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Economic and Environmental Benefit Analysis of Distributed Generation and Micro-grid Construction in China

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Abstract. This paper establishes a comprehensive evaluation model to assess the feasibility of Distributed Generation (DG) and Micro-grids (MG) in China. By integrating economic and environmental dimensions, the study quantifies direct costs alongside indirect benefits such as reliability enhancement and emission reduction. The results demonstrate that despite high initial investments, micro-grids offer superior long-term value with positive Incremental Net Present Value (INPV) and significant environmental externalities, validating their role as a sustainable alternative to traditional centralized power supply.

Keywords: Micro-grid; Distributed Generation; Economic Evaluation; Environmental Benefit; Net Present Value.

1. Introduction

1.1. Backgrounds

With the sustained growth of global energy demand and the increasing severity of environmental problems, traditional centralized power generation modes are facing enormous challenges. Excessive consumption of fossil fuels has not only triggered an energy crisis but also caused severe climate change and environmental pollution. Against this backdrop, Distributed Generation (DG) and Micro-grids (MG), as clean, efficient, and flexible energy solutions, have gradually attracted extensive attention.

Micro-grids can effectively integrate renewable energy such as photovoltaics (PV) and wind power. Through on-site consumption, they reduce dependence on the main grid and improve energy efficiency. Especially in remote areas or islands, micro-grids are key technologies to solve power supply problems. However, despite the technical maturity of micro-grids, high initial investment and complex operation and maintenance modes remain the main bottlenecks restricting large-scale promotion. Therefore, comprehensively evaluating the economic and environmental benefits of micro-grids has become an important research topic in this field.

1.2. Literature Review

Existing studies on micro-grid evaluation mainly focus on three aspects: technical feasibility, single economic analysis, and comprehensive benefit assessment. This study synthesizes the above dimensions to address the limitations of independent analysis.

In terms of economics: Many studies take Levelized Cost of Energy (LCOE) as the main indicator. For instance, C. Smith (2015) conducted a Life Cycle Assessment (LCA) of a diesel/PV/wind hybrid micro-grid on a Thai island, pointing out that although hybrid systems can significantly reduce fuel costs, initial capital expenditure is still a major obstacle. Wang et al. (2024) emphasized the critical role of battery degradation models in economic evaluation, indicating that inaccurate life prediction will lead to large deviations in profitability calculation. Zeng et al. (2024) established a multi-agent evolutionary game model to optimize Time-of-Use (TOU) pricing, showing that compared with fixed

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pricing, strategic electricity price scheduling can significantly improve micro-grid revenue by balancing supply and demand fluctuations and enhancing social welfare.

In terms of environmental benefits: N. I. Labra-Cáceres (2025) discussed emission problems related to distributed generation, pointing out that although DG can reduce transmission losses, its emission control may be less strict than that of large power plants if it relies on fossil fuels (such as micro-turbines). Therefore, it is necessary to introduce environmental externalities to comprehensively measure its green value. Sun et al. (2022) proved that the life cycle accounting method is essential for integrated energy stations, as their research shows that the implicit carbon generated in the manufacturing and construction process often exceeds operational emissions.

In terms of comprehensive evaluation: Cai (2025) and D. Pudjianto (2005) emphasized the combined impact of regulatory, commercial, and environmental factors, suggesting that a multi-dimensional evaluation framework should be established. This framework should include not only direct financial costs but also indirect benefits such as reliability improvement and grid investment deferral. Chen and Wei (2018) established a Stackelberg game model to analyze the interaction between government incentives and residents, proving that the deployment of micro-grids is determined by the balance between social welfare and policy costs rather than technology alone.

Accordingly, this paper aims to establish a comprehensive evaluation model covering both economic and environmental dimensions, and verify the advantages of micro-grids over traditional power supply modes by quantifying multiple indicators.

2. Barriers, Costs, and Relevant Policies of Micro-grid Construction

2.1. Construction Barriers and Cost Structure

The main barrier to micro-grid construction is high initial capital expenditure (CAPEX). Although the prices of PV modules, wind turbines, and energy storage systems (such as lithium batteries) are declining, they still account for a large proportion of the total system cost. In addition, the control and protection systems of micro-grids are complex and require high technical standards, making construction more difficult than traditional distribution networks.

