Evaluation of Investment Projects in Photovoltaic Solar Energy using the DNPV Methodology

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ABSTRACT

The evaluation of investment projects has been carried out mainly through the analysis of discounted cash flow (DCF), whose financial feasibility measures have been based fundamentally on approaches such as the net present value (NPV) and the internal rate of return (IRR), which are widely discussed in the field of energy project valuation. Despite this, the classical methods have a limitation when perceiving relevant characteristics for decision-making in high-risk investments, such as the uncertainty of the cash flows and the quantification of risk. An alternative to the use of these methods is the technique known as decoupled net present value (DNPV), which decouples the risk associated with the project from the value of money over time. This valuation methodology was applied to a photovoltaic solar energy self-generation project in Colombia. In this study, the results obtained through the DNPV was equivalent to 2.3-fold the value obtained by means of NPV. Thus, many renewable energy projects can become undervalued since traditional methods mistakenly associated a discount rate that includes a very high risk premium and that in many occasions it is more related to the sources of financing of the project instead of representing the risk component that it has.

Keywords: Decoupled Net Present Value, Renewable Energy Projects, Solar Energy Investments
JEL Classifications: Q2, Q4

1. INTRODUCTION

In the valuation of energy projects, different traditional techniques have been used such as the net present value (NPV), the internal rate of return (IRR) and the levelized cost of energy (LCOE) (Santos et al., 2014). However, investment projects in renewable energy have uncertain characteristics regarding market development, technological change and government policies. (Zhang et al., 2016a), which makes it vitally important to take these aspects into account when carrying out a financial feasibility analysis of a project of this nature. Under this premise, and besides of the classical methods, in financial feasibility of energy projects have been consider more sophisticated techniques such as real options (e.g., Shun, 2011; Zhang et al., 2016b; Agaton et al., 2020), which consider the uncertainty of the projects and the flexibility of investment decisions within the valuation analysis

(Menegaki, 2008). This research article specifically refers to the use of the technique known as decoupled net present value (DNPV) proposed by Espinoza and Morris (2013) and Espinoza (2014), a new method that complements the net present value technique in long-term projects (Shimbar and Ebrahimi, 2017a).

The NPV is a method used both for the valuation of projects and for the selection of investments, and probably it is the most applied in this field (González and Blanco, 2008). However, as discussed in Ho and Liao (2011); the application of methods such as the NPV to high-risk projects can underestimate the value of these and even their rejection, if higher discount rates are adopted for the valuation.

In the traditional NPV method (and other classical methods already mentioned), the discount rate used to discount flows combines

the time value of money with the risk premium (Espinoza et al., 2019a). Unlike this, the DNPV method postulates a valuation methodology which separates the risk associated with a project from the value of money over time. This approach is fundamentally based on the equivalent certainty method (CEM) introduced by Robichek and Myers (1966), who postulated that these two terms are independent variables and grouping them into a single factor (discount rate) can be attributed as an error.

According to Espinoza and Morris (2013), the DNPV method proposes to include risk exposures as negative flows within the cash flows of the projects, represented as costs (similar to an insurance policy). In this way, the risk price is subtracted from the expected income or added to the costs, if it is associated with the project's expenses. With this method, the evaluation of the project is carried out consideringg a risk-free rate, since the risks of the project are being included separately and therefore, the resulting flows can be considered risk-free (Espinoza et al., 2019b).

Analogously to the financial options, with the DNPV method the acceptation criterium is that DNPV of the project must be postive (DNPV>0). The income flows generated by the project are at least equal to the sum of its outgoing cash flows plus synthetic risk premiums. This feature is equivalent to accepting the project if it is "in the money." Additionally, DNPV's profit and loss profile are similar to a long position in call options and the cash flows are discounted using a risk-free rate (Espinoza, 2014). In the DNPV methodology, exposures to risk are identified and quantified from the beginning of the project, allowing the assessment of the synthetic risk premium to discount it from the flow. Thus, in essence, DNPV is considered a dual purpose method, valid as a valuation approach that overcomes the limitations of traditional methods and as a risk management and coverage tool (Silverio, 2014; Shimbar and Ebrahimi, 2017a).

