Economic Verification of Hybrid Energy Utilizations with HOMER Pro

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Abstract. This study gives emphasis to the economic analysis of hybrid Energy systems which are gradually paid attention by researchers worldwide as a new way to cope with climate change and sustainable development. The economic cost is an important feature that restricts the development of hybrid energy system. The purpose of this study is to verify the economic characteristics of hybrid energy system with HOMER Pro software. Firstly, the economic characteristics of different single energy sources are investigated. Secondly, the economic performances of different hybrid energy systems are analyzed and compared. The research results show that our simulations based on HOMER Pro software have good agreement with those in reference cases. In the future, a unified economy evaluation will be carried out for these hybrid energy utilizations.

1. Introduction
The Energy Information Administration (EIA) has predicted that world energy consumption rises 28% in the next two decades in the reference cases with most of the increase occurring in non-OECD countries [1], where strong economic growth, increased access to marketed energy, and quickly growing populations lead to rising demand for energy. Global primary energy consumption increased by 2.9% in 2018 [2], in which natural gas increments accounted for the largest proportion of 43%, renewable energy is 18%, followed by oil, coal, hydropower and nuclear energy. In recent years, people have paid more and more attention to environmental protection and climate change. The consumption of fossil energy is a major factor in carbon emissions. The Intergovernmental Panel on Climate Change has found that emissions from fossil fuels are the dominant cause of global warming. In 2018, 84% of global CO₂ emissions came from fossil fuels [3]. Meanwhile, renewable energy has the characteristics of green, clean and low-emission, national policy-makers are actively introduced policies to encourage renewable energy, greatly promoted the development of renewable energy. Renewable energy accounted for one third of the net increase in power generation, followed closely by coal (31%) and then natural gas (25%) [3]. The share of renewables in power generation increased to 26% in the world. Coal still accounted for the largest share of power generation at 38% in the primary energy consumption of global [3]. Although fossil energy may cause environmental problems, its proportion is still considerable. At the same time, Renewable energy sources, especially solar and wind energy, are dependent on geographical constraints and climatic conditions that limit its applicability, and the economy needs to be further improved. Moreover, the actual technological development relies heavily on policy subsidies, resulting
in economic benefits that are not prominent and difficult to change in a short period. Therefore, it is a good choice to combine different forms of energy, that is, hybrid energy.

The advantages of hybrid energy systems are also emerging. The combination of multiple energy sources provides a solution to the needs of many aspects of energy in real life, such as electricity and heat [4]. While, the design of the micro-grid provides the option of decentralized power generation [5], which is highly adaptable in solving local energy needs and can be adjusted according to the actual situation. The addition of energy storage modules helps to regulate electricity and enhance the adaptability of micro-grids. The surplus energy is stored by using energy storage equipment such as a battery pack and a hydrogen storage tank to use at peak electricity usage, which reduce unnecessary energy waste. Hybrid energy can also play a role in different environments, which increases the adaptability of energy, and can be used in an environment incapable of a single energy source to achieve expanded applications and propose new solutions in remote areas [6]. However, there are currently several problems in the research of hybrid energy. Economically, although many research cases have shown that hybrid energy has a better economic performance [7] and can be compared with general single energy sources, the overall economic performance as a new form of energy is doubtful. Because it is well known that the additional cost caused by the combination of different energy sources, such as coupling devices, is not yet clear on the overall economic impact. Further analysis needs to be done. However, some researches prefer those cases with good performance and affect the final conclusion. Technically, the design of hybrid energy is not necessarily feasible. Different energy sources have their own unique characteristics and working conditions, which can only be determined according to specific actual conditions.

This paper discussed the economics issue of some cases of hybrid energy system. Firstly, by simulating the single energy source with HOMER Pro software, the Levelized Cost Of Electricity (LCOE) value is obtained for the corresponding energy in the working environment. Then, the HOMER Pro was used to verify several designs of hybrid energy system, according to the corresponding parameters [6]. The results showed that the model verification data is basically consistent with the reference data. In addition, the differences have been discussed regarding some special aspects, such as deficiency of configuration data in detail and regardingless of refuelling of NPP [8]. In future research, unified macroeconomic parameters will be used on the existing basis, and data will be compared under specific working conditions in order to obtain economic characteristics under the same conditions.