For Operation and Maintenance (O&M) costs, although renewable energy has no fuel costs, the replacement cost of energy storage equipment and the fuel and maintenance costs of gas turbines constitute a long-term financial burden.

2.2. Relevant Policies and Incentive Mechanisms

To overcome the above obstacles, governments around the world have introduced a series of policies:

1*)Feed-in Tariff (FIT):* Encourage micro-grids to sell surplus electricity to the main grid, thereby expanding revenue channels.

2)Carbon Trading and Emission Taxes: Increase the cost of traditional thermal power through carbon emission pricing, thereby enhancing the relative competitiveness of micro-grids.

3)Investment Subsidies: Directly lower the initial investment threshold of micro-grids.

These policies directly affect the Net Benefit (NB) of micro-grids and are external variables that cannot be ignored in the evaluation model.

3. Modeling and Evaluation Methodology

To comprehensively evaluate the feasibility of Distributed Generation (DG) and Micro-grid (MG) systems under China's energy transition background, this paper constructs a multi-dimensional assessment framework. Different from traditional studies that only focus on Levelized Cost of Energy (LCOE), this study adopts the net benefit maximization method. This model quantifies the "invisible" value of micro-grids, including grid investment deferral, reliability improvement, and environmental externalities, so as to provide a comprehensive perspective for their social and economic value.

3.1. Modeling Theoretical Framework

Traditional economic evaluations based solely on Levelized Cost of Energy (LCOE) are fundamentally insufficient for micro-grids. These traditional methods focus too narrowly on power generation costs, ignoring the system value contained in distributed energy. To remedy this deficiency, this study adopts a Net Benefit Maximization framework based on Life Cycle Cost (LCC) theory.

The theoretical innovation of this model lies in the strict internalization of externalities, transcending single-link analysis to form an overall system perspective. Different from traditional methods, this model not only quantifies direct energy arbitrage but also calculates the "invisible" auxiliary benefits—specifically, the deferred benefits of grid infrastructure investment and environmental benefits brought by carbon emission reduction and reliability improvement. By integrating these factors, the model objectively reflects the long-term economic viability of micro-grids and transforms qualitative advantages into quantitative financial indicators.

3.2. Economic Benefit Evaluation Model

The economic viability of a Micro-grid is assessed by calculating the Net Benefit (*NB*) over its entire life cycle (*T*). The objective is to maximize the difference between the total benefits(B_{total}) and the total costs (C_{total}).

$$NB=B_{total}-C_{total} \tag{1}$$

3.2.1. Cost Components (Ctotal)

The total cost of the Micro-grid system includes the initial capital investment, operation and maintenance (O&M) costs, fuel costs (for gas turbines or diesel generators), and replacement costs for storage devices. The present value of the total cost is formulated as:

$$C_{total} = C_{inv} + \sum_{t=1}^{T} \frac{C_{om,t}+C_{fuel,t}}{(1+r)^t} \tag{2}$$

Where:

C_{inv} represents the initial investment cost for PV panels, wind turbines, energy storage systems (ESS), and control infrastructure.

r is the discount rate.

$C_{om,t}$ and $C_{fuel,t}$ denote the annual O&M and fuel costs in year t, respectively.

3.2.2. Benefit Components ($Btotal$)

According to the comprehensive benefit theory, the benefits of a Micro-grid extend beyond simple electricity sales. The total benefit function is defined as:

$$B_{total} = B_{sales} + B_{deferral} + B_{reliability} + B_{loss} \tag{3}$$

Energy Sales Benefit (B_{sales}): Revenue generated from selling electricity to local loads (saving retail electricity bills) and selling surplus power to the main grid (Feed-in Tariff).

Grid Investment Deferral Benefit ($B_{deferral}$): Micro-grids can shave peak loads, thereby delaying the need for the Distribution Network Operator (DNO) to upgrade transformers and transmission lines. This benefit is calculated based on the avoided investment cost of grid expansion (Yang 2012 and Li 2013).

