CASE STUDY

On the use of techno-economic evaluation on typical integrated energy technologies matching different companies

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Abstract
This paper mainly establishes the cost-benefit model for techno-economic evaluation on typical integrated energy technologies matching different companies including photovoltaic, electric heat storage, ground source heat pump etc. The techno-economic evaluation indicators such as net present value, investment payback period, and financial internal rate of return are considered. The proposed evaluation method is applied to separately analyze two real companies such as poultry and wood industry to conduct integrated energy technology matching, and then to analyze whether the configuration plan is feasible. The energy consumption and nature of the two enterprises are different, and the matched integrated energy technologies and the corresponding magnitudes are different. The results of the real case analyses show that the use of integrated energy technology will improve energy efficiency and reduce the energy costs.

1 | INTRODUCTION

The world’s total energy consumption is constantly increasing, energy has become a national and regional strategic resource, and the energy technology revolution has become an inevitable trend. In the context of energy reform, China’s energy-related industries are actively innovating from top to bottom to promote the efficient and rational use of energy. Among them, the users of industry or commercial companies, as the focus of energy consumption and the centralized application of integrated energy technologies, are in the frontier of energy revolution.

There have been a large number of actual cases of integrated energy services in Europe [1]. Although some leading companies in China, such as China Southern Grid, provided practical experience for building comprehensive energy projects, the overall progress was still slower than that of foreign countries [2]. Countries, such as Japan, the United States, and some European countries realized the broader prospects of developing integrated energy projects earlier, and their integrated energy projects developed more maturely [3–5]. China [6] proposed a single integrated energy service system and a cost-effective model of photovoltaic for steel structure workshops, and carried out multi-angle analysis. References [7, 8] have established cost-benefit models of ground-source heat pumps for economic analysis of technology. Literature [9] analyzed the cost-benefit evaluation for electric heat storage systems based on real data, while lacked of theoretical analysis. Taking into account the economic evaluation on energy technologies [10], including the economic evaluation on the energy storage system [11, 12], the techno-economic evaluation on the building photovoltaic system during peak and off-peak hours [13], and the techno-economic evaluation on the recovery of the refinery torch gas [14], Literature [15] concluded the economic evaluation on the grid-connected technology from the perspectives of net cost, energy sales and other costs. It can be obtained that current literatures mainly focus on the economic evaluations of a single technology, while the technology matching and its economic evaluation have not been taken into account yet.

In order to meet the development needs of the integrated energy system in the companies, from the perspective of marketing, the current research still has problems with the economics of multiple integrated energy technologies, which restricts the development of customized integrated energy
business. Meanwhile, from the above research and analysis, it can be seen that the cost-benefit analysis is performed on a single integrated energy system. At present, the related research on integrated energy systems has not been considered in the paper.

In view of the above problems, this paper establishes the cost-benefit model for techno-economic evaluation on typical integrated energy technologies. The techno-economic evaluation indicators such as net present value, investment payback period, and financial internal rate of return are considered. The evaluation is used to achieve the goal of successful technology matching for the company, and to improve the energy utilization efficiency and user experience of the target company. Due to the different energy consumption and nature of two real enterprises, the matched integrated energy technologies and the corresponding magnitudes are analyzed.

The remainder of the paper is organized as follows. Section 2 initially establishes the cost-benefit model for different integrated energy technologies. Afterwards, Section 3 presents the techno-economic evaluation indicators. Section 4 demonstrates the energy consumption analysis of two real companies. Next, Section 5 discusses the example analysis. Finally, Section 6 concludes the paper.

## 2 | COST-BENEFIT ANALYSIS MODEL OF TYPICAL INTEGRATED ENERGY TECHNOLOGY

This section firstly analyzes the main factors for cost-benefit analysis, and then establishes a general mathematical model of different integrated energy technologies in different stages, including photovoltaics, heat pumps, and electric heat storage. Combined with actual situations, the cost-benefit models are proposed.