The application of this methodology has been carried out in the evaluation of projects for different sectors, including energy industry within the framework of renewable energies, e.g. Piel et al. (2016) and Shimbar and Ebrahimi (2017a), appliedy DNPV to address investment risk in waste to energy and wind energy projects, respectively. Other studies as conducted by Espinoza and Rojo (2015) and Shimbar and Ebrahimi (2020) carried out the financial evaluation of photovoltaic solar projects and agree on the limitations of the classical methods for project appraisal and on the strength of the DNPV to overcome these limitations. Furthermore, Shimbar and Ebrahimi (2017b) carried out an extension of the DNPV using the modified decoupled net present value (M-DNPV) as the valuation method of a power generation project in Iran.

The main objective of this study is to evaluate the financial viability of a photovoltaic solar energy self-generation project in a Colombian home, by using DNPV. The different risks associated with the input variables of the project in question and the government policies established to promote the investment of this type of unconventional energy in the country were also considered.

2. METHODOLOGY

2.1. Input Variables and Financial Model
Based on the case study developed in Benítez Pelaez and Martínez Ruiz (2019), the investment project analyzed consisted of the installation of a photovoltaic solar self-generation system for a Colombian home, composed of a total of 16 solar panels, a minimal production of 490,000W per month and an investment of COP $ 38.9 million. The calculation of the income of this project was considered by three sources: (i) the savings of the investor, (ii) the income from the sale of energy and (iii) the tax benefit, as a result of the new regulations adopted by the Colombian government to encourage investment in this type of energy in the country (UPME, 2014; CREG, 2018). Expenses are represented by the trading charges that the investor must incur for each kWh produced and consumed at home. The financial model designed for this project considered a horizon of 20 years and the flows were detailed monthly. The prices were adjusted according to an annual inflation of 3%, while the energy production was calculated from the hours of sunshine and the number of panels in the system. Tables 1 and 2 show the input variables and project free cash flow for each month in year 1.

2.2. DNPV Analysis
As mentioned above, the DNPV methodology identifies the risks associated with the project from the moment of the financial evaluation. These risks, considered as synthetic insurance premiums, were taken into account separately and were included as additional costs to the project. Equation 1 represents the concept of DNPV according to Espinoza and Morris (2013) and Espinoza (2014), where $\tilde{V}_{(m,n)}$ and $\tilde{I}_{(m,n)}$ represent the expected income and expenses of the project in the month m for year n and $\tilde{R}_{V(m,n)}$ and $\tilde{R}_{I(m,n)}$ the expected synthetic premiums associated with the risk of lower income or higher than expected costs, respectively. In this way, the resulting flows are discounted at the risk-free rate r, which for this analysis is represented in a monthly format.

$$DNPV_{(m,n)} = \frac{\left(\tilde{V}_{(m,n)} - \tilde{R}_{V(m,n)}\right) - \left(\tilde{I}_{(m,n)} + \tilde{R}_{I(m,n)}\right)}{(1+r)^{(12\cdot(n-1)+m)}} \quad (1)$$

For this case study, the risks analyzed were associated with obtaining lower income than initially expected $(\tilde{R}_V)$, since the risks corresponding to the project expenses $(\tilde{R}_I)$ they did not represent significant values for analysis. These income risks were simulated under 100,000 scenarios using Monte Carlo Simulation according to the probability-based method (Espinoza and Morris, 2013) making use of MATLAB ® software. In this way, the risk premium that covers the investor from a drop in expected income can be represented by equations 2 and 3:

$$\tilde{R}_{V(m,n)} = \left(\tilde{V}_{(m,n)} - \tilde{V}_{(m,n)}^-\right) \cdot \Pr\left[\tilde{V}_{(m,n)} > V_{(m,n)}\right] \quad (2)$$

$$\tilde{R}_{V(m,n)} = \eta_{V(m)}\tilde{V}_{(m,n)} \quad (3)$$

where $\tilde{V}_{(m,n)}^-$ corresponds to the mean of the incomes whose values are lower than $\tilde{V}_{(m,n)}$ in the same period. The difference of these