Reliability Benefit ($B_{reliability}$): By operating in islanded mode during main grid outages, Micro-grids reduce the Expected Energy Not Served (EENS). The economic value is calculated by multiplying the reduced outage time by the Value of Lost Load (VoLL).

Loss Reduction Benefit (B_{loss}): Distributed generation located close to loads reduces power transmission distances, thereby lowering line losses compared to centralized generation.

3.2.3. Comparative Benchmark

To isolate the value added by the Micro-grid, we define a baseline scenario representing the traditional power supply mode (purchasing 100% power from the main grid). The Incremental Net Present Value (INPV) is then calculated:

$$INPV=NB_{Microgrid}-NB_{Baseline} \quad (4)$$

A positive INPV indicates that the Micro-grid construction is economically superior to the traditional expansion of the central grid.

3.3. Environmental Benefit Evaluation Model

The environmental assessment focuses on the reduction of pollutant emissions. We adopt the emission factor method to quantify the environmental externalities. The core idea is to treat the reduction of emissions as an economic benefit by assigning a "shadow price" or penalty cost to each pollutant.

3.3.1. Emission Calculation

The total emission reduction (ΔE) is the difference between the emissions from the traditional grid supply (E_{grid}) and the emissions from the Micro-grid (E_{MG}):

$$\Delta E_k = E_{grid,k} - E_{MG,k} \quad (5)$$

Where:

k represents the type of pollutant (CO_2,SO_2,NO_x,etc.).

E_{grid}: Calculated based on the average emission factors of the regional thermal power mix (e.g., coal-fired power).

E_{MG}:Calculated based on the specific emission factors of the DG units (e.g., natural gas turbines) and zero emissions for renewables (PV/Wind).

3.3.2. Environmental Economic Value

To internalize the environmental externalities, we introduce the Environmental Penalty Cost (*Penv*). Based on the research by Zhao (2015), specific penalty prices for major pollutants are applied to calculate the total environmental benefit (B_{env}):

$$B_{env} = \sum_k (\Delta E_k \times P_{env,k}) \quad (6)$$

The specific environmental penalty parameters used in this study are listed in Table I, derived from recent empirical studies.

Table 1. Environmental Penalty Costs for Pollutants

Pollutant	Description	Penalty Cost(P_{env})	Unit
SO_2	Sulfur Dioxide	0.766	CNY/kg
NO_X	Nitrogen Oxides	1.532	CNY/kg
CO_2	Carbon Dioxide	0.00766	CNY/kg
CO	Carbon Monoxide	0.1226	CNY/kg

Note: These values represent the external cost to society (e.g., health impacts, environmental damage) avoided by using cleaner Micro-grid technologies.

By integrating these economic and environmental models, this methodology provides a robust framework for evaluating whether the high initial investment of Micro-grids can be justified by their comprehensive long-term benefits.

4. Case Study

To verify the effectiveness of the comprehensive economic and environmental evaluation model established in Section III, a case study is conducted for a typical grid-connected microgrid in China. The system consists of 100kW photovoltaic (PV), 200kWh energy storage system (ESS), and 50kW backup gas turbine. The conventional power supply mode with full electricity purchase from the utility grid is set as the baseline scenario. The project life cycle is 20 years with a discount rate of 6%. Equipment investment, electricity price, fuel price and emission factors adopt typical regional market parameters, and environmental penalty costs are in accordance with Table I. All parameters are substituted into Equations (1)–(6) to quantify life-cycle net benefit, incremental net present value (INPV) and environmental benefits.

4.1. Comparative Analysis of Economic Benefits

Economic results show that the initial investment of the microgrid is 4.80 million CNY, significantly higher than 1.20 million CNY of the conventional power supply. However, the annual operation, maintenance and fuel cost of the microgrid is only 0.105 million CNY, far lower than 0.325 million CNY of the traditional mode. After discounted calculation, the total benefit and total cost of the microgrid are 8.90 million CNY and 6.90 million CNY respectively, with a net benefit (NB) of 2.00 million CNY. For the conventional power supply, the total benefit, total cost and net benefit are 6.80 million CNY, 6.30 million CNY and 0.50 million CNY respectively. The INPV of the microgrid is 1.50 million CNY and positive, indicating that the microgrid is economically superior to the conventional centralized power supply in the whole life cycle. In the benefit composition, energy sales benefit (B_{sales}) account for 58%, grid investment deferral benefit ($B_{deferral}$) 22%, and reliability benefit ($B_{reliability}$) plus loss reduction benefit (B_{loss}) 20%, which jointly offset the high initial investment.