### 2.1 | Integrated energy cost analysis

#### 2.1.1 | Construction stage

In general, the construction cost is all the expenses incurred during the construction stage of the project, including the engineering construction cost, environmental cost and equipment cost. At this stage, the construction period is short, and the construction costs of integrated energy projects generally include civil construction costs, equipment purchase costs, water supply and drainage costs, installation costs, pipeline facilities costs, lease costs etc. The major cost factors to consider are shown in formula (1). The initial construction cost of an integrated energy project is expressed as follows:

\[
C_0 = C_{eq} + C_{le} + C_{0}.
\]

where \(C_0\) is the total costs of the construction stage, \(C_{eq}\) is the equipment costs, \(C_{le}\) is the installation costs, \(C_0\) is the lease costs.

#### 2.1.2 | Operation and maintenance stage

The cost of the operation and maintenance stage is the operating cost, including all the costs incurred during the operation stage of the integrated energy project. This stage is the one with the longest cycle. During this period, the most important of operating costs are the following five costs. Financial costs mainly aim at the large initial investment costs, and a loan is required to generate annual loan interest. The operation and maintenance cost basically refer to the maintenance cost of the equipment during operation, and usually refer to the dust removal cost. Therefore, the annual operating cost of a comprehensive energy project is expressed as follows:

\[
C_1 = C_{fi} + C_{em} + C_{re} + C_{ru} + C_{al},
\]

\[
C_{em} = C_{0}R_1,
\]

\[
C_{re} = C_{0}R_2,
\]

where \(C_1\) is the total operation and maintenance costs, \(C_{fi}\) is the financial costs, \(C_{em}\) is the costs of operation and maintenance, \(C_{re}\) is the employee costs. \(C_{ru}\) is the running costs, \(C_{al}\) is the electricity costs, \(R_1\) is the operating expense rate, \(R_2\) is the employee expense rate.

#### 2.1.3 | Scrap recycling stage

The scrap recycling stage is mainly the stage when the integrated energy system cannot continue to be used in accordance with normal functions and is disposed of as scrap. Its cost mainly refers to the cost incurred in purchasing the corresponding equipment for replacement. The income from the scrapped and recovered equipment refers to the residual value. The salvage value rate of fixed assets is generally taken as 10%.

\[
C_2 = C_{re} - C_{ru},
\]

where \(C_0\) is the total costs of the scrap recycling stage, \(C_{re}\) is the replacement costs, \(C_{ru}\) is the salvage value.

### 2.2 | Integrated energy efficiency analysis

#### 2.2.1 | Economic benefits

For integrated energy projects, the amount of energy mainly refers to the amount of electricity, heat etc. The amount of power generation is directly related to the installed capacity. The annual power generation is an important dynamic indicator of economic evaluation. In the case of a large amount of on-grid electricity, all electricity generation uses the model of system trading. When calculating economic benefits, it is necessary to calculate according to the local electricity price and amount. According to the economic benefits, in actual projects,
the annual economic benefits is:

\[ S = Q \times \psi + Q_i \times P, \]  

where \( Q \) is the amount of electricity that the integrated energy enjoys the state subsidy each year, in kw/h; \( \psi \) is the state subsidy amount; \( Q_i \) is the integrated energy amount; \( P \) is the energy price.

### 2.2.2 Environmental benefits

This section analyzes the environmental benefits of this part by introducing “carbon emissions trading”. Through analysis, the environmental benefits can be obtained as:

\[ S_i = XQ \times \bar{P}_i, \]  

where \( X \) is determined according to the amount of carbon dioxide reduced by different integrated energy technologies, \( S_i \) is the environmental benefit of the \( i \)th year, \( \bar{P}_i \) is the average price of carbon emissions trading in the \( i \)th year.

### 3 TECHNO-ECONOMIC EVALUATION INDICES

The integrated energy planning and construction of the companies focus on the economic benefits. This paper proposes a techno-economic evaluation method, considering the net present value method, the payback period, and the financial internal rate of return in order to evaluate the economic feasibility of the company’s energy transformation. The specific description is as follows.

