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Life cycle analysis of wind power: A case of Fuzhou

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Abstract

As an important renewable energy, wind power has been paid more and more attentions in China recent years, in order to weaken the influence of climate change. We should know exactly the benefits wind power can produce, before government formulates relevant policies to accelerate its deployment. In this paper, we calculate the quantity of fossil energy saving and pollutant abatement in its life cycle, comparing with the baseline technology, i.e. 600MW coal-fired thermal power. Considering the damage cost of the pollutants, we can assess the benefits of development of wind power. By our model, we know that wind power can save 0.3839 kgce and avoid 0.203 yuan environmental cost when it generates 1 kWh electric quantity, comparing with coal-fired thermal power.

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Key words: Wind power, LCA, GHG, pollutant emission

1. Background

With the increasing graveness of Climate Change, renewable energies have been paid more and more attentions since 1990s. Compared with traditional fossil energy, renewable energy has many excellences, such as lower GHG and pollutant emission, and less consumption of fossil energy, than traditional energy. However, the cost of renewable energy is usually higher than fossil energy. The inner cost of renewable energy is higher than social cost. In other words, renewable energy has plus externality.

\begin{tabular}{|l|}
\hline
Nomenclature \\
LCA & Life cycle analysis \\
GHG & Greenhouse gas \\
GWEC & Global Wind Energy Council \\
\hline
\end{tabular}

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As an important renewable energy, wind energy is clear and renewable. Besides, wind power is abundant all over the world and relatively cheaper for utilization than other renewable energy, e.g., solar PV. However, the cost of wind power is also higher than traditional coal-fired power, as other renewable energy technologies. In order to accelerate the deployment of wind turbine, government should formulate stimulative policies, such as allowance, tax reduction, etc. Before government institutes relevant policies, it should know exactly the real social cost of wind power. In this paper, authors analyzed the benefits of wind power in its life cycle, compared with traditional coal-fired thermal power.

2. **Introduction of LCA**

LCA- Life cycle assessment, is the investigation and evaluation of the environmental impacts of a given production and service caused or necessitated by its existence. According to the ISO 14040 and 14044 standards, a LCA is usually carried out in four distinct phases. Firstly, explain the goal and scope of research, i.e., define system boundary. Secondly, analyze the inventory of LCA, including parameters of wind turbine, relevant materials and wind resource, etc. Thirdly, assess the impact of wind power in whole life cycle. Of course, in above three phases, researchers should interpret relevant decisions and outcome.

![Fig.1 main phases of LCA](image1)

3. **LCA of wind power**

3.1. **System boundary definition**

The system boundary of wind power for LCA, is defined as Fig.2. The life cycle of wind power includes 4 phases, i.e., manufacture of facility, transportation of facility, installation of facility and plant operation. The indicators include 3 parts: pollutant emissions, including SO₂, NOₓ and PM₁₀; GHG, including CO₂, CH₄, and N₂O; fossil energy depletion, which is shown by coal-equivalence.

![Fig.2. system boundary of LCA of wind power](image2)
3.2. Inventory analysis

The technology of wind power developed rapidly recent years in China. By now, 2MW wind turbine has become the dominating technology in China. Table 1 illustrates relevant data of 2MW wind turbine.

Table 1. relevant parameters of 2MW wind turbine (unit: t)

<table>
<thead>
<tr>
<th>Components</th>
<th>Nacelle</th>
<th>Blade</th>
<th>Tower</th>
<th>Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Steel</td>
<td>epoxy</td>
<td>Glass fiber</td>
<td>Steel</td>
</tr>
<tr>
<td>Weight</td>
<td>90</td>
<td>17</td>
<td>7</td>
<td>120</td>
</tr>
</tbody>
</table>

Resource: Huaneng Group inner data.

The parameters of fossil energy consumptions and pollutant emissions of relevant materials in China, such as steel, epoxy, glass fiber and concrete, are illustrated in Table 2.

Table 2. the parameter of fossil energy consumptions and pollutant emissions of relevant materials (t/t)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Fossil energy consumption (ce)</th>
<th>CO₂</th>
<th>CH₄</th>
<th>N₂O</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>6.290E-01</td>
<td>1.515E+00</td>
<td>0.000E+00</td>
<td>8.572E-06</td>
<td>3.500E-03</td>
<td>1.770E-03</td>
<td>1.730E-03</td>
</tr>
<tr>
<td>Epoxy</td>
<td>3.210E+00</td>
<td>6.900E-01</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>4.160E-03</td>
<td>2.800E-03</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>Glass fiber</td>
<td>6.000E-01</td>
<td>1.129E+00</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>3.500E-03</td>
<td>4.250E-03</td>
<td>1.750E-03</td>
</tr>
<tr>
<td>Concrete</td>
<td>9.500E-02</td>
<td>8.500E-01</td>
<td>0.000E+00</td>
<td>2.100E-05</td>
<td>8.100E-04</td>
<td>2.680E-03</td>
<td>6.590E-03</td>
</tr>
</tbody>
</table>

Resource: relevant industry councils of China.

The parameters of transportation in China are illustrated in Table 3.

