Cost-benefit risk of renewable energy

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Abstract

State-of-the-art economic analyses of renewable energy technologies (RETs) include using portfolio theory in renewable energy policy planning and using Monte-Carlo simulation to attain the risk profile of the technologies. Most economic analyses now co-list the risk index and GWP index as results of research/policy planning reports. After examining the variants of economic models for RETs, the risk dimensions of traditional energies and RETs were compared. The asymmetry risks allocated between traditional energy and RETs were shown. Combining these asymmetry risk allocations, a project-based RETs financial feasibility model which simultaneously integrates cost and risk information with respect to renewable and traditional energy technologies, was developed. Results of the analysis showed that the risk premium of traditional energies should include the effects of the escalation and volatility of fuel prices. On a national/regional level, the subsidy of fossil fuels for traditional energy production, which is embedded in the economic development policy, should be recovered and the degree to which investment of RETs improved the efficiency of cost-risk portfolio should be measured. On a project-based level, the effect of fuel price escalation and the saving of cost of risk-mitigation should be included.

Keywords: energy economics, project-based analysis, economic feasibility, risk evaluation, energy risk.

1 Introduction

When analyzing the economic feasibility of a renewable energy technology, both negative externality and price risk of traditional energy technologies (TETs) are major concerns, as well as the difficulty regarding integration into the evaluation model. Hsu et al. [1] used life cycle cost analysis and a saving-to-investment ratio to analyze the empirical data of a residential BIPV

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project located at Kao-Hsiung [1]. The results showed that compared to the low electricity price in the southern part of Taiwan, it was still not economically feasible for a home owner-occupant to embrace renewable energy, even with a government subsidy. Hsu et al. (2008) used discounted payback year and two-way sensitivity analysis to analyze the future feasible domain of BIPV based on empirical data of a residential BIPV project, but did little to address the implication of the risk-mitigation with respect to the price volatility of fossil fuel [2].

State-of-the-art technology for dealing with such a problem includes portfolio theory and Monte-Carlo simulation. Some researchers and renewable energy policy-makers used the portfolio theory to find the optimal renewable proportion which can decrease the risk of energy combinations at the national/regional level, because the cost risk of renewable energy always exhibits a low correlation to traditional energy technology. For example, some EU reports used Energy technology portfolios to address energy security and diversity [3–5]: Airtricity use of wind generators to enhance Scotland's energy diversity and security [6], along with California's 33% renewable portfolio standard goal [7].

Other approaches used the Monte-Carlo simulation results and co-listed the risk dimension for reference in the analysis, like: net present value (NPV), internal rate of return (IRR), life-cycle cost (LCC), and levelized cost of energy (LCOE/LOE). Only a few analyses now co-list the risk index and global warming potential (GWP) index as results of research/policy planning reports [13]. Some of them use the market transaction value of GWP as a cost component of the energy technologies. But determining how risk attributes can be integrated within an economic analysis framework still needs be developed.

In the following section, the paper first examines the variants of economic analysis for RETs. Then the risk dimensions of RETs and traditional energy technologies are discussed in Section 3. A project-based economic feasibility model for RETs under uncertainty is developed in Section 4. Finally, a discussion is offered and conclusions are drawn.

2 Variants of economic model for RETs

Different approaches were used in the economic analysis of renewable energy, e.g. NPV, IRR, LCC, and LCOE. When compared to an alternative with a lower initial cost but a higher future cost, the pervasive tool used in engineering is the LCC. The LCC practice establishes a procedure for evaluating the life-cycle costs of a system and comparing the LCCs of alternative systems that satisfy the same functional requirements. The method entails computing the LCC for alternative building designs or system specifications having the same purpose, and then comparing them to determine which has the lowest LCC over the study period [9].