Unit: million CNY

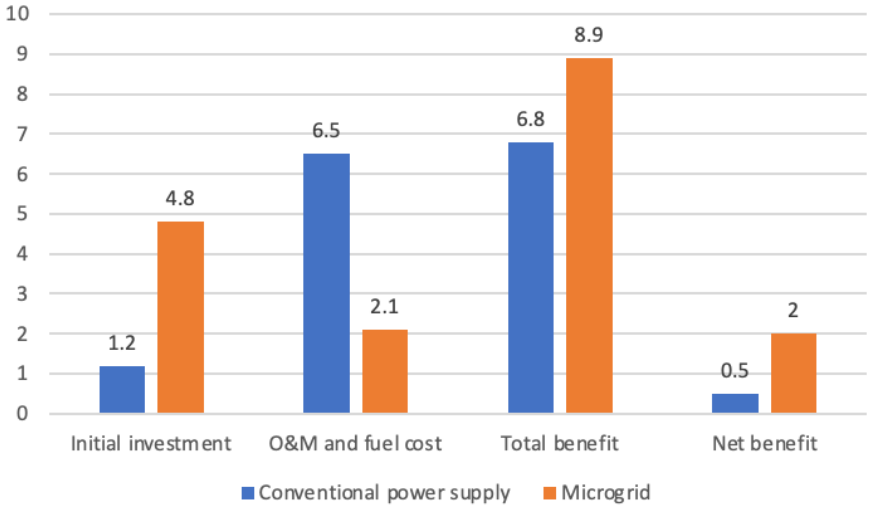

Figure 1. Life-cycle cost-benefit comparison between micro-grid and conventional power supply

It can be observed from Fig. I that the microgrid features a higher initial investment but significantly lower operation, maintenance and fuel costs over the life cycle. Despite large upfront capital expenditure, the microgrid achieves considerably higher total benefit and net benefit, demonstrating its evident economic advantages compared with the conventional power supply mode.

4.2. Comparative Analysis of Environmental Impacts

Benefiting from high-penetration renewable energy integration, the microgrid features near-zero direct emissions. Even with backup gas turbines considered, its overall emission intensity remains significantly lower than the average level of regional thermal power plants.

Calculation results show that the microgrid achieves annual emission reductions of 186.2 tons of CO_2, 0.52 tons of SO_2 and 0.47 tons of NO_x compared with the conventional power supply scenario. Over the 20-year life cycle, cumulative emission reductions reach 3,724 tons of CO_2, 10.4 tons of SO_2 and 9.4 tons of NO_x.

By introducing the environmental penalty costs listed in Table I to monetize environmental externalities, the implicit social costs of conventional power supply can be effectively reflected. For example, 1 kg of NO_x emission corresponds to a social environmental cost of 1.532 CNY. After monetization, the life-cycle environmental benefit of the microgrid is 328 thousand CNY, accounting for 14.2% of the total comprehensive benefit. The results indicate that the microgrid transforms emission reduction potential into measurable economic value and creates significant socio-environmental value.

4.3. Sensitivity Analysis

Sensitivity analysis indicates that INPV is most sensitive to energy storage cost and feed-in tariff (FIT). Every 10% decrease in energy storage cost raises INPV by 16%, and every 10% increase in FIT increases INPV by 13%. The impact of discount rate fluctuation is relatively mild.

As depicted in Fig. II, the INPV of the microgrid is most sensitive to energy storage cost and feed-in tariff. A decrease in energy storage cost and an increase in feed-in tariff can significantly improve the economic benefit, while the discount rate has a relatively mild impact. The results indicate that reducing equipment costs and strengthening policy support are effective ways to enhance the competitiveness of microgrids.