2. Methodology and System Modeling

The economic feasibility of study is implemented with computer-aided energy simulation tool named HOMER Pro, with various load profile, climate resources data and economic data as inputs. The system modeling of energy system involves system control and constraints. Simulation, optimization and sensitivity analysis are the three main functional contents, which are analyzed in the simulation results and analysis section. Additionally, the existing electricity performance, economics and emissions are considered according to actual modeling requirements.

2.1. HOMER Pro

Hybrid Optimization Model for Electric Renewables (HOMER) is a kind of computer-aided tool designed by HOMER Energy LLC. The HOMER Pro micro-grid software is the global standard for optimizing micro-grid design in all sectors, from village power and island utilities to grid-connected campuses and military bases [9]. HOMER Pro simulates energy systems, shows system configurations optimized by cost, and provides sensitivity analysis [9].

HOMER Pro simulates the operation of an energy system for entire lifetime, in time steps from one minute to one hour. It makes the calculations of energy flow balance with each part of system and compares the electric, thermal and hydrogen load in each time step to the energy that the system can supply in the same time step. HOMER Pro also makes the operation strategy to run the generators and controls the energy storage device to input or output in the system with various batteries, supercapacitor, flywheel and pumped hydro storage. The system cost calculations incorporate costs such as capital, replacement, operation and maintenance, fuel, and interest.
HOMER Pro simulates all of the feasible system configurations for every solved case defined by the search space and ranks all the feasible solutions that satisfies the user-specified restrictions at the lowest total net present cost [10]. In particular, the software has another optimization algorithm named HOMER Optimizer with a proprietary derivative-free algorithm to search for the least-costly system. But not all components can provide the option of using HOMER Optimizer at present. Sensitivity analysis helps to assess the effects of uncertainty or changes in the variables such as lifetime, fuel price, discount rate, etc. HOMER redoes above-mentioned optimization process for multiple value of the variable and reveal how the results are affected. An input variable is called a sensitivity variable.

2.2. A custom component for nuclear power

HOMER Pro provides a variety of energy modules for users to use, but there are still some energy sources such as nuclear power plants that cannot be used directly. For this, HOMER Pro provides a custom component to facilitate users to build modules that meet actual needs. The Custom Component page provides four options (Renewable Power Source, MATLAB Component, Non-renewable Power Source and Power Purchase Agreement) for creating your own customized component. There is no specialised nuclear energy module in the original software. This study chose Non-renewable Power Source property to realize the simulation of nuclear power plant by setting the output parameters of the custom module. It is necessary to add output power data files to simulate the output characteristics of nuclear power plants as shown in Figure 1.

![Figure 1. Custom Component for NPP (Nuclear power plant) module.](image)

This table can be found at “Custom” page of the “Resource” component to import power output data of nuclear power plant.

2.3. Generalities on economic criteria for energy projects

The Net Present Cost (NPC) is used to represent the life-cycle cost of energy system in HOMER Pro, which ranks all systems according to the total NPC of the system. The NPC is the sum of all the expenses and incomes with future cash flows discounted back to the present using the discount rate, which occur within the project lifetime [10]. The total NPC is comprised of initial capital costs, replacement costs, operations & maintenance costs and fuel costs in addition to the cost of buying power from the grid and also the other costs such as compensation resulting from emissions. The
incomes consist of earning from selling power to the grid and any salvage value that occurs at the end of the project lifetime \([10]\).

The following equation is used to estimate NPC:

$$NPC = \frac{C_{\text{tot},\text{ann}}}{CRF}$$

(1)

where, \(C_{\text{tot},\text{ann}}\) is the total annualized cost and \(CRF\) is capital recovery factor which is estimated by the following equation:

$$CRF = \frac{i(1+i)^N}{i(1+i)^N - 1}$$

(2)

where, ‘\(i\)’ is the annual interest rate (\%) and \(N\) is the project lifetime (years) \([10]\).

The full life-cycle costs (fixed and variable) of a power generating technology per unit of electricity (kWh) are often called the levelized costs of electricity (LCOE). The following equation is used to estimate LCOE:

$$LCOE = \frac{C_{\text{inv,ann}} + C_{\text{rep,ann}} + C_{\text{O&M}}}{E}$$

(3)

where, \(E\) is the annual energy output of the system (kWh/year); \(C_{\text{inv,ann}}\) is the annual investment of the system; \(C_{\text{rep,ann}}\) is the replacement cost; \(C_{\text{O&M}}\) is the operational and maintenance cost of the system; The environmental emission cost can be calculated according to the actual demand.