Since RETs are always used as substitutes for current energy technologies, energy saving and environmental impact are treated as major benefits. RETs always have higher initial costs and lower future costs (operating, maintenance, repair, or replacement costs); under these assumptions, it seems suitable to use in an economic analysis of renewable energy and an energy efficiency scheme. The present value of life-cycle cost ($PVLCC_e$) for an energy technology can be presented as follows:

$$PVLCC_e = IC_e + PVM_e + PVR_e + PVF_e - PVS_e \quad (1)$$

where IC is the present value of the initial investment cost; PVM, operation and maintenance; PVR, facility replacement cost; PVF, fuel price expenditure; PVS, energy saving; and subscription $e = te$ (traditional energy), re (renewable energy). Under the same theoretical concept, LCOE was developed to compare different energy production technologies. Most energy policy research organizations, like IEA, USDOE, or textbook used LCC or LCOE to simplify the analysis of RETs, e.g. in [1, 8, 10, 11, 14, 15].

Theoretically, the decision process in selecting between the alternatives should include consideration not only of the comparative LCCs/LCOEs of competing systems, but also the risk exposure of each alternative relative to the investor's tolerance for risk, any unquantifiable aspects attributable to the alternatives, and the availability of funding as well as other cash-flow constraints. Sensitivity analysis and probability analysis are the two major tools used in determining risk and uncertainty. In case of RETs evaluation, we always include the different price risk and externality scenarios in all the alternatives. Because $PVLCC_{te}$ and $PVLCC_{re}$ are evaluated separately, we list the resulting PVLCC and risk dimension in a descriptive table. IEA/OECD (2005) listed both the environmental externality index (e.g. GWP) and the risk index (e.g. standard deviation) of each energy technology, as supplementary to the comparisons [6]; however, the report did not provide full information regarding the impact of fuel price risk.

Recently, at the level of national/regional energy policy, more and more researches have used the portfolio theory to deal with the cost-risk profile of energy. The portfolio theory approach used mean-variance analysis to find the efficient frontier of different energy technology combinations, thus deciding the optimal proportion of renewable energy technologies. For example, Awerbuch and Berger (2003) used the portfolio theory to add renewable energy to the EU traditional generation mix [5]. Awerbuch (2005) used the same approach in "Wind Provides Competitive Advantage for Scotland" [6]. Bates White, LLC, (2007) used the same approach in *Achieving California's Generation Mix to 2020*: California's 33% Renewable Portfolio Standard Goal [7].

3 Risk dimensions of TETs vs. RETs

When evaluating the financial feasibility of a PV system, this paper refers to the capital investment in a photovoltaic electric generated system in which the initial capital cost can induce streams of cash inflows without fuel input and less environmental negative externality (e.g. GWP) at a minimum maintenance and

Table 1: Comparisons of risk characteristics of TETs vs. RETs.

	Input/ Cost components	**Output / Benefit and Externality**
RETs	1. More expensive initial capital investment compared to traditional fuels 2. Zero fuel price 3. Quantity of electric power generated fluctuates according to weather variations 4. Little maintenance and low operation fee across facility life cycle	1. Electricity power 2. Little GHG emission/GWP
TETs	1. Sunken cost of former capital investment 2. Fuel price with high escalation rate and volatility rate ***National/regional scale:*** 3. Uneven fuel distribution affecting energy security of the country 4. Global fuel potential exhausted	1. Electricity power 2. Large GHG emission/GWP

operation fee. Normally, the cash inflow of the PV investment is an opportunity to benefit from the substitution of a traditional electrical system generated from a primary energy material like fossil fuel. Compared to the new renewable technologies, one of the most prominent characteristics of the traditional energy systems is a sunken cost with escalating and fluctuating fuel prices, followed by an environmentally negative externality.

Table 1 presents a summary of the risk characteristics of cost components in regard to renewable and traditional energy technology. Focusing on PV electric power generated from photovoltaic system, due to the uneven distribution of such primary energy material (e.g. coal, oil and natural gas) across the continent, they are quite concentrated in some specific areas. This not only results in complicated geo-political relationships, but also results in energy security problems in most countries in the world and affecting the vulnerability of the economic development of most countries.

Based on the primary comparison among renewable energy and traditional energy in the above paragraph, the major differences between renewable and traditional energy include ***Risk and Externality.*** In terms of ***Externality***, the negative externalities accompanying traditional electric power production process are always on a global scale. Although it is hard to include externality cost completely in a practical way, it is possible to use the GWP market transaction price as proxy and compute it into the evaluation. In terms of ***Risk***, an examination of the effects of different risk properties regarding renewable and traditional energy technology reveals that RETs are always viewed as an intermittent energy source; as a result, the stochastic production quantity always involves variability. The risk of traditional energy technologies is mainly based on fuel price escalation and fluctuations along the whole life span.