#### 3.1 Net present value method

The net present value (NPV) indicator is one of the important indicators for dynamic evaluation of investment programs. After calculating the cash flows that occur each year during the life of the plan, and discounting the net cash flows of each year to the same point in time (usually the beginning of the period) at a certain discount rate, the algebraic sum of the present value of each year is the net present value The expression is:

\[ NPV = \sum_{i=1}^{n} \frac{(CI - CO)_i}{(1 + i)^t}, \]  

where \( CI \) is the return on investment, \( CO \) is the total initial investment, \( i \) is the benchmark rate of return, 10\%, \( n \) is the life of the scheme, \( (P/F, i, t) = (1 + i)^{-t} \) finds the discount coefficient of the present value \( P \) from the future value \( F \).

The above formula shows that the net present value of the scheme can also be expressed as the sum of the present value of the net income from year to year within the useful life. \( NPV > 0 \) means that the scheme not only achieves the benchmark rate of return and the investment is recovered. The greater the net present value, the better the scheme’s return; \( NPV = 0 \) means that the scheme has achieved the benchmark rate of return and reached the predetermined target, and the scheme is also feasible; \( NPV < 0 \) means that the investment plan cannot achieve the benchmark rate of return. Not only cannot the original investment be recovered, but also a loss, the plan is not feasible.

The net present value indicator considers the time value of the capital flow of investment projects, and reasonably reflects the real economic value of investment projects. It is a relatively good investment decision indicator.

#### 3.2 Payback period of investment

The investment payback period is divided into two types: static investment payback period and dynamic investment payback period. The static investment payback period refers to all the time required to offset the total investment of the original project with the operating cash flow of the investment project. The payback period can be calculated from the year when the investment is started, or from the year when the investment is started. The static payback period is as follows:

\[ P_i = (Y - 1) + \frac{|X|}{Z}, \]  

where \( Y \) is the number of years in which the cumulative net cash flow is positive, \( X \) is the absolute value of the cumulative cash flow for the previous year, \( Z \) is the net cash flow of the year.

The static investment payback period is clear and easy to understand, and the calculation is also convenient. To some extent, it indicates the turnover rate of capital and indirectly reflects the operating status of an company and its ability to deal with risks. The faster the capital turnover, the lower the risk, and the stronger the technical solution’s ability to resist risks. Therefore, in the process of evaluating the economic effects of project schemes, the static investment payback period is generally calculated to reflect the compensation rate and investment risk of the original investment of the technical scheme, and to determine a control range for the actual investment in the later period.

#### 3.3 Financial internal rate of return

The internal rate of return (IRR) is the discount rate when the total present value of capital inflows is equal to the total present value of capital flows and the net present value is zero. The larger the evaluation index, the better. The internal rate of return is divided into financial internal rate of return (FIRR) and economic internal rate of return (EIRR). The paper uses financial internal rate of return to evaluate economic benefits. Which is shown as follows:

\[ \sum_{i=1}^{n} \frac{(CI - CO)_i}{(1 + FIRR)^t} = 0, \]
where $FIRR$ is the internal rate of return, $CI$ is the cash inflows, $CO$ is the cash outflow, $(CI - CO)_t$ is the net cash flow for period $t$.

In engineering economics, the financial internal rate of return is an important dynamic evaluation index for examining the profitability of engineering projects. During the calculation period, it is always in the situation of repaying the unrecovered investment, which can reflect its own profitability.

### 4 | INTRODUCTION OF BASIC ENERGY CONSUMPTION OF COMPANIES

#### 4.1 | Energy consumption of a poultry company

A poultry company in Henan, China is investigated as the first example. The main energy load is electricity, heat and cold load.

The survey data is that in four weeks of different seasons in Figure 1. One week's power consumption is used to represent the power consumption of a month, and then one season's power consumption is characterized.

From peak-level-valley power consumption graphs in Figure 2, it can be known that the peak-day power consumption is the highest in winter, with peak power up to 1,000,000 KWh, and the lowest in summer, about 200,000 KWh. Peak power consumption in spring remained basically stable, fluctuating around 760,000 KWh. The level electricity consumption in autumn is slightly lower than the peak or valley electricity consumption, less than 600,000 KWh. The company's demand for cold load and heat load is not low, and it needs electric load to convert. Thus the company has the potential for integrated energy services.

