DOI: 10.53469/jgebf.2025.07(04).09

Economic and Ecological Benefit Evaluation of Clean Energy Power Generation Projects in Minority Areas—Taking F Project as an Example

Huixin Wen

School of Economics and Management, Qinghai Minzu University, Xining 810007, China

Abstract: ***Clarifying the actual benefits of the project is an important reference for government departments to promote the transformation of the clean industry in ethnic minority areas. Focusing on the clean energy characteristics in ethnic regions and the advantages and disadvantages of clean energy projects, this paper constructs a benefit evaluation system for multi-energy complementary projects from the perspectives of ecology and economics based on externality theory, systems theory, ethnic economic development theory and sustainable development theory. It also uses value substitution method, ecological value accounting method, remote sensing inversion method and cost-benefit analysis method for comprehensive measurement and analysis. Taking the Qinghai F project with prominent ethnic characteristics and relatively mature multi-energy complementary projects as a case study, this paper uses field survey data, data in the project feasibility report and remote sensing satellite data to evaluate its ecological benefits, economic benefits and spillover benefits, and deeply explores the actual value of the multi-energy complementary projects of clean energy power generation in ethnic areas. The main research conclusions are as follows: (1) The carbon emission reduction of the F project in 25 years is 37.9625 million tons, the emission reduction value is 2.24 billion yuan, and the carbon fixation and oxygen release value of the project is 77,282.39 yuan, which highlights the core contribution of the multi-energy complementary project to the "dual carbon" goal. Clean energy development in ethnic minority areas can effectively reduce greenhouse gas emissions and has good ecological benefits. (2) Based on the vegetation coverage in different operation periods of the project inverted based on remote sensing data, the trend of vegetation coverage in the study area was analyzed. It can be seen that the area of desertified land has decreased significantly, and the area of photovoltaic-grassland system has increased. This proves the potential of the "photovoltaic + ecology" model for desertification land governance and achieves synergistic efficiency between ecological restoration and renewable energy development. (3) Over the 25 years, the total cost of Project F was RMB 1.473 billion, the total revenue was RMB 2.188 billion, and the return on investment was 48.49%. The economic benefits are considerable, but there is a problem of over-reliance on government subsidies. (4) The ecological cost of Project F accounts for 1.03% of the total cost, but the benefits and value spillover account for 12.06% and 34.79% of the total value, respectively. The asymmetric relationship between ecological costs and benefits was revealed, and it was demonstrated that the multi-energy complementary system in ethnic areas has the characteristics of ecological input-output nonlinear gain. This shows that the project has great potential in terms of ecological benefits, but it has not yet been fully released.***

Keywords: Clean energy power generation, Multi-energy complementary projects, Ecological benefits, Economic benefits, Spillover benefits, Ethnic regions**.**

1. Introduction

In the context of coping with the dual challenges of global energy transformation and climate governance, the clean energy multi-energy complementary industry in ethnic regions, as a key carrier of low-carbon development, has become an important research object for regional energy structure optimization. The Chinese government also released a blue paper on the development of a new power system in 2023 and issued a series of documents such as the "Notice on Strengthening the Management of New Energy Electricity Price Policy" [1].

Qinghai Province is located in the northwest inland area and has abundant clean energy such as wind energy, hydro energy, and solar energy. The province has unique advantages in developing the clean energy industry. Qinghai Province accounts for one-thirteenth of the country's total land area. The province is at a high altitude, most areas are dry and windy, the sunshine hours are long, and the clean energy categories are complete and the reserves are large. The theoretical reserves of hydropower resources rank fifth in the country, the technically exploitable amount of solar energy resources ranks second in the country, the cost of photovoltaic power generation is the lowest in the country, and the technically exploitable amount of wind energy ranks among the top in the country. It has abundant reserves of geothermal energy, natural gas and shale gas, as well as significant advantages in silicon mineral resources, and possesses comparative advantages in developing the photovoltaic basic industry. In addition, there are many Gobi deserts, grasslands and desertified lands in the province, with an area of more than 100,000 square kilometers. The unused land area accounts for 34.77% of the province's land area, which provides the geographical conditions for building a large-scale clean energy industry [2]. However, according to relevant literature, there is still a large gap between the actual application level of clean energy in Qinghai Province and the potential for clean electricity application, and there is still much room for improvement [3]. On this basis, it is of great significance to conduct in-depth research on the current status of project benefits in Qinghai Province and clarify its development value.

In the economic evaluation of projects, methods such as macroeconomic model (C-GEM) [4], principal component analysis [5], life cycle method [6] [9], cost-benefit analysis (CBA) [10], risk assessment method and grey correlation analysis are usually used to evaluate the economic benefits and feasibility of projects. Research shows that a deep transformation of the energy system with new energy as the mainstay is a necessary condition for driving sustained economic growth [7] [8]. Ecological benefit evaluation is also an important part of the research. Commonly used methods include ecological value accounting method [11], remote sensing monitoring method, ecosystem service assessment and environmental impact assessment method [16], which are used to evaluate the impact of projects on the ecosystem and its value. The focus is on two aspects: (1) Contribution to improving environmental quality such as pollutant emission reduction and air purification. The project generates no waste gas during operation and has significant environmental benefits compared to coal-fired power plants [12]. (2) Environmental regulation and other linked ecological service impacts: The shading effect of photovoltaic modules and the weakening of wind speed within the station are conducive to the restoration of vegetation within the station and the improvement of local microclimate, thereby increasing the biomass and species diversity of ground plants in deserts, Gobi and wasteland areas [13-16]. However, current research has mostly focused on the regional scale, with relatively few studies on the project level. Moreover, current research often adopts a single evaluation method for economic evaluation or ecological evaluation, and fails to fully consider the complexity and diversity of the nature-economy-energy system that urgently needs to be developed and upgraded for human activities. When studying the spillover benefits of a project, we also need to have correct measurement data as a basis to explore the long-term and sustainable nature of the project.