Variability of RETs

Sinden [17] used UK empirical data to show that onshore wind speed correlations rapidly decrease as distance between wind farms increase [17]. Thus, the variability of wind energy in combination with dispersed location will significantly lower the electric generation risk. Empirical data in Germany also showed high wind in the winter and more sun in the summer [3]. The inverse correlation of seasonal capacity factors (actual power output divided by maximum potential output) of wind and PV can be complementary via careful renewable planning; this showed that the variability of renewable issues can be transformed via management strategies, technical system integration, and planning processes.

Fuel price risk

Market risk of the traditional energy production includes fuel price escalation and fluctuations. There are two kinds of approach that deal with market risk: national/regional policy level and project-based level. As we discussed in the previous section, national/regional policy uses the portfolio theory to determine the optimal level of RETs. At a project-based level, if we hope to combine the market and production uncertainty in the framework of the economic analysis of RETs, we will face the problem of computing energy-saving functions. How can the risky information on traditional energy technology be integrated into an energy-saving function? Some transformational method needs be developed in advance.

By examining the risk properties within different energy technologies, we find the asymmetry risk between renewable and traditional energy. This will definitely affect the result of project-based economic analysis. These biases will hinder research results. For example, the fuel price risk in a traditional energy technology will result in higher risk-premium cost and cost transfer to the end user. Also, whenever analyzing the renewable technologies, this risk from the counter-side alternative energy cannot be assigned to an energy-saving function. Whenever the asymmetry risk is misallocated, biases will follow. Without proper treatments of the model specification, these asymmetry risk properties will affect the result of a project-based economic analysis; thus, biases will definitely hinder research results.

4 Project-based model for RETs under uncertainty

If the benefits and costs can be completely discounted, net present value of a RET investment can be evaluated by inverting the sign of the right hand side in

Eq. (1). By comparing the risk attributes of additional investment of renewable energy respect to each items of traditional energy, the cost-benefits of renewable energy is developed, as shown in Table 2.

Table 2: The cost-benefit of choice energy technologies.

	Items (present value)	**RETs**	**TETs**
Cost	Initial investment cost	C_{re}	C_{te}
	Operation and maintenance	M_{re}	M_{te}
	Facility repair or replacement cost	RP_{re}	RP_{te}
	Fuel price expenditure	*0*	F_{te}
	Cost of environment externality/GWP	GWP_{re} (small)	GWP_{te} (large)
Benefit	Electricity power	Electricity power	Electricity power
NPV	Net present value	PW_{re}	PW_{te}

Let PW_{te} denote the present value of traditional energy technology. C_{te} denotes the present value of the sunken value of the capital investment, M_{te} denotes the present value of the annual operation and maintenance costs; RP_{te} denotes the present value of the repair or replacement fee of the energy facility; F_{te} denotes the cost of the fuel and GWP_{te} denotes the cost of *GHG* emissions which were summarized as an index of global warming potential (*GWP*). Let A_{te-0} denote the initial bill of the energy user at time 0. Without considering the escalation effect of energy prices, the net present value of unit investment in traditional energy with life span, *n,* can be rewritten as follows:

$$PW_{te} = -C_{te} - M_{te} - RP_{te} - F_{te} - GWP_{te} + A_{te\text{-}0}\,\frac{(1+i)^n - 1}{i(1+i)^n} \qquad (2)$$

The first five terms on the right hand side of Eq. (2) are a summation of the present value of the cost components; the last term is the present value of the cash inflow from electric bills. Normally, if the net present value is positive, the evaluated project is feasible. Supposing the energy market is completely competitive and the normal profit of the investment is zero, then PV(B_{te})=PV(C_{te}) can be set without loss of reality. The equivalent computed electric price (A_0^*) of the traditional energy-k (including the cost of environmental externality and risk premium of the fuel escalation rate and volatility) at time zero thus can be obtained; therefore A_0^* can be interpreted as the risk-adjusted levelized cost of traditional energy technology.