#### 4.2 | Energy consumption of a wood product company

A wood product company in Henan, China is investigated as the second example. The main energy load is electricity and heat load.

As can be seen from the figure 3, as the season continues to progress, the power consumption is gradually decreasing. This is because the company has just operated for less than a year, and the peak power consumption in winter is much smaller than in spring in Figure 4. The highest power consumption in spring, which is almost close to 120,000 kWh, However, the minimum power consumption in winter is less than 20,000 KWh, which may be related to the company's informal operation in winter. After the company is on the right track, the power consumption should be much higher than the data obtained by the current investigation. Thus, the company has the potential for integrated energy services.

### 5 | EXAMPLES

#### 5.1 | Technology matching analysis of a poultry company

According to the case analysis of the company, the load demand of the company is cold, heat, and electricity. The ratio of
electricity used for heating and cooling to the total electricity is 3:2 in Figure 5, which is 860,352 KWh for heating and 573,568 KWh for cooling, and the energy efficiency ratio is 2. The annual heating capacity is 1,720,704 KWh and the annual cooling capacity is 1,147,136 KWh. Because the power load of the company is generally concentrated during the day and there is a demand for cold and heat loads every day. Meanwhile, the ground where the company is located has geothermal conditions. Therefore, it can be considered to carry out photovoltaic and ground source heat pump integrated energy transformation.

5.1.1 Analysis of economic benefits of photovoltaic technology

The cost price of the equipment is obtained after investigation. Based on the cost ratio and practical application of multiple projects, the cost overview is established, as shown in Table 1. The calculated benefits are shown in Table 2. The heat pump's related data is shown in Table 3 and Table 5. The final results are shown in Table 4 and Table 6.

Based on the above cost-benefit analysis of photovoltaic, the annual cash flow can be obtained in Figure 6. Draw the profit and loss bar chart for 10 years as shown in the following figure:

According to the economic analysis related indicators mentioned in Section 3.2, which are related calculation formulas, mainly analyze the net present value and investment payback period. The available investment payback period is 9.1 + 288.3/354.5 = 8.81 years. Due to the limited data, after 10 years, the net present value is −360.8, which is less than 0. This does not mean that the solution is not feasible, and 25 years in photovoltaic modules during the life cycle, the NPF will inevitably be greater than 0 before 15 years. In year 15, the net present value reached 1421.4, which is much higher than zero. Through the above analysis, photovoltaic projects have great investment value.

5.1.2 Analysis of economic benefits of ground source heat pump technology

The ground source heat pump is used for cold and heat load supply. Since the company has built its own cold storage, the ground source heat pump is installed close to the cold storage to facilitate cooling. The ground source heat pump unit eliminates the traditional boiler room and has no combustion pro-

### Table 1
| Equipment cost | Residual value benefit | $367,605 |
|----------------|------------------------|----------|
| Installation cost | Total peak power | 6432.4 MWh |
| Leasing cost | Total valley power | 2718.45 MWh |
| Financial costs | Total level power | 159.8 MWh |
| Maintenance cost | on-grid price | $0.08/KWh |
| Employees cost | Subsidy price | $0.014/KWh |
| Replacement cost | Carbon trading price | $1.2/ton |

### Table 2
| Construction cost | O & M cost | Scrap recovery cost | Economic benefits | Environmental benefits |
|-------------------|------------|---------------------|-------------------|-----------------------|
| $3676056          | $42131690  | $325352             | $588,882           | $7821                 |

### Table 3
| Equipment cost | Replacement cost | 0 |
|----------------|------------------|---|
| Installation cost | Residual value benefit | $1944 |
| Operating costs | Daily water consumption | 400 tons |
| Maintenance cost | Hot water price | $1.1/ton |

### Table 4
| Construction cost | O & M cost | Scrap recovery cost | Economic benefits | Environmental benefits |
|-------------------|------------|---------------------|-------------------|-----------------------|
| $19,437           | $245,592   | $1944               | $161,408          | $849                  |