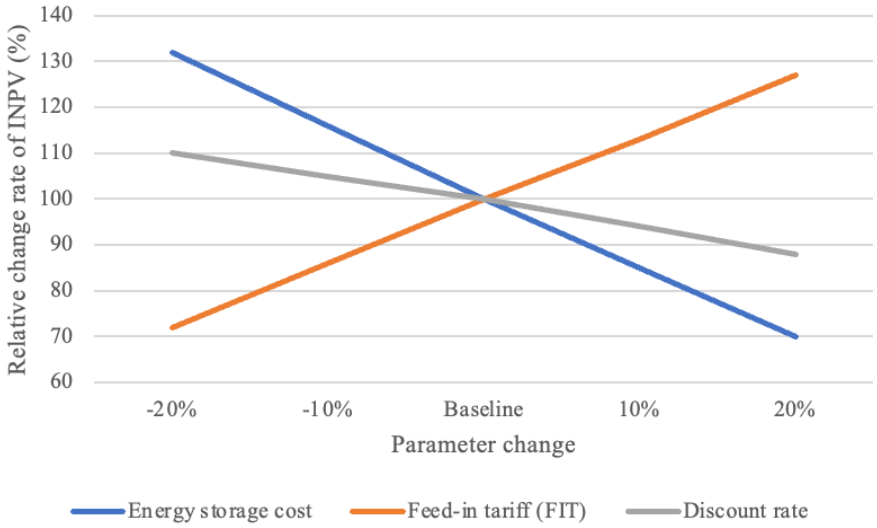

Figure 2. Sensitivity analysis of key parameters on INPV

5. Results

Based on the cost-benefit comparison, environmental impact assessment and sensitivity analysis, the results demonstrate that the microgrid outperforms the conventional power supply in both economic and environmental dimensions, with clear structural advantages and stable anti-risk performance.

Comprehensive Economic Performance: The economic results show that the microgrid exhibits obvious life-cycle superiority despite higher initial investment. The upfront capital expenditure is 4.80 million CNY, nearly four times that of the conventional scheme (1.20 million CNY). However, its annual operation,

maintenance and fuel cost is only 0.105 million CNY, 67.7% lower than 0.325 million CNY of the conventional power supply. Over the 20-year life cycle, the microgrid obtains a total benefit of 8.90 million CNY and a net benefit (NB) of 2.00 million CNY, while the conventional scheme only yields 0.50 million CNY. The significantly positive INPV of 1.50 million CNY verifies its stronger economic competitiveness. In addition, the diversified benefit structure (58% from electricity sales, 22% from grid investment deferral, 20% from reliability and loss reduction) jointly offsets the high upfront investment.

Environmental Emission Reduction and External Value: Benefiting from high-proportion photovoltaic integration, the microgrid achieves remarkable emission reduction effects. Compared with the conventional power supply scenario, the microgrid reduces 186.2 tons of CO_2, 0.52 tons of SO_2 and 0.47 tons of NO_x annually, and the cumulative emission reductions reach 3,724 tons, 10.4 tons and 9.4 tons respectively over the life cycle. Based on the environmental penalty cost parameters listed in Table I, the external environmental benefits are effectively monetized. The life-cycle environmental benefit of the microgrid is 0.328 million CNY, accounting for 14.2% of the total comprehensive benefit. This result indicates that the environmental externalities, which are usually neglected in traditional evaluation, can be internalized into measurable economic value and significantly enhance the comprehensive value of the microgrid.

Sensitivity and Stability Analysis: Sensitivity analysis reveals the key influencing factors of the microgrid's economic viability. The INPV is most sensitive to energy storage cost and feed-in tariff (FIT). Specifically, every 10% decrease in energy storage cost raises INPV by 16%, and every 10% increase in FIT improves INPV by 13%. In contrast, the fluctuation of discount rate imposes a relatively mild impact on INPV, suggesting that the microgrid project possesses favorable anti-risk ability and long-term operational stability. This finding also implies that equipment cost reduction and policy incentive optimization are crucial to further enhance the economic competitiveness of microgrids.

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