In view of the above shortcomings, this paper intends to innovate in the following aspects. First, based on the existing method theory and combined with the characteristics of ethnic minority areas, this paper establishes a more scientific and comprehensive benefit evaluation system for multi-energy complementary projects in ethnic minority areas, and takes the F project in Qinghai Province as an example to explore the benefits of clean energy power generation multi-energy complementary projects in ethnic minority areas from the project scale. Secondly, the cross-disciplinary research methods such as ecology, economics and geography are used to measure the benefits of the project, so that the evaluation results are more accurate and scientific. Finally, based on the systematic theory, by analyzing the benefit results, the advantages and disadvantages of the development of multi-energy complementary projects in ethnic minority areas are explored, and corresponding policy recommendations are given to strengthen the long-term benefits of the project and the sustainable development of the region. The research conclusions are helpful to provide decision-making basis for government departments, enterprises and research institutions, and strengthen the participation of the people in ethnic minority areas in multi-energy complementary projects, thereby promoting the development of multi-energy complementary projects in ethnic minority areas.

2. Evaluation Index System

2.1 Economic Value Evaluation Framework of Multi-energy Complementary Projects in Ethnic Areas

By combing through relevant literature and field investigation, the study found that the economic value of multi-energy complementary projects can be analyzed from multiple levels, mainly including the following aspects: direct economic benefits mainly include power generation income and energy saving costs. Power generation income is the direct income calculated based on the annual total power generation of the project and the on-grid electricity price, which is the main source of economic value of the project. Energy saving costs refer to reducing dependence on traditional energy power generation and reducing fuel costs on the one hand; on the other hand, it refers to optimizing grid access costs and reducing long-distance transmission losses in distributed energy systems; finally, it also includes reducing the dispatching cost of the power system. Multi-energy complementary projects can reduce the instability of power generation through a combination of different energy sources (such as wind energy, solar energy, hydropower and biomass energy). This stable power supply ensures the stable operation of the power grid and reduces the dispatching cost of the power system. It can be calculated by using the difference in charging and discharging income formed by the peak-valley electricity price difference. Multi-energy complementary projects reduce the dispatching cost of the power system. Indirect economic value mainly includes boosting the local economy, creating employment opportunities and policy support. The specific explanations are as follows: boosting the local economy means that multi-energy complementary projects can drive local economic growth, increase local gross domestic product (GDP) and promote the development of related industries. Job creation means that the construction and operation of the project will directly provide a large number of jobs, improving the income level and quality of life of local residents. Policy support means that the national and local government’s support policies for multi-energy complementary projects (such as tax exemptions, electricity price subsidies, etc.) have improved the feasibility of the project and enhanced the economic returns. The economic value assessment framework of the multi-energy complementary project is shown in Figure 1.

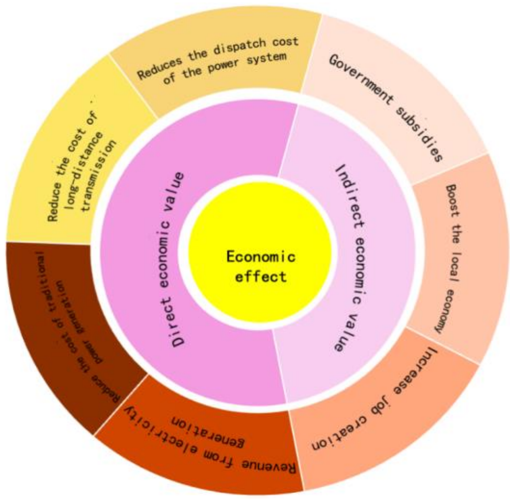

Figure 1: Framework diagram of economic value assessment of multi-energy complementary projects

The economic value of a project is often the most important factor that the government considers in promoting the development of the province’s industry. The economic value evaluation framework for multi-energy complementary projects provides a scientific evaluation tool by comprehensively and systematically analyzing the economic benefits of the project at all levels. The framework should comprehensively consider the direct economic value and indirect economic value of the project, the feasibility of the indicators, and the availability of data. The economic value evaluation framework involving the clean energy system in ethnic minority areas should also take into account the economic characteristics of ethnic minority areas. Therefore, in terms of direct economic value, the market value method is used to estimate the power generation benefits based on the annual total power generation of the project and the clean energy grid-connected electricity price, reflecting the basic economic benefits of the project. In terms of indirect economic value, the policy support of the government in ethnic minority areas, especially the electricity price subsidy, reduces the investment cost of projects in ethnic minority areas and further improves the economic feasibility of the project’s commissioning and construction in ethnic minority areas. Through this comprehensive economic value and benefit framework for ethnic minority areas, the overall economic benefits of multi-energy complementary projects can be effectively evaluated, providing decision-making support for governments, enterprises, and research institutions, and promoting the continuous optimization and sustainable development of clean energy projects in ethnic minority areas.