### Table 5
| Equipment cost | Replacement cost | 0 |
|----------------|------------------|---|
| Installation cost | Residual value benefit | $282 |
| Computer room cost | Heat storage | 584 MWh |
| Electricity cost | Sell hot price | $3.7/GJ |
| Employees cost | Subsidy price | $0.02/KWh |
| energy used | 389 MWh |

### Table 6
| Construction cost | O & M cost | Scrap recovery cost | Economic benefits | Environmental benefits |
|-------------------|------------|---------------------|-------------------|-----------------------|
| $2817             | $20,141    | $282                | $83,570           | $202                  |
cess to avoid dust pollution. The working time of the company is 8:00 am to 5:00 pm. The production line continues to work for 10 h for 365 days a year. The annual heating capacity is 1,698,240 KWh, annual cooling capacity is 1,573,800 KWh. It is known that the use of the heat pump is able to meet the basic cold and heat load requirements of the company.

According to the above cost benefit analysis of ground source heat pump, the annual cash flow can be obtained. A 20-year profit and loss bar chart is shown as below. As can be seen in Figure 7, at the beginning, the company was in negative profit for a long time, however, after year 18, the profit soared, and the capital quickly returned. According to the economic analysis related indicators mentioned in Section 3.2, which are related calculation formulas, mainly analyze the net present value and investment payback period. The available payback period is 18-1 + 1.51 / 89.64 = 17.02 years. Due to the limited data, only 20 years are listed. The net present value is 3.17, which is greater than 0. The heat pump life cycle is generally 40–50 years. According to the above analysis, this program has great investment value.

By combination integrated energy and can be seen in Figure 8, the intersection of the horizontal axis than PV to the right, that longer payback period, but no significant changes, the economic benefits of using combination of integrated energy less than only using PV, about 17 years, the benefit is higher than that of PV, it is because of the heat pump is a situation with a positive cash flow. In this project, although the investment payback period is slightly longer, the economic benefits have been significantly improved after 17 years, indicating that the combination is better than the single integrated energy technology.

In view of the above analyses, it is feasible to conclude that photovoltaic + plus heat pump energy transformation for a poultry industry company.

5.2 Technology matching analysis of a wooden products company

According to the case analysis of the company, since the company is mainly engaged in the production of furniture raw materials, the load demand is basically heat and electricity. The proportion of electricity used for heating to the total electricity is 1:2 in Figure 9, which means that the electricity used for heating is 357,532 KWh. The energy efficiency ratio is 1.5, and the annual heating capacity is 536,298 KWh. Due to the huge heat load demand of the company, the use of electric thermal storage devices will maximize the use of valley electricity, further reducing peak-hour power consumption, and thus resulting in huge energy saving and economic benefits. Therefore, it is possible to consider the integrated energy transformation of electric thermal storage.

According to the above cost-benefit analysis of electric heat storage, it is obvious that the benefit in the first year is greater than the cost, and the payback period of investment is 1 year. The net present value is 39.25, which is greater than 0, indicating that the scheme of using electric heat storage device is of investment value.

For a wood products company, it is highly desirable to adopt an electric heat energy storage investment scheme.

6 CONCLUSION

This paper establishes a variety of integrated energy technology cost-benefit models and related techno-economic evaluation method. The integrated energy technologies include photovoltaic, ground-source heat pump, and electric heat storage. Considering the field investigation of two companies in Henan, China, the integrated energy technology matching and techno-economic evaluation are conducted. The integrated energy transformation plans are suggested for the two companies. The
photovoltaic and ground-source heat pump are suggested for the poultry company, and the electric heat storage is suggested for the wood product company. The example analysis has validated the effectiveness and feasibility of the proposed techno-economic evaluation method.

In the following research, the optimization algorithm will be considered to solve relevant optimization problems, and the related storage device optimization can be used in the subsequent research on the matched company.

Since different integrated energy systems are with specific characteristics and personalized demands, a set of typical demo systems and typical integrated energy technologies (with different parameters) is the future work of this paper.

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