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RESEARCH ARTICLE

Real Option Valuation Methodology for Household-Scale Renewable Energy Systems

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Abstract: Installing household-scale renewable energy (RE) assets, such as solar home systems, micro-wind turbines, pico-hydro systems, biomass space heaters, and improved cook-stoves, offers a range of benefits to householders. These include the possibility of working longer hours, enhancing the efficiency of production processes, improving the quality of life, and gaining greater control over their immediate environment. In several settings, artisans pursuing the same vocation are known to work from homes located in clusters. Consequent to procuring and deploying the RE asset, the community of individual investors bestows upon itself the option to derive incremental money incomes. This is subject to each member's access to working capital credit and raw material, skill levels and levels of effort, productivity, and more. This paper argues that householders assess the option to derive incremental incomes and go on to make the investment decision in RE micro-infrastructure based on the estimated value of such options. The model so developed is applied to a community of silk weavers in southern India to estimate the premiums that investors pay to opt into deriving incremental incomes. This study could estimate that by installing a solar home system, a weaver could derive an economic benefit of 17.36% and an intangible benefit of 82.64% of the amount invested into the asset.

Keywords: micro-infrastructure, real option valuation, renewable energy, income generation, Black-Scholes formula, captive-use renewable energy system

1. Introduction

Traditional valuation methods, including the commonly used net-present-value (NPV) and internal-rate-of-return (IRR) measures, are known to be inadequate in appraising proposed outlays, or in explaining past investments in infrastructure projects in general, and smaller projects in particular. This is largely due to high upfront costs and low transaction volumes over the life of the underlying infrastructure asset. Risks associated with the performance of such project assets are presumed to be built into the discount rate applied, while the "flexibility" offered to the end-user might often be overlooked (Santo et al., 2014). Even though so-called "micro-infrastructure" projects that impact individual households or commercial establishments might be simpler in construction, and be subject to fewer uncertainties, they might be subject to a wide range of operating conditions over their lifetimes. Consequently, IRR and other methods that rely exclusively on information available on the date of evaluation might not serve to assess investment in a micro-infrastructure asset. The value of household-scale standalone electricity systems powered by solar photovoltaic (PV) modules, micro-wind turbines, or pico-hydro generators is enhanced by evolution in battery technology as well as by technology evolution on the demand side. Mainstreaming of energy-efficient LED lamps, low-energy television sets and mobile phones, and efficient water pumps has reduced the size and therefore cost of RE systems required to power such end-use appliances. An appraisal exercise based exclusively on the energy output from a system, while ignoring the value-addition from prospective complements, would be insufficient to capture the total value derived by the end-user [1].

Venetsanos et al. [2] had employed the real options framework to assess a utility-scale wind energy project. This was done in the face of market uncertainty and to quantify the value added from offering project developers the option to expedite, defer, or abandon expansion of the wind farm. Kim et al. [3] propose the application of the real options analysis (ROA) framework, which is more commonly applied to investments with relatively volatile returns, as in oil, gas, mining, research and development, semiconductors, and similar industry segments. This approach works to accommodate macro-economic, policy, and project-specific uncertainty and to assess the viability of investments into renewable energy (RE, used interchangeably with cleaner or sustainable energy) projects hosted in developing countries. This is also evident from the conclusions drawn in the study conducted in Ghana [4]. The authors also list studies that had previously applied ROA frameworks to RE projects. These include assessing hydropower, wind energy, and solar PV projects, RE projects with clean development mechanism (CDM) revenues, and studies that explicitly considered the uncertainties associated with political and economic factors in emerging economies. The proposed framework is purported to overcome the shortcomings from traditional net present value (NPV) and internal rate of return (IRR) methods. It comprises four major steps: investment scenario development, cash-flow development, real-options valuation, and finally, decision-making. In summary, traditional discounted-cash-flow methodologies focus on investment decisions made based on

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information available at the time the decision is due. Meanwhile, real option approaches build flexibility in timing of investment commitments, and *advanced real option* methodologies consider flexibility in engineering design as well as in investment timing to maximize the value of projects [5].

Research on the subject of applying real options to RE project investments brings out the value in accommodating a range of policies and the impact of such policies on RE investments [6]. It also indicates a reciprocal relationship between the investment environment and the need for flexibility to recalibrate the policy frameworks applicable. Such interaction between policy changes and the investment environment also impacts the sustainability of investments in small-scale RE projects [7]. To support this, previous studies reveal that relative advantage and cost reduction have an impact on the intention of small-scale RE usage [8].