Table 1: Input variables for year 1

Year 1	Energy production		Consumption (kWh)	Energy service fare (COP$/kWh)	Electricity price (COP$/kWh)	Trading charge (COP$/kWh)
	Sun h/day	Energy prod. (kWh)				
January	5.5	705.0	366.8	577.7	244.0	41.9
February	5.4	692.3	489.1	579.5	244.0	41.9
March	5.4	683.8	489.1	582.5	244.0	41.9
April	5.1	649.8	489.1	583.4	244.0	41.9
May	5.1	654.0	489.1	615.8	244.0	43.4
June	5.3	671.1	538.0	610.5	244.0	41.4
July	5.6	713.5	366.8	584.5	244.0	41.6
August	5.4	692.3	489.1	596.0	244.0	41.6
September	5.3	675.3	489.1	584.5	244.0	42.7
October	5.2	662.6	489.1	600.6	244.0	42.2
November	5.3	671.1	489.1	601.1	244.0	41.6
December	5.4	688.0	586.9	615.9	244.0	41.5

Based on Benítez Pelaez and Martínez Ruiz (2019)

Table 2: Free cash flows for year 1

Year 1	All figures in COP$ unless otherwise indicated					
	Savings	Power sale		Tax benefit	Trading charge	Free cash flow (FCF)
		(kWh)	($)			
January	211,896	338	82,528	0	15,350	279,074
February	283,425	203	49,588	0	20,467	312,545
March	284,891	195	47,515	0	20,467	311,938
April	285,334	161	39,220	0	20,467	304,086
May	301,156	165	40,257	0	21,215	320,198
June	328,412	133	32,473	0	22,272	338,613
July	214,386	347	84,599	0	15,251	283,734
August	291,473	203	49,588	3,895,296	20,335	4,216,022
September	285,846	186	45,442	0	20,893	310,395
October	293,716	173	42,332	0	20,629	315,419
November	293,983	182	44,406	0	20,350	318,039
December	361,478	101	24,685	0	24,373	361,790

Based on Benítez Pelaez and Martínez Ruiz (2019)

two expressions is multiplied by the probability of obtaining less than expected income. Similarly, in equation 3, the expected revenue $\tilde{V}_{(m,n)}$ are multiplied by the risk factor $\eta_{V(m)}$ associated with income, to calculate the risk premium.

2.3. Energy Cost Savings
One of the sources of income for the project is represented by energy cost savings, which consider all those outputs that the residential user will not have to pay the service provider company, due to having a photovoltaic solar energy self-generation system in their home. These savings were calculated with the following expression.

$$S_{(m,n)} = C_{(m,n)} * T_{(m,n)} \qquad (4)$$

As can be seen in equation 3, the savings are made up of energy consumption $C_{(m,n)}$ and energy service fare $T_{(m,n)}$. Therefore, any decrease in any of these two variables would result in lower savings than expected. Since consumption is a variable that clearly depends on the user and it represents the energy demand of the home under study, we proceed to analyze the risk associated with obtaining a lower rate than expected. The calculation of the cost of risk corresponding to this variable was calculated month by month, considering a normal distribution where the means correspond to the figures detailed in Table 1 and the standard deviation was equal to 29.7 for all cases. Figure 1 represents the normal distribution

used to calculate the risk premium associated with obtaining an energy service fare lower than expected, in the month of January of the 1st year:

As can be seen, 49.96% of the time the energy service fare will take a value lower than $ 577.7, a figure used as an average to calculate the expected savings in the month of January of year 1. Centering the interest on the left side of the distribution, since it is this fraction which represents the risk, it is obtained that the expected value of those rates that adopt values lower than $ 577.77 is equal to $ 554.01. Replacing in equation (2) we have that the risk premium of the energy service fare is equal to:

$$\tilde{R}_{T(1,1)} = (\$577.7 - \$554.01) \cdot 49.96\% = \$11.83$$

In this way, the risk factor corresponding to project savings is obtained from equation 3:

$$\eta_{S(1)} = \frac{\$11.83}{\$577.7} = 2.05\%$$

Therefore, the risk premium that covers a decrease in the expected savings in the month of January of each year due to a lower energy

service fare, corresponds to 2.05% of the savings in this period. The cost of risk for each month of year 1 is presented in Table 3.

2.4. Solar Energy Availability

Project income from the sale of energy ($EI_{(m,n)}$) is represented by surpluses of unconsumed energy that are injected into the National Interconnected System (SIN, for its acronym in Spanish) and are settled at the market price of the current month ($EP_{(m,n)}$). These surpluses, defined as energy credits, are presented when the consumption of the month ($C_{(m,n)}$) is less than the system output ($Pn_{(m)}$) and they are remunerated to the residential user according to equation 5:

$$EI_{(m,n)} = \begin{cases} \left(Pn_{(m)} - C_{(m,n)}\right)* EP_{(m,n)} & Si\, C_{(m,n)} \le Pn_{(m)} \\ 0 & Si\, C_{(m,n)} > Pn_{(m)} \end{cases} \quad (5)$$

In this way, an energy production lower than expected would result in lower income from the sale of energy or no income in the event that energy production does not exceed household consumption. According to equation 6, the amount of kWh produced in the month by the self-generation system in the case study depends on the number of panels used in the system and the solar energy availability (daily number of hours of sunshine expected during the month):

$$Pn_{(m)}(kWh) = 0,03*Npanel*Epanel*Ppower*SH_{(m)} \quad (6)$$

where the number of panels (*Npanel*), the efficiency of panel (*Epanel*) and peak power (*Ppower*), are constant parameters with values equal to 16, 0.9 and 295W, respectively. The risk of obtaining a lower energy production and therefore lower income than expected, is associated with the risk that the daily number of hours of sunshine (*SH*) expected for the month *m*, is less than those listed in Table 1. This risk in the variable sunshine hours

can be modeled month by month as a triangular distribution, with a maximum value of 6.1 and a minimum of 4.6 for all months, according to the number of hours of sunshine recorded in the area where the home under study is located (Instituto de Hidrología Meteorología y Estudios Ambientales, 2014). For the case of January, this risk is represented in Figure 2, with a mode of 5.9.

With a probability of 44.76% that the daily number of sunny hours in the month of January is lower than expected and 5.22 being the average of the figures 5.53, the risk premium related to the variable of solar energy availability (hours of sunshine) was calculated , applying equation 2.

$$\tilde{R}_{SH(1)} = (5.53 - 5.22)\cdot 44.76\% = 0.139$$

In parallel to the calculations made in section 2.3 (Energy cost savings), the risk factor corresponding to monthly energy production was equal to 2.51%. Then, the risk premium associated with obtaining a lower than expected energy production due to a decrease in the daily number of hours of sunshine, is equal to 2.51% of the production of the month of January.

$$\eta_{Pn(1)} = \frac{0.139}{5.53} = 2.51\%$$

Applying the risk factor calculated to the production of January of year 1, the expected income from the sale of energy is reduced from COP $ 82,528 (Table 2) to COP $ 78,206. This decrease of COP $ 4,322 corresponds to the cost of the risk that covers a reduction in the expected income from the sale of energy due to a lower energy production in the self-generation system. These figures are detailed monthly in Table 3, for the 1st year of the project.

