Environmental Benefit Assessment under the Vision of Global Energy Interconnection

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Abstract. Under the vision of Global Energy Interconnection (GEI), which can optimally allocate global resources and bring huge positive benefits to ecological environment, this paper proposes interconnection and disconnection power planning scenarios. By establishing a GEI environmental benefit assessment index system, benefits like resource saving, atmospheric pollutant emission reduction and combating to climate change benefits, can be evaluated quantitatively. The results indicated that, GEI could not only bring huge resource conservation benefits and conventional pollutant emission reduction benefits, but also ease global climate change by achieving the goal of 2 degree Centigrade global temperature rise control under the interconnection scenario.

1. Introduction

Currently, global energy development is facing severe challenges, such as resource shortage, environmental pollution and greenhouse gas emission, which leads to traditional energy development mode based on fossil energy being unsustainable. Developing clean-oriented energy system will become main trend of global energy development, and by LIU Zhenya’s [1] proposal, the construction of GEI will facilitate a large-scale development and exploitation as well as a wide-scope coordination and balance of clean energy, promote energy revolution and sustainable development, and thoroughly solve the problems that restrict the development of human society involving energy security, environmental pollution and greenhouse gas emission.

At present, scholars have done relevant researches on key technologies, operation mechanism, policy guarantee system and social benefit evaluation of GEI. TIAN [2] proposed key technologies of the energy Internet based on practices and researches of energy Internet (including GEI) in Europe, the United States and China. LI [3] explored some new investment and financing mechanism, market mechanism, collaborative innovation mechanism and construction of organization safeguard mechanism in the process of GEI development. WANG [4] studied GEI policy guarantee system. ZONG [5] built GEI society benefit evaluation system based on pressure-state-response model and evaluated social benefits through "clean energy replacement", grid network optimization and "electricity replacement" by using china’s smart grid construction data. ZHOU [6] recited the necessity of building GEI and qualitatively analyzed impacts of GEI on natural environment, public life and social change.

Nowadays, studies of quantitative assessment of environmental benefits for GEI are lack. In view of GEI conception, this paper established interconnection and disconnection power planning scenarios, by comparison of two scenarios, qualitative analysis impacts of construction GEI to resource consumption, pollutant emissions and climate change has been done and an environmental assessment
index system has been built. Then, modularization model of environment benefit evaluation was built, and quantitative evaluation has been done.

2. Vision of GEI and Power Planning Scenario
As proposed by LIU Zhenya in [1], GEI is a globally interconnected strong and smart grid with UHV grid as the backbone, which will serve as a platform for extensive development, deployment and utilization of clean energy globally. It can make an overall development, allocation and utilization of global energy, ensure the safe, clean, efficient and sustainable supply of global energy, and realize the coordinated development of energy resources, economy, society and environment. Vision of GEI in 2050 is shown in figure 1.

![Figure 1. Vision of Global Energy Interconnection in 2050.](image)

Considering different boundaries of clean energy development goals and intercontinental interconnection, this paper builds two power development scenarios as interconnection scenario and disconnection scenario, global power capacity of these two scenarios are shown in table 1. The disconnection scenario refers to fulfill of countries’ commitments of reduce emissions and accomplishment goals of renewable energy development, which will lead global clean energy proportion to be double from the 2010 level in 2050. In this scenario, continents are not connected, and balance of power supply and demand and emission reduction targets of each continents will be achieved mainly dependent on their own energy resources. The interconnection scenario can promote clean energy high proportion development and drive global energy transformation. Emerging economies and other major developing countries will do harder to reduce carbon emissions, which leads global clean energy accounting for a higher proportion of primary energy consumption, and basically complete the GEI in 2050.

| Power Capacity (10^6×kWh) | Interconnection Scenario | Disconnection Scenario |
|----------------------------|--------------------------|------------------------|
|                            | 2030 | 2030 | 2030 | 2030 | 2040 | 2050 |
| Coal                       | 11.4 | 7.3  | 4.3  | 11.4 | 7.3  | 4.8  |
| Gas                        | 22.0 | 19.7 | 17.9 | 30.1 | 31.6 | 34.8 |
| Nuclear                    | 5.7  | 9.2  | 10.8 | 5.8  | 7.5  | 8.2  |
| Hydro                      | 17.6 | 25.1 | 36.1 | 15.9 | 25.6 | 37.1 |
| Wind                       | 16.0 | 20.5 | 32.5 | 9.1  | 14.7 | 45.6 |
| Solar                      | 9.4  | 53.0 | 114.6| 5.8  | 37.3 | 83.3 |
| Sum                        | 83.5 | 136.0| 217.6| 79.6 | 125.3| 215.2|

| Power Demand (10^12×kWh) | 2030 | 2030 | 2030 | 2030 | 2040 | 2050 |
|---------------------------|------|------|------|------|------|------|
| Sum                       | 33   | 43   | 57   | 33   | 43   | 57   |
3. GEI Environmental Benefit Assessment Index and Model

Through power transmission across continents, GEI can achieve comprehensive optimization allocation of kinds of resources. As extensive developing the renewable energy bases in "the Arctic and Equatorial" regions, clean energy with wind and solar power as priority will account for higher proportion of global total power generation, meanwhile fossil energy’s proportion will decline. So, environmental benefits can be the following three aspects. Firstly, to reduce consumption of fossil energy, water and land resources. Secondly, to reduce emissions of conventional pollutants such as SO2, NOx and fine particulate matter (PM). Thirdly, to reduce greenhouse gas emissions, and promote global temperature rise control target of 2 degree Centigrade. Based on these, this study designed environmental benefits evaluation indexes, including three primary indicators categories and eight secondary indicators, as shown in figure 2.