2. Scope of the Present Study

The previous studies on real option methodologies have been with regard to assessing and valuing the flexibility within utility-scale projects, wherein the principal revenue streams for such projects had come from the sale of electric power from wind energy, solar PV, or hydropower projects. For instance, one of the earlier researches applied the binomial tree as a part of the real option analysis to assess the value to defer investments into a small hydropower plant[1] [9]. Another research had observed as recently as year 2016 that the volatility in CO_2 prices and in electricity prices was not conducive to attracting immediate investments into solar PV plants in China [10]. However, the authors found that by increasing the levels of subsidy, technological progress and market stability have helped stimulate investments.

In contrast, this study deals with investment decisions relating to the purchase of micro-infrastructure assets. Such decisions most commonly involving solar PV systems, micro-wind generators, solar thermal water and space heaters, and biomass heaters and cookstoves; which are paid for and utilized by individual households and micro-enterprises. Unlike earlier studies, a real option methodology is developed and applied to situations where the electricity from the RE asset by itself is not exported for sale. Consequently, no revenues are generated. The illumination from household solar PV lamps or the electricity derived from micro-wind turbines and other RE equipment are applied to on-site income-generating activities. This paper explores the investment decision-making process based on the activities to be undertaken and the dispersion in income levels. These activities and income levels would justify the purchase and installation of RE micro-generation systems, thus personalizing and contextualizing the analysis. Earlier research found that due to the use of such technologies, children are able to spend more time studying as compared to children who do not have access to these products [11,12].

3. Consumer Receptivity and Willingness-to-Pay

Social acceptance of large RE projects is presumed from relatively passive consent, and is in effect, the absence of active resistance. Domestic micro-generation, on the other hand, requires active acceptance and is a function of attitudes, behaviour, and actual investments [13]. Some consumer segments are more receptive to new ideas and tend to stimulate the diffusion of innovations more vigorously than others. Higher levels of awareness among these segments could have been brought about by more intense marketing efforts of vendors, awareness creation campaigns, or through closer interaction with peers in densely populated urban areas [14]. The capital costs and the willingness-to-pay (“w-t-p”) are tied together by the payback periods for such assets to be owned, deployed, and utilized by individual households. This is even as secondary attributes and benefits, though desirable, might not enhance consumers’ w-t-p [15]. Likewise, Willis et al. [16] find that the age of the householder–decision-maker plays a role in determining the adoption of solar PV systems, solar water heaters, small-wind turbines, and to some extent wood pellet boilers. Consumers aged 65 years and above demonstrate a low propensity to acquire and deploy these technology options. Senior citizens might be apprehensive about their ability to maximize the utility from such investments. However, making most of installations also appears to be a concern among those segments of end-users who *do* invest into small-scale RE systems. For instance, Hyysalo et al. [17] found that active acceptance of the RE system was also demonstrated through inventions and modifications. These improved the efficiency, suitability, usability, maintenance, or price of the underlying asset. Users were seen to customize biomass heaters for specific applications and then disseminate such design improvements. These users were seen to add features and customize product attributes to suit their own homes; that manufacturers and vendors might not have contemplated.

4. Conceptual Framework

“Substantial poverty reduction can only be achieved if a wide range of productive and non-productive (welfare-enhancing) uses of electricity are established” [18]. A productive application of a small-scale standalone RE plant could include water-pumping for agriculture and horticulture, rice de-husking, and grain milling (especially with water mills and wind mills), tailoring, refrigeration and milk chilling, commercial entertainment centres, computer training classes, and internet kiosks. “Quality of life” applications include household television and music players, outdoor lighting at dusk, fans, and power-driven kitchen appliances. These might not directly bring in revenues for the householder and hence are sometimes classified as “non-productive”. In reality, though, there are medium-term welfare benefits to the purchase and deployment of the RE asset, including favourable health and educational outcomes. These are difficult to quantify, and if estimated, such benefits cannot be directly and exclusively attributed to the acquisition and use of the RE asset. Further, for weavers, carpenters and other artisans, especially those operating out of their homes that are located within remote settlements, the distinction between a productive and non-productive asset might be “artificial” [19]. The electric power or ambient climate moderation provided by the micro-infrastructure asset serve the residential space, which also doubles as a place of employment.