3. RESULTS

Once the risks of the case study project had been quantified, the decoupled free cash flow (DFCF) was calculated according

Figure 1: Normal distribution diagram of the energy service fare in January of year 1
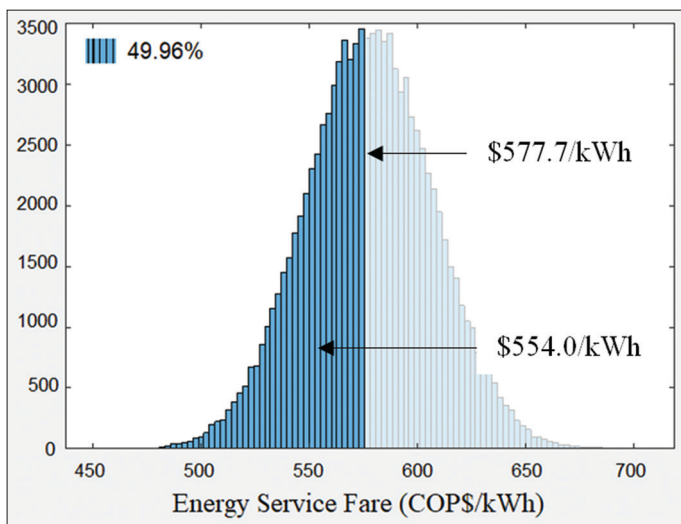

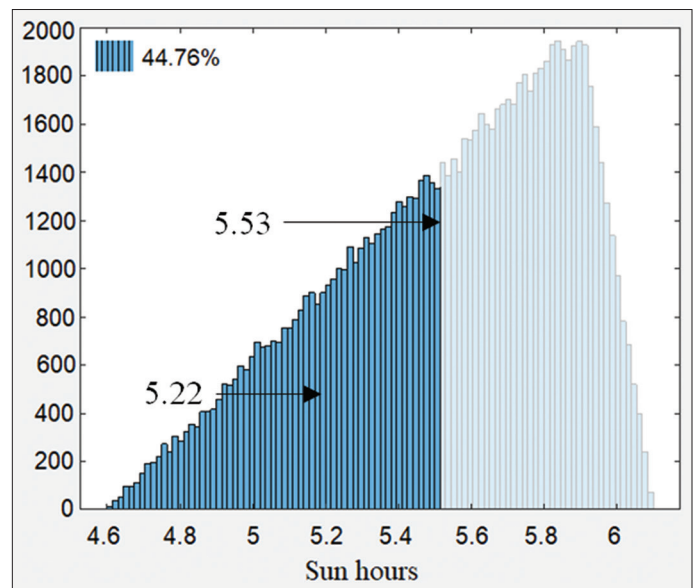**Figure 2:** Triangular distribution diagram of sunshine hours in January

Table 3: Cost of risk and project DNPV

Year 1	Risk factors (%)		Cost of risk			Decoupled free cash flows
	ηs	η_{Pn}	Savings	Power sale	Total cost of risk	
January	2.05	2.51	4339	4322	8661	270,413
February	2.04	2.37	5786	4000	9786	302,759
March	2.03	2.33	5786	3893	9679	302,259
April	2.03	2.91	5786	4609	10,395	293,692
May	1.92	2.80	5786	4461	10,246	309,952
June	1.94	2.44	6364	4000	10,364	328,249
July	2.02	2.65	4339	4607	8946	274,787
August	1.99	2.37	5786	4000	9786	4,206,236
September	2.02	2.39	5786	3932	9718	300,677
October	1.97	2.60	5786	4199	9985	305,434
November	1.97	2.44	5786	4000	9786	308,253
December	1.92	2.34	6943	3932	10,875	350,915

All figures in COP$ unless otherwise indicated

to the DNPV methodology. The risk costs considered for this analysis correspond to income lower than expected in savings and income from energy sales. The latter refers to the risk that energy production during the month will decrease compared to that initially proposed as a consequence of the fact that the resource of sun hours obtained is less than expected, which can happen due to climatological variations at different times of the year to throughout the life of the project. After the results obtained for the 20 years of the project, it was observed that the most significant cost of risk is represented by savings, which represents 59% of the total cost of risk, compared to 41% represented by the risk premium of income for the sale of energy. The study did not consider the risk of obtaining a lower than expected tax benefit since this is an income that remains constant in the first 5 years of the project and the annual income for this concept corresponds to 10% of the initial investment required for the project .