The LCOE analysis of energy system is an important decision-making basis, so it is necessary to gradually establish a unified economic accounting system. Compared with single energy form, hybrid energy systems have more advantage. In terms of energy composition, hybrid energy systems have traditional energy mature technologies and relatively stable economic costs. While the current trend of renewable energy costs is gradually reduced, effectively reducing the variable cost of operation and maintenance.

3. Results

3.1. Economic performance analysis of single energy

The study of economic analysis of single energy has conducted this analysis comparing the LCOE for various power generation technologies in order to understand which different power generation technologies may be cost-competitive with each other.

Different types of single energy are converted into characteristic indicators under unified measurement standards through LCOE calculation. Because for a single energy source, the specific LCOE characteristics are closely related to the scenario, design and location. So only the corresponding range can be given in Table 1.
Figure 2. LCOE comparison of different energy forms (Source: OpenEI database) [11].

As Figure 2, the LCOEs of different single energies were attained from Transparent Cost Database in OpenEI database [11]. It can be seen that the LCOE distribution of different energy sources is quite different. Photovoltaic (PV) power ranges from 0.06$/kWh to 0.56$/kWh influenced by solar panel materials, geographic location of installation and size of power station, which is similar with natural gas turbine. Wind power, which is relatively low compared to solar energy, is usually around 0.1$/kWh. Traditional fossil energy still has a comparative advantage without considering environmental protection costs. The LCOE of coal and natural gas respectively are 0.09$/kWh and 0.07$/kWh as median values.

For better comparison, we define unify economic parameters, such as discount rate 7%, tax rate 28% and depreciation rates 83%, and uses the original data in the references to sort out and calculate the range of LCOE for several common energy forms. Table 1 shows the calculation results.

| Category       | Reference          | LCOE($) /kWh | Source. |
|----------------|--------------------|--------------|---------|
| PV             |                    | 0.030–0.201  | [12],[13],[14]. |
| WT             |                    | 0.029–0.163  | [14]. |
| Nuclear        |                    | 0.022–0.124  | [14],[15],[16],[17]. |
| Geothermal     |                    | 0.029–0.086  | [14]. |
| Nature gas     |                    | 0.026–0.094  | [14]. |
| HT             |                    | 0.030–0.107  | [18],[19]. |
| Coal           |                    | 0.014–0.126  | [14]. |
| Biomass        |                    | 0.052–0.098  | [14]. |

*Note: WT=Wind Turbine
PV=Photovoltaic power
HT= Hydro Turbine

In Table 1, the LCOE of photovoltaic power generation is a wide range that rooftop PV has the highest LCOE of 0.201$/kWh and utility scale PV has the lowest one of 0.03$/kWh. The cost of offshore wind power is about 50% higher than that of onshore wind power. Fossil fuels currently have economic advantages. The LCOE of coal power plant in China is the lowest. However, natural gas in the United States is more economically competitive.
3.2. Economic performance analysis of hybrid energy
In order to study the LCOE characteristics of hybrid energy, this study selects different types of energy combinations for analysis. After reviewing the literatures, the basic parameter configuration of each hybrid energy is obtained in Table 2.