Displacing the use of kerosene lamps and biomass-fired cook stoves leads to lower smoke and improved indoor air quality. This is known to have a significant positive impact on the health of residents, more specifically on the women and children in the household. Improved “quality of life” through the use of electric lamps and fans and other such gadgets are projected to have positive physical as well as psychological impacts. Intangible benefits, entertainment, and psychological comfort from improved

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[1] As a part of a comprehensive review of 101 research papers employing real option methodologies to assess the viability of RE projects, Kozlova [21] found that 48% (the highest proportion) of papers related to uncertainty associated with electricity price.

control over one's immediate environment are valuable in their own right. However, the present model is structured to consider the range of tangible money earnings that the RE asset makes possible. The RE asset offers the investor the option to derive money incomes from within a range of possible values. This approach differs from previous approaches, which compare the price of the RE asset to avoided costs (of kerosene etc.) or to displaced services, such as electricity from diesel generators, or other such counterfactual alternatives[2]. This paper argues that it is the *money value* of the options to derive incremental incomes, as assessed by the prospective investor, which eventually leads to the investment decision.

5. Model Construction

There are several factors that lead to a range of income levels within a group of professionals. Some of those include differences in access to working capital facilities and raw material, productivity, skill levels, and quality of work. This means that within a group of artisans, all members of the community do not earn a discrete income over a given time horizon. Further, for the purposes of building the real options model, there were qualitative "welfare" benefits accruing from installing and using the RE asset. These included improved health and education, both of which are presumed to enhance productivity and to ultimately feed into change in income levels. The real options model provides estimates of the "premium" that individuals are willing to pay to opt into deriving a range of incomes. This methodology could also serve to assess the need for capital or interest subsidies to promote the acquisition and use of RE micro-infrastructure.

6. Application of the Model

Ilkaltownin Bagalkot district of the south-western Indian state of Karnataka is a traditional weaving centre, known for cotton and silk fabric. The 300 households at Gurlingappa Ashraya Colony, an isolated settlement, had used kerosene lamps for indoor lighting [20] and third-party charging stations for charging mobile telephone handsets. The open flame left weavers exposed to the real and imminent threat of having their produce burnt down. A two-light solar home system was proposed to alleviate this risk; which would also provide for a mobile phone charging point. It would have variants in configuration and installation to suit individual households and would improve the quality of indoor lighting. A rural bank recommended the formation of joint liability groups ("self-help groups") to expedite the processing of loans for the basic home system. This cost INR 7200 *ca* year 2010 (~USD155). A total of 37 households were supplied with solar home systems as a part of the first phase. User surveys provided data on socioeconomic status before and after the installation.

The summary input data presented within Table 1 indicate that the installation of the solar home systems led to a modest increase in working hours on the average day for the average artisan. Table 2 provides revenue and expense estimates for the business as usual (BAU) scenario, while Table 3 provides revenue and expense estimates for the post-solar home system installation (PI) scenario. Expenses take into account the costs of owning, operating, and maintaining the system. The revenues were projected based on the year-on-year change in prevailing index prices of the silk yarn as it is an indicator of the change in the price of the final product sold by the weavers. Table 4 details the

Table 1
Input data for real option valuation

	Pre installation					Post installation				
	Work hours/ day Hour	Work hours/ year Hour	Income per week INR	Annual income INR	Average income/ hour INR	Work hours/ day Hour	Work hours/ year Hour	Income per week INR	Annual income INR	Average income/ hour INR
Respondent 1	10	3000	300.00	15,600.00	5.20	11	3300	600.00	31,200.00	9.45
Respondent 2	10	3000	300.00	15,600.00	5.20	13	3900	600.00	31,200.00	8.00
Respondent 3	10	3000	300.00	15,600.00	5.20	12	3600	600.00	31,200.00	8.67
Respondent 4	11	3300	300.00	15,600.00	4.73	11	3300	600.00	31,200.00	9.45
Respondent 5	9	2700	300.00	15,600.00	5.78	11	3300	600.00	31,200.00	9.45
Respondent 6	11	3300	900.00	46,800.00	14.18	13	3900	1,500.00	78,000.00	20.00
Respondent 7	10	3000	300.00	15,600.00	5.20	12	3600	500.00	26,000.00	7.22
Respondent 8	8	2400	350.00	18,200.00	7.58	10	3000	500.00	26,000.00	8.67
Respondent 9	9	2700	350.00	18,200.00	6.74	11	3300	600.00	31,200.00	9.45
Respondent 10	10	3000	300.00	15,600.00	5.20	12	3600	600.00	31,200.00	8.67
					2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Change in price of silk relative to base year (2010 – '11)						0.8791	1.0810	1.3559	1.2252	0.9889
Change in price of kerosene relative to base year (2010 – '11)						1.2141	1.2805	1.3089	1.2200	1.1435

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[2] See for instance, Hossain Mondal [22].