The present value of energy savings for renewable energy investment in Eq. (1) will show the fuel market price risk of traditional energy technologies (PVS_{te}). However, due to the asymmetry risk between traditional energy and RETs, the stochastic property of fuel price risk should not be directly specified in the investment value function of RETs. The risk premium of risk-mitigation of RETs should be counted as part of energy saving, thus raising the normal traditional electric market price. The traditional electricity price function with price fuel risk includes a high escalation rate (e) and high volatility (v), thus raising the opportunity cost of risky capital investment.

Thus the present value function of a RET, like BIPV can be written as follows,

$$PW_{re} = -C_{re} - M_{re} - RP_{re} - GWP_{re} + A_0^* \frac{(1+i)^n - 1}{i(1+i)^n} \tag{3}$$

In Eq. (3) the cost of the fuel F_{re} is zero. The present value of operation and maintenance cost M_{re}, the repair or replacement fee of the energy facility RP_{re}, and the cost of environmental externality GWP_{re} of the renewable energy, like BIPV, is rather small. But the risk-premium of the fuel price risk of the traditional energy is now positive for renewable energy, which can be considered in imputed equivalent electric price A_0^*. At the national/regional level, the subsidy of fossil fuel for traditional energy production embedded in economic developed policy should be recovered, ΔA_1.

The effect of fuel price escalation

Considering that the rate of energy price escalation trend (e) is always faster than the rate of general price inflation, the final term of Eq. (3) can be replaced as $A_0 \sum_{j=1}^{n} \left(\frac{1+e}{1+i} \right)^j$, which denotes the present value of energy saving for TETs .

The adjusted present value factor of energy saving can then be derived as follows,

$$\sum_{j=1}^{n} \left(\frac{1+e}{1+i} \right)^i = \begin{cases} \dfrac{(f^n - 1)f}{f-1} & , if\ f \neq 1. \\ nR_0 & , if\ f = 1. \end{cases} \tag{4}$$

in which $f = \dfrac{1+e}{1+i}$; and i is the discount rate.

The effect of fuel price volatility

The risk premium of the computed equivalent electricity price A_0^* should include both the effect of fuel price escalation and volatility in the market. The benefit from improving the efficiency frontier for the cost-risk portfolio of social welfare (ΔA_2) with respect to the specific RETs investment and energy security (ΔA_3) should be measured and added to the benefit terms of RETs. On a project-based level of project feasibility evaluation, the opportunity cost of risk-mitigation for traditional energy production with respect to fossil fuels ΔA_4 should be estimated and added to the opportunity benefit terms of RETs.

On a national/regional level, the subsidy of fossil fuels for traditional energy production, which is embedded in the economic development policy, should be recovered and the investment of RETs improved by the efficient frontier of cost-risk portfolio as well as the energy security of the society should be measured as: $\Delta A_1 + \Delta A_2 + \Delta A_3$. On a project-based level, the effect of fuel price escalation and the saving of opportunity cost of risk-mitigation should be included: ΔA_4. Based on the computed equivalent electricity price of the traditional energies, which includes the adjusted factor of price escalation of energy-saving, the relevant risk-premiums for Eq. (3) can be summarized and expressed as follows:

$$\Delta A = \Delta A_1 + \Delta A_2 + \Delta A_3 + \Delta A_4 \tag{5}$$

5 Conclusion

By examining different risk dimensions of energy technologies, the asymmetry risks allocated between and TETs and RETs were shown. Combining the attributes of the asymmetry risk, a project-based economic feasibility model of RETs was developed. Such a model can simultaneously integrate all of the cost and risk information of RETs and TETs into one. This showed that the parameters of asymmetry risk of the two kinds of energy technologies and the environmental externalities could be adjusted. The risk premium of traditional energies should include the effects of escalation and volatility of fuel price. On a national/regional level, the subsidy of fossil fuel for traditional energy production which is embedded in the economic development policy should be recovered and the investment of RETs improving the efficient frontier of cost-risk portfolio should be measured. On a project-based level, the effect of fuel price escalation and the saving of opportunity cost of risk-mitigation should also be included.

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