The aforementioned risk costs were considered as additional costs and subtracted from the initial cash flow, in order to obtain the cash flows without risk. The results are shown in Table 3 for the 1st year of the project. The risk-free rate used to calculate the DNPV was equal to 0.56% and corresponds to the yield of a treasury security issued by the Colombian government (TES) with a maturity of 16 years (Banco de la República, 2020). The estimated value of the project discounting the decoupled cash flows was equal to COP $ 67.8 million. Therefore, when considering the initial investment of the project, the DNPV resulted in a value of COP $ 28.8 million.

Using the classic valuation method, the NPV of the project was equal to COP $ 12.5 million using a discount rate of 0.94%, which at the time of the estimates corresponded to the return obtained by the investor in case of having invested in other alternatives different to this project. Despite the fact that the FCF project relate higher values than the DFCF, the final DNPV of the project greatly exceeds the value indicated by the NPV. This is due to the effect of the risk-free rate to assess the financial feasibility of the project, since the risks in the project flows are considered, the latter can be discounted at a lower rate than that used to calculate the NPV (0.54 % vs. 0.94%).

Although the results obtained through the 2 methods used indicated that the investment was economically viable since under both approaches the value was positive, the result of the methodology proposed by the DNPV method was equivalent to 2.3 times the value obtained through the traditional valuation method.

4. CONCLUSIONS

This case study was presented as an example for the application of the DNPV approach to solar energy self-generation projects, one of the most developed technologies in the field of renewable energies. In this study, the new valuation method allowed the analysis of the variable known as the energy service fare and identified the sun hours parameter as a resource similar to that of any other project, but considering the risks of these variables within the flows of the project. The DNPV methodology has a great applicability in the field of energy, since it allows to identify and quantify the sources of risk that can affect the expected cash flows of the power generation projects.

The application of the DNPV to the project in question showed that the use of a very high discount rate can classify a project as unviable or underestimate its true value. As evidenced by the analyzes carried out in the case study, many renewable energy projects can become undervalued as a result of the use of traditional methods, by mistakenly associating a discount rate that includes a very high risk premium and that in many occasions it is more related to the sources of financing of the project instead of representing the risk component that it has.

One of the advantages that DNPV has over other valuation methods is the identification of potential project risks from the moment of valuation. This allows risks to be modeled and included as additional costs in cash flows when calculating risk premiums that cover lower-than-expected income or higher-than-estimated cash outflows, rather than assuming certainty in expected cash flows. DNPV proposes a new perspective within the framework of project appraisal, providing a simple and comprehensive methodology that reflects results that are more consistent with the projects, the investment alternatives and their economic viability.

REFERENCES

Agaton, C.B., Guno, C.S., Villanueva, R.O., Villanueva, R.O. (2020), Economic analysis of waste-to-energy investment in the Philippines:

A real options approach. Applied Energy, 275, 1-10.

Banco de la República. (2020), Departamento de Operaciones y Desarrollo de Mercados-DODM, Sistema de Subastas, Subastas de TES en Pesos Colombianos. Available from: https://www.banrep.gov.co/es/estadisticas/tes-pesos. [Last accessed on 2020 Jul 08].

Benítez Pelaez, J.A., Martínez Ruiz, Y. (2019), Metodología Para la Evaluación Financiera de Proyectos de Inversión de Energía Solar Fotovoltaica Considerando el Marco Regulatorio Existente. Colombia: Universidad del Valle.

CREG. (2018), Resolución CREG No. 030 de 2018. Por la Cual se Regulan Las Actividades de Autogeneración a Pequeña Escala y de Generación Distribuida en el Sistema Interconectado Nacional. Bogotá: Comisión de Regulación de Energía y Gas.