Table 2
Projected revenues and expenses for the BAU scenario

BAU scenario		Annual income (INR)						Annual expenditure (INR)					
Name	Work hr/day	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Respondent 1	10	15,600	13,713	16,863	21,153	19,114	15,427	216.0	262.2	276.6	282.7	263.5	247.0
Respondent 2	10	15,600	13,713	16,863	21,153	19,114	15,427	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 3	10	15,600	13,713	16,863	21,153	19,114	15,427	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 4	11	15,600	13,713	16,863	21,153	19,114	15,427	216.0	262.2	276.6	282.7	263.5	247.0
Respondent 5	9	15,600	13,713	16,863	21,153	19,114	15,427	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 6	11	46,800	41,140	50,590	63,458	57,342	46,282	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 7	10	15,600	13,713	16,863	21,153	19,114	15,427	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 8	8	18,200	15,999	19,674	24,678	22,300	17,999	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 9	9	18,200	15,999	19,674	24,678	22,300	17,999	432.0	524.5	553.2	565.4	527.0	494.0
Respondent 10	10	15,600	13,713	16,863	21,153	19,114	15,427	432.0	524.5	553.2	565.4	527.0	494.0
Average		19,240	16,913	20,798	26,088	23,574	19,027	389	472	498	509	474	445
Net income									16,441	20,300	25,579	23,099	18,582
Change in net income relative to 2010 – ‘11									−12.79%	7.69%	35.69%	22.54%	−1.43%

Table 3
Projected revenues and expenses for the post SHS installation scenario

PI scenario	Work hours		Annual income (INR)						Annual expenditure (INR)					
Name	Before	After	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Respondent 1	10	11	15,600	27,426	33,727	42,305	38,228	30,855	216.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 2	10	13	15,600	27,426	33,727	42,305	38,228	30,855	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 3	10	12	15,600	27,426	33,727	42,305	38,228	30,855	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 4	11	11	15,600	27,426	33,727	42,305	38,228	30,855	216.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 5	9	11	15,600	27,426	33,727	42,305	38,228	30,855	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 6	11	13	46,800	68,566	84,317	105,763	95,569	77,137	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 7	10	12	15,600	22,855	28,106	35,254	31,856	25,712	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 8	8	10	18,200	22,855	28,106	35,254	31,856	25,712	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 9	9	11	18,200	27,426	33,727	42,305	38,228	30,855	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Respondent 10	10	12	15,600	27,426	33,727	42,305	38,228	30,855	432.0	2,400.0	2400.0	2400.0	2400.0	2400.0
Average			19,240	30,626	37,662	47,241	42,688	34,454	389	2,400	2,400	2,400	2,400	2,400
Net income										28,226	35,262	44,841	40,288	32,054
Change in net income relative to 2010 – ‘11										49.73%	87.05%	137.87%	113.71%	70.04%