2.2 Ecological Value Assessment Framework for Multi-energy Complementary Projects in Ethnic Minority Areas

By combing through literature and field survey data, this section summarizes the impact of clean energy power generation projects on the value of ecological products. The ecological values of clean energy power generation multi-energy complementary projects are as follows: (1) Impact of regulatory service value, contribution to environmental quality improvement such as air purification: Compared with traditional energy power generation, clean energy project power generation does not produce any waste gas during the project operation period, wastewater comes from a small amount of domestic sewage and component cleaning wastewater, and solid waste comes from a small amount of domestic garbage, waste batteries and electrical components, maintenance waste oil, etc., which has significant environmental benefits compared with coal-fired power plants [62]. (2) Impacts on climate regulation and other linked ecological services: The impacts of photovoltaic power generation projects on temperature, humidity, and precipitation vary under different ecological and environmental conditions, depending on multiple factors such as albedo changes, array size, and orientation. Photovoltaic panels in cities will increase the albedo and thus reduce regional temperature, while photovoltaic panels in desert areas will increase the near-ground temperature at night [35]. When photovoltaic panels are combined or integrated with buildings, the shading effect of the panels and the conversion of solar energy will weaken solar radiation and reduce the surface temperature of the building [36]. In addition, photovoltaic power generation projects have a significant effect on reducing wind speed within the station and making the wind direction more uniform [37]. The impact on the local climate will also indirectly affect the region’s ecosystem service functions such as water conservation, wind and sand control, and soil conservation. (3) Contribution to carbon emission reduction: Clean energy is zero-carbon electricity. (4) Impact of species conservation services Photovoltaic power generation projects have different impacts on plant communities of different land types. The shading effect of photovoltaic arrays in deserts, Gobi and wasteland areas is conducive to the recovery of vegetation within the station and the improvement of local microclimate, thereby enhancing the ecosystem service function, while some grassland photovoltaic arrays will result in relatively low biomass and species diversity of ground plants underneath them.

Considering the scientific nature of the ecological benefit indicators of multi-energy complementary projects in ethnic minority areas and the availability of data, the ecological benefit indicators selected in this paper are the ecosystem emission reduction value and ecological service value, and the ecological value assessment framework of multi-energy complementary projects in ethnic minority areas is constructed as shown in Figure 2. Specifically, the ecological benefit assessment is mainly carried out from the following two aspects: First, the ecosystem emission reduction value is reflected by quantifying the amount of pollutant emissions reduced by the multi-energy complementary project, including the emission reduction of major pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), smoke and nitrogen oxides (NO_x). The reduction of these pollutants not only helps to improve regional air quality, but also reduces the negative impact on the ecological environment, thereby providing a guarantee for the healthy operation of the ecosystem. The reduction of pollutant emissions is converted into economic value through the market value method, which directly reflects the contribution of the project to reducing environmental pollution. Secondly, the ecological service value mainly evaluates the positive impact of the multi-energy complementary project on the ecosystem, including increasing the oxygen release and carbon fixation of the ecosystem. The oxygen release reflects the ability of vegetation to release oxygen through photosynthesis, while the carbon fixation reflects the ability of the ecosystem to absorb and fix carbon dioxide in the atmosphere. These two indicators can not only measure the project’s improvement of the regional ecological environment, but can also be converted into economic value through the carbon trading market or ecological compensation mechanism, further highlighting the ecological benefits of the project.

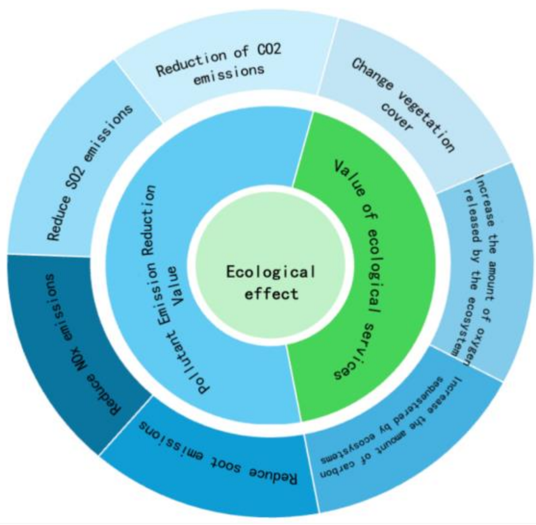

Figure 2: Framework for assessing the ecological value of multi-energy complementary projects

3. Evaluation Methodology

3.1 Ecological Benefit Assessment of Multi-energy Complementary Projects

3.1.1 Value of pollutant emission reduction

The emission reduction indicators of multi-energy complementary projects are mainly based on the reduction of CO_2, SO_2, NO_x and smoke emissions by replacing thermal power generation with clean energy. According to the "China Power Annual Development Report 2023", the national unit thermal power generation CO_2, SO_2, NO_x and smoke emissions are shown in Table 1. The pollutant emission reduction of the project is calculated by the following formula:

$$Q_i = S_{total} * A \quad (1)$$

Where, *Qi* is the emission reduction of the i-th pollutant of the project (tons), *S is the total* power generation of the multi-energy complementary clean energy power generation project during its entire life cycle (MWh), *and A* is the unit pollutant emission of thermal power generation nationwide.