Espinoza, D., Morris, J., Baroud, H., Bisogno, M., Cifuentes, A., Gentzoglanis, A., Luccioni, L., Rojo, J., Vahedifard, F. (2019a), The role of traditional discounted cash flows in the tragedy of the horizon: Another inconvenient truth. Mitigation and Adaptation Strategies for Global Change, 25, 643-660.

Espinoza, D., Morris, J.W.F. (2013), Decoupled NPV: A simple, improved method to value infrastructure investments. Construction Management and Economics, 31(5), 471-496.

Espinoza, D., Rojo, J., Cifuentes, A., Morris, J. (2019b), DNPV: A valuation methodology for infrastructure and capital investments consistent with prospect theory. Construction Management and Economics, 38(3), 259-274.

Espinoza, R.D. (2014), Separating project risk from the time value of money: A step toward integration of risk management and valuation of infrastructure investments. International Journal of Project Management, 32, 1056-1072.

Espinoza, R.D., Rojo, J. (2015), Using DNPV for valuing investments in the energy sector: A solar project case study. Renewable Energy, 75, 44-49.

González, J.L., Blanco, P.L. (2008), Multicriteria cash-flow modeling and project value-multiples for two-stage project valuation. International Journal of Project Management, 26, 185-194.

Ho, S.H., Liao, S.H. (2011), A fuzzy real option approach for investment project valuation. Expert Systems with Applications, 38(12), 15296-15302.

Instituto de Hidrología Meteorología y Estudios Ambientales (IDEAM).

(2014), Atlas de Radiación Solar, Ultravioleta y Ozono de Colombia. Available from: http://www.atlas.ideam.gov.co/visoratlasradiacion.html. [Last accessed on 2020 Apr 22].

Menegaki, A. (2008), Valuation for renewable energy: A comparative review. Renewable and Sustainable Energy Reviews, 12, 2422-2437.

Piel, J.H., Humpert, F.J., Breitner, M.H. (2016), Applying a Novel Investment Evaluation Method with Focus on Risk-a Wind Energy Case Study. Hamburg, Germany: Proceedings of the International Conference on Operations Research of the German Operation Research Society (GOR).

Robichek, A.A., Myers, S.C. (1966), Conceptual problems in the use of risk-adjusted discount rates. The Journal of Finance, 21, 727-730.

Santos, L., Soares, I., Mendes, C., Ferreira, P. (2014), Real options versus traditional methods to assess renewable energy projects. Renewable Energy, 68, 588-594.

Shimbar, A., Ebrahimi, S.B. (2017a), The application of DNPV to unlock foreign direct investment in waste-to-energy in developing countries. Energy, 132, 186-193.

Shimbar, A., Ebrahimi, S.B. (2017b), Modified-decoupled net present value: The intersection of valuation and time scaling of risk in energy sector. Environmental Energy and Economic Research, 1, 347-362.

Shimbar, A., Ebrahimi, S.B. (2020), Political risk and valuation of renewable energy investments in developing countries. Renewable Energy, 145, 1325-1333.

Shun, C.L. (2011), Using real option analysis for highly uncertain technology investments: The case of wind energy technology. Renewable and Sustainable Energy Reviews, 15, 4443-4450.

Silverio, M.G. (2014), Separando valor tiempo de dinero y riesgo en la evaluación de proyectos. El valor presente neto desacoplado (VPND). Análisis Financiero, 126, 45-67.

UPME. (2014), Ley 1715 de 2014. Por Medio de la Cual se Regula la Integración de las Energías Renovables no Convencionales al Sistema Energético Nacional. Bogotá: Unidad de Planeación Minero Energética.

Zhang, M.M., Zhou, D.Q., Zhou, P., Liu, G.Q. (2016b), Optimal feed-in tariff for solar photovoltaic power generation in China: A real options analysis. Energy Policy, 97, 181-192.

Zhang, M.M., Zhou, P., Zhou, D.Q. (2016a), A real options model for renewable energy investment with application to solar photovoltaic power generation in China. Energy Economics, 59, 213-226.