Parameter	Notation	Description and application
1. Business as usual scenario	BAU	i. Revenue accruals for the base case are projected. ii. Expenses incurred in earning such revenue including for instance the use of kerosene, candles, dry cells, etc. are projected using appropriate price indices. iii. BAU incomes = BAU revenue – BAU expenses iv. BAUaverage income for community = BAU average revenue for community – average cost for community.
2. Post installation scenario	PI	i. Revenue accruals for the post-installation scenario are assessed. ii. Cost of revenue including costs associated with acquiring and operating and maintaining the RE asset (periodic pay out) are tabulated. iii. PI incomes = PI revenue – PI costs iv. PI average income for community = PI average revenue for community – PI average cost for community.
3. Incremental income	i	PI income – BAU income
4. Growth rate	g	i. Growth rate in incremental income wrt $t = 0$ ii. "g" is applied to forecast incomes for individuals starting from actual values reported at $t = 0$.
5. Planning horizon: $t = 0$ ton (where n = tenure of debt to fund the RE asset)	t	Revenues, expenses, and incomes are projected for the tenure of project debt ("n" years).
6. The Black-Scholes option valuation formula is applied to assess the value of the option to "call" the incremental income each year. $C = S_t N(d_1) - K\ e^{-rt} N\ (d_2)$ where $d_1 = \frac{ln\frac{S_t}{k} + (r + \sigma_v^2)\ t}{\sigma_s \sqrt{t}}$ $d_2 = \ d_1 - \ \sigma_s \sqrt{t}$ and	S_t K r σ C t N	i. "Price" S_t = median income at t = 0 ii. "Exercise price" K = median of (projected income range for the year) for t = 1 to n. iii. Risk-free rate, r = appropriate surrogate applicable to the circumstances iv. Variability, σ = standard deviation of the market prices of the independent variable (finished product prices, for instance). v. C is the call option price. vi. t is the time to maturity. vii. N denotes a normal distribution.

Table 4
Computations and results post SHS installation benchmarked against the BAU scenario

	Income dispersion				
	2011–12	2012–13	2013–14	2014–15	2015–16
Respondent 1	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 2	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 3	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 4	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 5	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 6	76,058.07	83,943.00	94,618.77	89,471.41	80,245.47
Respondent 7	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Respondent 8	29,578.14	32,644.50	36,796.19	34,794.44	31,206.57
Respondent 9	29,578.14	32,644.50	36,796.19	34,794.44	31,206.57
Respondent 10	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
Spot price	15,168	15,168	15,168	15,168	15,168
Exercise price	25,352.69	27,981.00	31,539.59	29,823.80	26,748.49
No. of years	1.00	2.00	3.00	4.00	5.00
Compounded risk-free interest rate (rf)	6.00%	6.00%	6.00%	6.00%	6.00%
Annualized standard deviation	17.98%	17.98%	17.98%	17.98%	17.98%
Present value of exercise price (PV(EX))	23876.26	24816.92	26344.08	23460.23	19815.77
s*t^.5	0.1798	0.2543	0.3115	0.3597	0.4022
d1	−2.4327	−1.8085	−1.6165	−1.0326	−0.4636
d2	−2.6126	−2.0629	−1.9280	−1.3923	−0.8657
Delta N(d1) normal cumulative density function	0.0075	0.0353	0.0530	0.1509	0.3215
Bank loan N(d2)*PV(EX)	107.28	485.46	709.44	1921.73	3830.80
Call option	6	49	94	367	1045
Total option value (INR)	1,563				
Average price of SHS	8,999				
Economic benefit	17.36%				
Intangible benefits	82.64%				

application of the Black-Scholes option pricing model. This is to estimate the premium paid to opt into deriving the incremental revenues.

7. Concluding Remarks

The procurement, installation, and utilization of decentralized, standalone RE systems, including the likes of solar home systems, improved cookstoves, micro-wind turbines, and pico or mini-hydro power systems, are frequently justified on the basis of the avoided costs of kerosene or displacement value of electricity from diesel generators or other potential substitutes; i.e. (hypothetical counter-factual scenarios). Subsidies from governments or development finance institutions are justified on the strength of the environmental credentials relative to such alternatives, which might be more polluting in comparison. The real option methodology developed in this paper attempts to estimate the premium that individual householders and small business persons pay to *implicitly* give themselves the option to derive incremental incomes relative to the business-as-usual scenario. As opposed to working with a discrete income level, this methodology provides for the fact that dispersion in incomes within a given community often arises from differences in skill levels and productivity, access to credit and raw material, and level of effort.

The *Black-Scholes* option pricing model applied to the dataset suggests that about 17% of the upfront cost of the hardware served as the implicit option price. The residual 83% might help the householders derive physical comfort and less tangible psychological benefits. In this specific case, the artisans had reported a nominal increase in work hours per day, while the improved quality of work and variations in the prices of the finished goods led to incremental incomes. Thus, the results indicate that a relatively small monetary benefit could aid in encouraging small-scale infrastructure investment decisions. The estimate of economic benefits could serve to determine the quantum of subsidy that could encourage investments into quality of life-enhancing RE investments. This methodology could be applied to estimate the increases in income derived by end-users, and thereupon, policymakers could decide on the quantum of subsidy that might encourage the uptake of standalone captive-use RE systems.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

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