The functional value assessment method is used to convert the calculated pollutant reduction data into monetary value to estimate the environmental value brought by the project. It should be noted that the Pollutant Discharge Charge Standard (PCS) is not the same as the Environmental Value Standard (EVS). Environmental value refers to the value contained in the pollutant reduction itself, and the pollutant discharge charge is only the external monetary expression of environmental value. According to relevant experts, the losses caused by environmental pollution and the destruction of environmental resources in China are at least 200 billion yuan (about 25% of GDP in the same period). According to the new charging standard, the annual pollutant discharge charge is only 50 billion yuan, accounting for only 25% of the environmental loss. In other words, the compensation rate of pollutant discharge charge for pollution loss is only 25% [17]. Therefore, the environmental value of pollutants reduced by the project is shown in Table 1. According to the relevant data of China's "Measures for the Administration of Pollutant Discharge Charge Standards", "Environmental Protection Tax Law of the People's Republic of China" and "China Carbon Market Annual Report 2023", the formula for calculating the environmental value of pollutants is as follows [18].

$$W_i = Q_i * V \quad (2)$$

Wi is the environmental value of the i -th pollutant of the project (ten thousand yuan); *Qi is* the emission reduction of the i-th pollutant of the project (*kg*); V is *the* unit environmental value of the i-th pollutant of the project (yuan/ kg).

Table 1: Pollutant emission reduction value scale of multi-energy complementary projects

Main pollutants	Unit emission reduction mg /kwh	Pollution value Yuan/kg	Compensation %	Unit environmental value Yuan/kg
CO_2	824		25	0.06815
SO_2	83	1.26	25	5.05
NO_X	133	1.26	25	5.05
Smoke	17	0.28	25	1.10

3.1.2 Project carbon sequestration value

CO_2 by the terrestrial ecosystem under the photovoltaic array through plant photosynthesis and conversion into organic matter, which then enters the soil through litter and other forms. This paper uses the carbon sequestration rate method [19] to calculate the carbon sequestration of grassland. Since grassland vegetation withers every year, the carbon fixed by the grassland will return to the atmosphere or enter the soil. Therefore, in the calculation of grassland carbon sequestration, the carbon sequestration of grassland vegetation is not considered, only the soil carbon sequestration of grassland is considered. Refer to Ouyang Zhiyun's [20] research method based on the ecosystem service function to calculate the carbon sequestration value. The calculation formula [21] is as follows:

$$GSCS = R_{GS} \times S_{GS} \times 44/12 \quad (3)$$

$$CSV = GSCS \times H \quad (4)$$

Where *GSCS* is the carbon sequestration amount of the restored grassland ecosystem in the photovoltaic park (tons), *RGS* is the carbon sequestration rate ($_t$ C·m^{-2} ·a^{-1}), the carbon fixation rate of grassland ecosystem under photovoltaic array in Qinghai Province is based on the method of reference [22], and the average value of 0.33Mg is taken in references [23] [24] [25]. C/(hm2 · a), 44/12 is the coefficient for converting C into CO_2, SGS *is the* grassland area under the project's photovoltaic array (hm2); *CSV* is the carbon sequestration value of the grassland in the park's photovoltaic project, *H* is the value of each ton of CO_2 fixed (yuan/ton), calculated according to the average trading price of CO_2 in the carbon trading market in 2023.

3.1.3 Project oxygen release value

The carbon fixation and oxygen release function produced by plant photosynthesis is of great significance to the survival of the ecosystem and even humans. The oxygen release is an important indicator for evaluating the regulation service of the multi-energy complementary energy system. Referring to the GEP physical quantity accounting model for oxygen release, according to the research method based on the ecosystem service function quantity by Ouyang Zhiyun [26], the industrial oxygen production method is used to calculate the oxygen release value of the multi-energy complementary system. The calculation formula is as follows:

$$Qo_2 = Mo_2/Mco_2 \times GSCS \quad (5)$$

$$ORV = Qo_2 \times O \quad (6)$$

In the formula, *Qo_2 is the oxygen release of* the grassland ecosystem restored in the park (tons). According to the reaction equations of photosynthesis and respiration, 1.62g CO_2 is required to form 1g of dry matter and 1.2gO2 *is* released. Therefore, Mo_2/Mco_2 = 32/44 is the conversion coefficient of CO_2 to O2. O *is* the value of each ton of O2 released (yuan/ton). The price is 448.04 yuan/ton, referring to the 2020 industrial oxygen transaction price of the China Industrial Gases Association and converted through the 2023 Consumer Price Index of Qinghai Province (previous year = 100).

3.1.4 Project vegetation coverage index

The basic concept of vegetation coverage is that vegetation coverage refers to the percentage of the vertical projection area of vegetation (including leaves, stems, and branches) per unit area. Vegetation coverage and its changes are important indicators of changes in regional ecosystem environment. The main calculation methods of remote sensing methods include empirical model method, vegetation index method and pixel decomposition model method [27]. Since the pixel binary model in the pixel decomposition model has the advantages of simple and reliable calculation model, universal and easy-to-obtain data parameters, and high inversion accuracy, we use the pixel binary model to invert the vegetation coverage of the study area of this article. GIS and ENVI software are used for data processing and mapping. By selecting three representative time nodes in 2013, 2017 and 2021 to analyze the trend evolution of vegetation coverage, and taking the year of project operation as the segmentation point, the vegetation recovery in the photovoltaic area of the park is evaluated by comparing the data before and after the construction of the power station. Among them, the vegetation coverage rate refers to the ratio of the area covered by vegetation to the entire pixel area. The basic formula for calculating vegetation coverage using the pixel binary model [27] is:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \tag{7}$$

NDVI is the vegetation index, and the normalized difference vegetation index is usually selected. $NDVI_{Soil}$ is the selected bare soil end member *NDVI* value, and $NDVI_{veg}$ is the vegetation end member *NDVI* value.