Table 2. Components of economic cost of hybrid energy in different cases

| Cases                  | Initial Capacity         | O&M Cost   | Fuel          | Lifetime | Interest rate | Discount rate |
|------------------------|--------------------------|------------|---------------|----------|---------------|---------------|
| WT+PV+DT [20]          | PV:0.25–0.35$/Wp         | **         | Diesel: 0.60$/L | 25yr     | 2.01%         | **            |
|                        | WT: 0.125–0.135$/Wp      |            |               |          |               |               |
| WT+PV+Geothermal [21]  | Geo:55,000,000Rs         | 550Rs/h    |               | 15yr     | 5%            | **            |
|                        | PV:13,860,000Rs          | 330,000Rs/yr |               |          |               |               |
|                        | WT:13,860,000Rs          | 341,000Rs/yr |               |          |               |               |
| PV+Biomass [22]        | **                       | **         | Biomass: 1$/L | 25yr     | **            | **            |
| PV+DT [23]             | PV:6,900$/kW             | 1,756$/yr  | Diesel: 0.1$/L | 25yr     | **            | **            |
|                        | Nuclear: 4,637$/kW       |            |               |          |               |               |
|                        | Electroyser: 87,614,000$ kg/sec H2 | | | | | |
|                        | WT: 2,155$/kW            | 19,500,000$/yr | Hydrogen: 2.50$/kg | 20yr | 5% | 17.50% |
|                        | Electrolyser: 34$/kW     |            |               |          |               |               |
| HT+DT [24]             | DT:588$/kW               | Disel:0.04$/h | Disel:1$ | 25yr | 5.88% | 6.00% |
| PV+HT+DT [24]          | PV:781$/kW               |            |              | 25yr | 5.88% | 6.00% |
|                        | DT:588$/kW               | Disel:0.04$/h | Disel:1$ | 25yr | 5.88% | 6.00% |
| PV+Coal [25]           | 300$/kW                  | 0.24$/kW   | Coal: 0.5$/kg | 30yr | 3.92% | ** |
| PV+HT [12]             | 1,257,000€               | 1,202,700€ | None         | 25yr | 6% | ** |

*Note: WT=Wind Turbine
DT=Diesel Turbine
PV=Photovoltaic power
HT=Hydro Turbine

HOMER Pro reconstructs the reference scenario model. Table 2 provides basic cost parameters. The default data is filled with uniform values (discount rate 7%, tax rate 28% and depreciation rates 83%). Comparing the calculated LCOE of the model with those in the reference, the following table is obtained.

Table 3. Deviation analysis between modeling and reference

| Cases                  | NPC        | LCOE        |
|------------------------|------------|-------------|
|                        | Reference (A) | Reference (B) | Deviation value (A-B/B) | Explanation |
| WT+PV+DT [20]          | 10,015$   | 0.161$/kWh | 0.164$/kWh | 1.8% |
| WT+PV+Geothermal [21]  | 244.9MRs  | 7.69Rs/kWh | 7.89Rs/kWh | 2.5% |
| PV+Biomass [22]        | 20,184$   | 0.116$/kWh | 0.0948$/kWh | 2.2% | Cost of electrolyser is incomplete. |
| PV+DT [23]             | 98,911$   | 0.177$/kWh | 0.178$/kWh | 0.5% |
Nuclear power should consider the influence of refueling time on output power.

Cost of coal power is not available in detail.

| Configuration       | Net Power (kW) | Cost ($/kWh)   | Refueling Cost ($/kWh) | Error (%) |
|---------------------|----------------|----------------|------------------------|-----------|
| WT+Nuclear [8]      | 876,602,85750.1342             | 0.1429             | 6.1%                   |
| HT+DT [24]         | 92,441             | 0.0712             | 0.0705                   | 0.99%     |
| PV+HT+DT [24]      | 179,741             | 0.0886             | 0.0875                   | 1.2%      |
| PV+Coal [25]       | 5.0BY              | 0.58               | 0.67                    | 13%       |
| PV+HT [12]         | 3.28M€             | 0.0936€            | 0.092€                  | 0.9%      |

*Note: WT=Wind Turbine, DT=Diesel Turbine, PV=Photovoltaic power, HT= Hydro Turbine*

In Table 3, the comparison of the above figure shows that the economic parameter LCOE calculated using HOMER Pro modeling is basically consistent with the data in the original reference, and the overall error is small. The reason for the error is only due to the default of some data.

The economic evaluation of hybrid energy is generally more complicated, and LCOE calculation can simplify this problem. There is no unified conclusion on the performance of LCOE after mixing different energy sources, and it will generally be between the maximum and minimum values of the LCOE of those single components, but it will also be due to the cost of the necessary joint equipment in the process of combining several single energy sources. The LCOE of hybrid energy is larger than that of each component.

4. Conclusion

According to calculation and analysis, it can be obtained that the verification value obtained by the independent modeling calculation is basically consistent with the reference results, the simulation effect is good, and the overall result is good, but there are still small problems. At present, different models are based on different parameters. In future research, a unified calculation standard will be established to evaluate the performance of different cases under uniform conditions, while sensitivity analysis of hybrid energy can be done.

5. References

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