Table 3. the parameters of fossil energy consumption and pollutant emissions of transportation (units: t/t)

<table>
<thead>
<tr>
<th>Type</th>
<th>Fossil energy consumption (ce)</th>
<th>CO₂</th>
<th>CH₄</th>
<th>N₂O</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipping</td>
<td>7.14E-01</td>
<td>1.52E+00</td>
<td>7.30E-05</td>
<td>5.04E-04</td>
<td>4.13E-03</td>
<td>2.23E-02</td>
<td>8.26E-04</td>
</tr>
<tr>
<td>Train</td>
<td>3.75E+00</td>
<td>8.92E+00</td>
<td>2.43E-04</td>
<td>1.70E-03</td>
<td>3.37E-02</td>
<td>8.53E-02</td>
<td>7.13E-03</td>
</tr>
<tr>
<td>Truck</td>
<td>7.17E+00</td>
<td>1.52E+01</td>
<td>6.75E-04</td>
<td>6.75E-04</td>
<td>4.15E-02</td>
<td>1.40E-01</td>
<td>4.15E-03</td>
</tr>
</tbody>
</table>

Resource: [1]

3.3. Impact assessment

In this paper, we take a wind farm in Fuzhou for example. The full load hours of turbine are 2000 hours per year. We hypothesize that the main equipments of turbine are produced by Shanghai Electric Group. They are transported from Shanghai to Fuzhou by 750km shipping and 100km truck. The materials for building foundation, i.e. steel and concrete are transported by 100km truck. Basing on above hypothesis, we can get the outcomes as listed in Table 4.
4. Benefits analysis of wind power

In China, the capacity of coal-fired thermal power occupies almost 80% of total capacity. Development of wind power can decrease the capacity of coal-fired power, accordingly save fossil energy consumption and abate pollutant emissions. In this paper, the benefits of wind power refer those caused by the substitution of coal-fired thermal power by wind power, to satisfy people’s power need.

4.1. LCA of coal-fired power

At present, 600MW coal-fired thermal power acts as the main force in power industry in China. Hence, it is selected as the baseline technology, when we assess the benefits of wind power. Its relevant parameters are illustrated in Table.5.

Table.5. the parameters of 600MW coal-fired power plant (unit: t)

<table>
<thead>
<tr>
<th>Component</th>
<th>Boiler</th>
<th>Steam engine</th>
<th>Generator</th>
<th>Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>12700</td>
<td>1630</td>
<td>406</td>
<td>3300</td>
</tr>
</tbody>
</table>

Resource: State power economic research institute

In Table.5, the main components of power plant are produced mostly by steel. Besides, in the phase of building the plant, another 18433t steel and 60625t concrete are needed. In Fuzhou, the steam coal is usually transported from Shanxi, by 2000km shipping, 2300 km train, and 100km truck. The heat quantity of coal is 5000kc/kg. Here, we also hypothesize that, 1) the main equipments are transported from Shanghai Electric Group, by 750km shipping and 100km truck; 2) the materials for building foundation, i.e. steel and concrete are transported by 100km truck.

The parameters of coal consumption and pollutant emissions of 600MW coal-fired thermal power have achieved the advanced level in world. They are illustrated in Table.6.

Table.6. the parameters of coal consumption and pollutant emission of 600MW coal-fired thermal power (unit: kg/kWh)

<table>
<thead>
<tr>
<th>Item</th>
<th>Coal consumption (ce)</th>
<th>CO₂</th>
<th>CH₄</th>
<th>N₂O</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>3.20E-01</td>
<td>9.037E-01</td>
<td>0.000E+00</td>
<td>4.310E-06</td>
<td>5.000E-04</td>
<td>6.000E-04</td>
<td>1.500E-04</td>
</tr>
</tbody>
</table>

Resource: Huaneng Group
4.2. The benefits of wind power

Based on above analysis, we can calculate the fossil energy saving and pollutants abatement of wind power, compared with 600MW coal-fired thermal power. They are illustrated in Table 7.

Table 7. The parameters of fossil energy saving and pollutant abatement of wind power (unit: kg/kWh)

<table>
<thead>
<tr>
<th>Item</th>
<th>Fossil energy consumption(ce)</th>
<th>GHG (CO2 equivalent)</th>
<th>SO2</th>
<th>NOx</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving or abatement quantity</td>
<td>3.839E-01</td>
<td>1.111E+00</td>
<td>8.862E-04</td>
<td>1.645E-03</td>
<td>2.503E-04</td>
</tr>
</tbody>
</table>

In Table 7, GHG abatement includes the total effects of CO2, CH4 and N2O. Hereinto, the greenhouse effect of CH4 is 21 times of CO2; the greenhouse effect of N2O is 270 times of CO2 [2].

In order to let people realize the benefits of wind power clearly, we monetize its effect of pollutant abatement in following text. In order to achieve the objective, of course, we should know the environmental costs of the relevant pollutants. They are illustrated in Table 8.

Table 8. The environmental costs of relevant pollutants

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>GHG (CO2 equivalent)</th>
<th>SO2</th>
<th>NOx</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price(yuan/t)</td>
<td>170</td>
<td>6320</td>
<td>6320</td>
<td>2750</td>
</tr>
</tbody>
</table>

Resource: [3], [4]

The assessment of environmental costs of GHG and pollutants is a complicated task. In our paper, we use other’s research outcomes for reference. Then, we can know that 0.203 yuan environmental cost per kWh can be avoided, when wind power substitutes the coal-fired thermal power.

5. Conclusion

In this paper, we calculated fossil energy consumption and pollutant emissions of wind power in life cycle, basing on the data of a wind farm in Fuzhou. Comparing with traditional coal-fired thermal power, wind power can save 0.3839 kgce and avoid 0.203 yuan environmental cost in life cycle, when it produces 1 kWh electric quantity. From above research, we can conclude that wind power is an effective energy technology, considering its social cost. And government should formulate stimulative policies to accelerate the deployment of wind turbine.

References