3.1.5 Environmental costs

With the advancement of the market-oriented reform of China’s power system, the environmental protection regulatory system applicable to the power industry will continue to improve, and it is a trend to include environmental costs in power generation costs. To quantitatively evaluate the environmental costs of power generation projects, the evaluation methods can be roughly divided into three measurement principles: 1. The value of the damage caused by pollutants is used as the measurement basis; 2. The cost of clearing the consequences of pollution and the cost of damage compensation is used as the measurement basis; 3. The cost of preventing pollution from occurring is used as the measurement basis [28]. Due to its characteristic of using clean energy for power generation, the multi-energy complementary system generally does not emit pollutants during the power generation process, but energy consumption is required during the production and manufacturing of power generation equipment and the construction of power plants; the use of power generation equipment has a lifespan, and energy consumption is required during the production, installation, operation and recycling of power generation equipment. To comprehensively analyze the environmental value of multi-energy complementary projects, its negative environmental benefits must be considered [29].

Because photovoltaic power generation accounts for a large proportion (90%) of the multi-energy complementary energy system involved in this paper, and considering the availability of data, this paper calculates the environmental cost of the multi-energy complementary project based on the energy consumption demand of the photovoltaic system included in the project during its entire life cycle. Referring to Gong Daoren et al. [31], the power consumption and carbon emission characteristics of a typical 1kW photovoltaic power generation system were studied, and it was found that the power consumption of a 1kW photovoltaic power generation system over its entire life cycle (25 years) is about 2707 kWh, and carbon emissions are 2409 kg. Based on the calculation method of Wang Xinmiao et al. [22], the energy consumption and carbon emission characteristics of the photovoltaic power generation system over its entire life cycle (25 years) are obtained, as shown in Table 2, and the calculation formula is as follows:

$$EC = GW \times P_{electric} \times A \tag{8}$$

EC is the environmental cost of the project; *Gw* is the power of the project; *P is* the unit power consumption of the photovoltaic power generation system in its entire life cycle. This paper takes the average value of the calculation results in the literature in Table 2. *A* is the carbon emission released by consuming 1kwh of electricity. According to the statistics of the China Energy Research Institute, residents consume 0.4kg of standard coal and 0.997kg of carbon dioxide for every kilowatt-hour of electricity consumed.

Table 2: Characteristics of energy consumption and carbon emissions in the whole life cycle of photovoltaic power generation systems

Power/kw	Power consumption/kwh	Consumption of standard coal/kg	Carbon emissions/kg
500	1.35 ^10 ^{6} [22]	4.06^10 ^{5}	1.00^10 ^{6}
1	2707 [31]	1082.8	2409

3.1.6 Ecological spillover benefits

Value spillover refers to the external impact of multi-energy complementary projects on other economic entities. This externality will bring social costs that cannot be fully included in private costs. The cost-benefit analysis method is usually used to estimate the value spillover of multi-energy complementary projects [32]. The environmental spillover benefit formula of the multi-energy complementary project is as follows:

$$EE = ORV + CSV + Wi \tag{9}$$

$$ESV = EE - EC \tag{10}$$

ESV represents the ecological spillover value of the project; *EE* represents the ecological benefit of the project; *EC* represents the ecological cost of the project.

3.2 Economic Benefit Evaluation of Multi-energy Complementary Project

3.2.1 Economic Benefits

3.2.1.1 Direct economic benefits

The economic value is estimated using the market value method, using the total power generation of the project and the current on-grid electricity price to estimate the power generation benefits of the project:

$$V_{electricity} = S_{total} \times P \tag{11}$$

Among them, $V_{electricity}$ represents the economic benefit of the theoretical total power generation of the project (10,000 yuan), S_{total} represents the theoretical total power generation of the project (kWh/a), and represents the on-grid electricity price of clean energy power generation (yuan/ kW h). According to the statistical data of Qinghai Province, it is taken as 0.19 yuan/kWh [33].

3.2.1.2 Indirect economic benefits

In Qinghai Province, the on-grid electricity price of clean energy is lower than that of thermal power, which not only reflects the rich clean energy resources in the region, but also demonstrates the government's active policy support in the field of clean energy. The government has adopted a series of policy measures to encourage the development of clean energy, effectively reducing the investment cost of clean energy projects [33]. Based on the power structure and actual situation of Qinghai Province, the National Development and Reform Commission issued the "Reply on the Subsidy Benchmark of Renewable Energy Power Generation on-grid Electricity Price in Qinghai Province" [34], approving that the subsidy benchmark of renewable energy power generation in Qinghai Province shall be implemented according to the weighted average on-grid electricity price of conventional energy power generation of 0.24 yuan per kilowatt-hour, which was adjusted to 0.2277 yuan in 2016 and has been implemented to date. Therefore, the calculation formula of the government subsidy value of the multi-energy complementary system is as follows:

$$Z = S_{total} \times \mathcal{E} \tag{12}$$

Government subsidy Z is the value of government subsidy (10,000 yuan), $\mathcal{E}$ is the unit price of government-subsidized renewable energy power generation, which is 0.2277 yuan/kwh.

