the basis of the derived financial and risk performance, it is recommended to acquire the project rights and construct and operate the proposed fictive PV farm. This thesis focuses on probability based methods for the calculation of SIPs

that cover the potential cash flow losses occurring from risk exposure. However, further research should implement option pricing methods in the presented DSS. By means of the risk-averse nature of investors, this approach takes into account time-dependent random variations of revenues and expenditures modeled by stochastic processes where the value of the underlying asset can take several randomly arising price paths.

Furthermore, in the DSS risk modeling techniques are utilized incorporating MCS to account for risk correlations. On this account, it provides a technical basis for further and more extensive consideration of risk correlations by utilizing the implemented Iman-Conover method in combination with a Cholesky-decomposed correlation matrix. In further research well-grounded and proven photovoltaic-specific correlations should be implemented for a more accurate valuation result.

For improving the handling, performance and applicability of the DSS several adjustments can be implemented: a GUI should be programmed and further MATLAB add-ons such as the "Parallel Computing Toolbox" allowing for performance improvement should be utilized. In addition, the DSS should be elaborated to a more variable tool allowing for a better implementation of project-specific cash flow items or country-specific regulations. On this basis, the DSS could be applied to other renewable energy or infrastructure investments. Furthermore, the DSS has only been reviewed applying it to a fictive project. Its consistency and practicability should be further tested by valuing a real-world PV farm using a company's detailed historical data.

It can be concluded that the DSS is based on a unique combination of approaches making an enhanced contribution to Green IS allowing for the valuation of PV investments. For its improvement in further research several suggestions are made.