3.2.2 Power generation cost

The power generation cost of a project refers to the sum of various expenses incurred during the power generation process, mainly including depreciation, maintenance, wages and benefits, insurance, material costs, amortization, interest expenses and other expenses. Specifically, depreciation refers to the cost incurred due to the decrease in value of power generation equipment during use, maintenance costs refer to the costs of maintenance and repairs to keep the equipment running normally, wages and benefits refer to the costs used to pay workers' wages and related benefits, insurance premiums refer to the insurance costs required to purchase equipment and facilities, material costs refer to the costs used to purchase raw materials and accessories required for power generation, amortization refers to the cost of allocating related costs to each year based on the service life of equipment and facilities, interest expenses refer to the interest expenses incurred by borrowing, and other expenses include comprehensive boiler operation and maintenance costs, boiler water costs, boiler electricity costs, and other costs related to the power generation process such as land rental plus land use tax. The comprehensive calculation of these costs can help evaluate the power generation cost level of the project. The calculation formula is as follows:

$$LCOE = I_t + M_t + F_t + E_t + R_t + N_t + \partial \tag{13}$$

LCOE represents the power generation cost during the life cycle of the project (10,000 yuan), I_t represents the depreciation of the project in t years, M_t represents the maintenance cost of the project in t years, F_t represents the salary and benefits of the project in t years, E_t represents the insurance premium of the project in t years, R_t represents the material cost of the project in t years, N_t represents the interest expense of the project in t years, ∂ is other expenses. The unit of each expense is 10,000 yuan.

3.2.3 Economic spillover benefits

The economic value spillover of the multi-energy complementary project is obtained by deducting the economic cost of the multi-energy complementary project from the economic benefit of the multi-energy complementary project. Among them, economic benefits include direct economic benefits and indirect economic benefits. Direct economic benefits refer to the power generation income of the multi-energy complementary project, while indirect economic profits refer to the government's electricity price subsidies and power shortage costs. Economic costs mainly include project construction costs, operation and management costs, etc. The economic spillover benefit calculation formula of the multi-energy complementary project in this paper is as follows:

$$ECO = EC_{electricity} + Z - LCOE \tag{14}$$

4. Overview of the Study Area and Data Sources

4.1 Overview of the Study Area

The project is located in the Dachaidan Administrative Region of Haixi Mongolian and Tibetan Autonomous Prefecture (hereinafter referred to as "Haixi Prefecture") in Qinghai Province. Haixi Prefecture is located in the northwest of Qinghai Province. It is the crossroads of the Qinghai-Tibet Plateau, connecting Tibet in the south, Gansu in the north, and Xinjiang in the west. It is located in the central area where the four provinces of Qinghai, Gansu, Xinjiang and Tibet meet, and has rich solar and wind energy resources. The installed capacity of this photovoltaic project is 1,000MW, and it is planned to use 550W p monocrystalline silicon bifacial battery modules. The photovoltaic power generation system of this project consists of 333 3.0MW and 1 1.2WM photovoltaic sub-arrays, and each photovoltaic module string is composed of 26 photovoltaic modules in series. Each 22 strings of photovoltaic modules are connected to a 300KW string inverter, and each 3.0MW array is equipped with 10 string inverters, and each 1.2MW array is equipped with 4 string inverters.

4.2 Data Source

In view of the fact that the multi-energy complementary project will be put into operation in 2023, this paper selects the data from 2023 onwards for the 25 years to evaluate the benefits of the power station as the research stage. The data used in this paper include statistical data, remote sensing satellite data and field survey data. The annual power generation, the area and geographical location of the project, the zoning design map and other statistical data are predicted and provided by the power station, see Appendix 1, Feasibility Report of Qinghai Province F Project. The remote sensing satellite data of the project such as vegetation coverage comes from the Landsat-8 TM remote sensing data of Gonghe County, Qinghai Province in 2014, 2017 and 2021 of China Geospatial Cloud Data. The vegetation coverage (Fractional Vegetation Cover) is calculated and mapped using ENVI and GIS geographic mapping software. Other accounting data come from the Qinghai Statistical Yearbook, the China Statistical Yearbook and relevant policies and regulations.

5. Results and Analysis

5.1 Comprehensive Benefit Analysis of Project F

The above calculations summarize the ecological, economic and spillover values of Project F over its entire life cycle, see Table 3.

Table 3: Ecological, economic, and spillover values over the whole Life cycle of F Projects

Level	Cost (ten thousand yuan)	Proportion (%)	Income (10,000 yuan)	Proportion (%)	Value overflow (10,000 yuan)	Proportion (%)
Ecology	15201.32	1.03	263786.25	12.06	248584.93	34.79
economy	1458159.39	98.97	1924019.41	87.94	465860.02	65.21
total	1473360.71	100	2187805.66	100	714444.95	100

Among the costs of the F project during its entire life cycle, economic costs accounted for the highest proportion, reaching 98.97%. High operating expenses were the main reason for the highest proportion of economic costs. Among them, interest expenses were an important factor affecting operating expenses. In contrast, ecological costs accounted for a smaller proportion, only 1.03%. The relatively low ecological costs of the project implied the importance and potential impact of multi-energy complementary projects in the cost structure. Specifically, the significance of the small proportion of ecological costs is reflected in the following aspects: First, the small proportion of ecological costs means that the investment and cost of the project in ecological environmental protection are relatively low. Second, the small proportion of ecological costs may reflect the effective management and control of the project’s environmental impact, reducing the damage and pollution to the ecosystem, thereby reducing the relevant ecological costs. In addition, the small proportion of ecological costs may also mean that the project has performed well in ecological benefits, achieved good ecological benefits, and made positive contributions to the protection and improvement of the local ecosystem. It reflects the excellent performance of the project in environmental protection and ecological benefits, and also highlights the importance of the project in sustainable development and ecological protection.

In terms of the benefits of Project F, the proportion of economic benefits is much higher than that of ecological benefits, which are 87.94% and 12.06% respectively. Among them, the economic benefits mainly benefit from the subsidies for clean energy power generation prices by the Qinghai Provincial Government, while the proportion of ecological benefits is relatively low. This phenomenon reflects the imbalance between economic and ecological benefits of multi-energy complementary projects, which is specifically manifested in the following aspects: First, the dominance of economic benefits means that the project has achieved great success at the commercial operation level. The government subsidy policy provides important economic support for clean energy power generation projects, promotes the investment and operation of projects, and thus achieves considerable economic benefits. This further strengthens the position of clean energy in the energy structure and promotes the development of sustainable energy. However, excessive reliance on government subsidies may distort competition in the power generation market, causing clean energy companies to rely on subsidies rather than their own competitiveness to gain market share, hindering normal competition and development in the market. It will also put pressure on government finances and affect the sustainable development of the local economy. Secondly, the relatively low proportion of ecological benefits may imply that there is still room for improvement in the project’s investment and benefits in ecology. Although ecological benefits account for a low proportion of total benefits, their importance in promoting the green transformation of the energy structure cannot be ignored. In the future, the project can increase the protection and improvement of the ecological environment, further enhance the contribution of ecological benefits, reduce the company’s dependence on government subsidies through relevant measures, and achieve a win-win situation of economic and ecological benefits.

At the spillover level of the project, the ecological value spillover of Project F accounted for a relatively low proportion, only 34.79%, while the economic value spillover accounted for a high proportion, reaching 65.21%. This reflects that the current multi-energy complementary projects have shown strong advantages in economic benefits, but in comparison, the potential of the current multi-energy complementary projects in terms of ecological benefits has not yet been fully realized, and the contribution to the ecological environment needs to be strengthened. It may be due to the fact that the current development stage of relevant energy systems such as multi-energy complementary projects in my country is still immature, and some multi-energy complementary projects may be in the early stages of development, and the realization of ecological value has not been fully considered or integrated into project planning and operation. In the early stages of project development, economic benefits are often the main focus, while ecological benefits are less valued, resulting in a relatively low proportion of ecological value spillover.

Overall, the ecological cost of Project F accounts for 1.03% of the total cost, but the income and value spillover account for 12.06% and 34.79% of the total benefit, respectively. Among them, the value of pollutant emission reduction and the ecological regulation services provided by the grassland-photovoltaic ecosystem constitute the key influencing factors of ecological value spillover. This result not only provides strong data support for the evaluation of the ecological benefits of multi-energy complementary projects in ethnic minority areas, but also further highlights the important role and potential advantages of multi-energy complementary systems in achieving the coordinated path of environmental protection and economic sustainable development in ethnic minority areas.

5.2 Basic Conclusion

Based on the estimated data of Project F and combined with the resource endowment characteristics and economic development needs of ethnic regions, the study reached the following main conclusions.

5.2.1 Ecological benefits are significant, but potential has not yet been fully released

(1) The value of pollutant emission reduction dominates the ecological benefit structure: Among the 25-year ecological benefits of the F project, the carbon emission reduction is 37.9625 million tons, the emission reduction value is 2.24 billion yuan, and the carbon fixation and oxygen release value of the project is 77,282.39 yuan. Among them, the value of $CO_{2\ \mathrm{emission}}$ reduction accounts for 98.05%, highlighting the core role of multi-energy complementary projects in supporting the “dual carbon” strategy. The development of clean energy in ethnic minority areas can effectively reduce greenhouse gas emissions and have good ecological benefits.

(2) The ecological restoration effect is beginning to show: after the project was put into operation, the vegetation coverage in multiple sections increased significantly (especially the area of 0.5-1 high coverage area), proving that the “photovoltaic + ecology” model has a positive effect on desertification land governance. However, the carbon fixation and oxygen release value of the project only accounts for 0.003% of the ecological benefits, and there is still much room for improvement in the ecosystem service function.

(3) The potential for ecological spillover value is outstanding: the ecological cost of the project accounts for only 1.03%, but the benefits and spillover value account for 12.06% and 34.79% respectively. This reflects that the value returns at the ecological level are significant but have not yet been fully released. In the future, we should further tap the potential of ecological value, promote innovation in the monetization path of ecosystem services, and enhance the level of ecological - economic synergy.

5.2.2 Economic benefits depend on policies, and the income structure needs to be optimized

(1) Government subsidies dominate benefits: Government subsidies account for 54.51% of the total economic benefits of Project F, reflecting the high dependence of clean energy projects on policies. Ethnic regions need to be wary of the fiscal burden and market distortion risks caused by long-term subsidies.

(2) Limited economic spillover: The economic spillover benefit is RMB 4.7 billion (accounting for 65.21% of the comprehensive spillover). Compared with the ecological spillover, the input and output are not proportional. In the future, it is necessary to increase the capital investment and technological development in ecology, further enhance the contribution of ecological benefits, and continuously optimize the project’s income structure.

5.2.3 The overall benefits are unbalanced and need to be coordinated and optimized

(1) Imbalance between economic and ecological benefits: The economic benefits of Project F accounted for 87.94%, while the ecological benefits accounted for only 12.06%, highlighting the general tendency of current multi-energy complementary projects to “emphasize economy and neglect ecology”.

(2) Significant cost pressure: Economic costs account for as much as 98.97% of the total cost, mainly from operating costs and financial expenses, indicating that cost structure optimization is still a key issue for the sustainable development of the project.

6. Discussion and Policy Recommendations

The research results show that the construction of clean energy multi-energy complementary systems in ethnic minority areas has shown significant economic feasibility and has great potential in the dimension of ecological gain (such as increased vegetation coverage, carbon sink gain and synergistic effects of ecosystem restoration). However, its economic benefits still face structural constraints such as high policy dependence and imbalanced multi-dimensional benefits. It is urgent to build a differentiated policy support mechanism to optimize the synergistic path of “economic-ecological-social” benefits.

6.1 Optimize the Policy Support for Multi-energy Complementary Power Generation Projects in Ethnic Minority Areas

In view of the problem of clean energy subsidy dependence in ethnic regions, it is recommended to implement a dual-track mechanism of “subsidy reduction + innovation incentive”. First, formulate a 3-5 year tiered electricity price subsidy reduction plan, and simultaneously establish a dynamic subsidy standard based on power generation efficiency; second, for projects that adopt core technologies such as energy storage integration and intelligent scheduling, give value-added tax refund and corporate income tax “three exemptions and three reductions” policies; finally, establish a special development fund for multi-energy complementarity, give priority to supporting advanced technology demonstration projects jointly declared by industry, academia and research, and form a diversified investment mechanism of “fiscal guidance-financial support-social participation”.

6.2 Promote the Integration of multi-energy Complementary Power Generation and Ecological Restoration in Ethnic Minority Areas

The huge potential of the multi-energy complementary system lies in ecology, and ecology is a major feature and advantage of ethnic regions. Therefore, ethnic regions should actively incorporate ecological restoration plans into the planning and construction of multi-energy complementary power generation projects. Vegetation restoration projects can be implemented simultaneously in wind farms and photovoltaic power generation areas to increase vegetation coverage. Eco-friendly construction plans are encouraged, such as "photovoltaic + agriculture", "photovoltaic + pasture" and other models, which can ensure power generation efficiency without affecting groundwater levels and soil quality, realize the compound utilization of land resources, and promote the economic development of ethnic regions.

6.3 Strengthen the Carbon Emission Reduction Benefit Evaluation and Incentive Mechanism for Multi-energy Complementary Power Generation Projects in Ethnic Minority Areas

Through field research at power plants and collection of relevant literature, it was found that the carbon emission trading process in most ethnic minority areas is not very clear, and there are gaps in the market planning and related processes for energy systems such as multi-energy complementarity. A complete carbon emission rights trading market should be established to transform the carbon emission reduction benefits of multi-energy complementary power generation projects in ethnic minority areas into economic benefits. By implementing the "carbon benefit prepayment" incentive policy, we can allow projects to obtain green credit by pledging expected carbon sink income during the development phase, thereby increasing the investment attractiveness of projects in ethnic minority areas. And more additional rewards will be given to multi-energy complementary power generation projects that achieve significant carbon emission reduction effects.

6.4 Strengthen the Carbon Emission Reduction Benefit Evaluation and Incentive Mechanism of Multi-energy Complementary Power Generation Projects in Ethnic Minority Areas

Compared with other regions, ethnic regions are relatively backward in technology and education. The state should support ethnic universities, research institutions and enterprises to cooperate in research on multi-energy complementary power generation technology in ethnic regions, solve technical bottlenecks in ethnic regions, and improve the energy efficiency and stability of the system. Ethnic regions are encouraged to actively build innovative experimental projects, such as implementing the "East-West Technology Pairing" project, establishing a technical assistance mechanism for coastal enterprises and ethnic regions; establishing a data sharing platform for multi-energy complementary projects in ethnic regions, and promoting the construction of an open source community for wind, solar, and water storage coordinated scheduling algorithms.

6.5 Strengthen the Publicity and Education of the Ecological Benefits of Multi-energy Complementary Power Generation Among the People in Ethnic Minority Areas

Influenced by ethnic culture, people in ethnic areas generally have awe for nature. The government can create a new communication paradigm of "ecology-energy-culture" by embedding new energy themes in traditional ethnic festivals. Popularize the environmental significance and ecological benefits of multi-energy complementary power generation in ethnic areas. And establish a "new energy ecological guardian" system, give priority to hiring local residents to participate in photovoltaic panel cleaning, vegetation management and other work, so as to increase the participation of the public in ethnic minority areas. Encourage them to actively participate in the construction and supervision of multi-energy complementary power generation projects, and form a good atmosphere for the joint participation of the government, enterprises and ethnic minority people.

Through the implementation of these policy recommendations, not only can the development of multi-energy complementary power generation projects in ethnic minority areas be effectively promoted, but also the improvement of the local ecological environment and the realization of carbon emission reduction targets can be promoted, contributing to the construction of a green and low-carbon energy system and sustainable social economy in ethnic minority areas.

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