![Figure 2. Environmental Benefit Assessment Index.](image)

In this study, GEI environmental benefit assessment model has three modules, including resource saving assessment module, atmospheric pollutant emission reduction assessment module and climate change assessment module. Among them, resource saving and pollutant emission reduction assessment modules are mainly calculated based on whole life cycle factors of each type of power generation technology. And climate change assessment module is using the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) to simulate.

3.1. Resource Saving

Formula (1) is used to calculate global or continental fossil energy consumption of power sector $F_i$.

$$F_i = G_{coal}^i \times r_{coal}^i + G_{gas}^i \times r_{gas}^i$$

Where, $i$ presents the number of every continents. $G_{coal}^i$, $G_{gas}^i$ present coal-fired and gas plants’ generation of continent $i$ in planning period respectively. $r_{coal}^i$, $r_{gas}^i$ present power consumption rate of coal-fired and gas plants respectively of continent $i$.

Formula (2) is used to calculate global or continental water use of power sector $W_j$.

$$W_j = \sum G^j_{water}$$

Where, $j$ presents the number of every power technologies. $G^j_{water}$ presents generation of technology $j$ in planning period. $water_j$ presents water consumption coefficient of technology $j$.

Formula (3) is used to calculate global or continental land use of power sector $L_j$.

$$L_j = \sum G^j_{land}$$

Where, $land_j$ presents land use coefficient of technology $j$. Due to land value of each continents has obvious difference, land value $l_v$ has been defined and calculated by the ratio of regional GDP and land area. Formula (4) is used to calculate global or continental land value of power sector $L_{v_j}$.

$$L_{v_j} = l_v \times \sum G^j_{land}$$

3.2. Atmospheric Pollutant Emission Reduction

Formula (5) is used to calculate global or continental SO2 emission of power sector $S_i$.
Where, $V$ presents flue gas emission level of raw coal, the general value is $9.93 \text{m}^3/\text{kgce}$ as mentioned in [8]. $\lambda_{i,\text{SO2}}$ presents content of $\text{SO}_2$ in per unit volume flue gas of continent $i$.

Formula (6) is used to calculate global or continental NOx emission of power sector $N_i$.

$$N_i = \frac{V}{0.714} \times F_i \times \lambda_{i,\text{NOx}}$$

Where $\lambda_{i,\text{NOx}}$ presents content of NOx in per unit volume flue gas of continent $i$.

Formula (7) is used to calculate global or continental primary PM emission of power sector $PM_i$.

$$PM_i = \frac{V}{0.714} \times F_i \times \lambda_{i,\text{PM}}$$

Where $\lambda_{i,\text{PM}}$ presents content of PM in per unit volume flue gas of continent $i$.

### 3.3. Response to Climate Change

To estimate anthropogenic greenhouse gas emission of different power generation technologies indirectly by use of life cycle and full spectrum emission factor referred to [9] and [10], which measured with CO2 equivalent. To define $E_j$ as energy consumption of power generation, $S_j$ as consumption share of technology $j$, $emf_j$ as the corresponding life cycle and full spectrum emission factor, then total greenhouse gas emission ($E_{\text{GHG}}$) can be estimated as formula (8).

$$E_{\text{GHG}} = \sum_j S_j \cdot emf_j \cdot E_j$$

MAGICC model can be used to simulate the future global temperature change. As introduced in [11], MAGICC is a climate change assessment model which links to atmospheric circulation and climate and melting module, and it is a earliest models referred by IPCC to predict future climate change and sea level rise. Climate model of MAGICC is a diffusion energy balance model interactively coupled with a series of atmospheric circulation models, which can predict greenhouse gas concentration and simulate future global temperature change.

### 4. Calculation Results

#### 4.1. Resource Saving Benefits

According to formula (1) ~ (3), global and continental resource accumulative consumption of two scenarios from 2016 to 2050 is calculated and shown in table 2.

| Region     | Coal Consumption ($10^8\text{tce}$) | Water Use ($10^8\text{t}$) | Land Use ($10^8\text{m}^2$) |
|------------|------------------------------------|-----------------------------|-------------------------------|
|            | Dis- | Inter- | Dis- | Inter- | Dis- | Inter- | Dis- | Inter- |
| Asia       | 816.78 | 664.72 | 193089.38 | 215346.32 | 20683.43 | 20970.02 |
| Europe     | 167.31 | 143.53 | 61507.76 | 54147.18 | 4234.99 | 3479.19 |
| North America | 296.71 | 224.38 | 76534.47 | 66953.15 | 6069.92 | 5530.62 |
| South America | 31.41 | 20.94 | 71634.05 | 5484.79 | 1089.29 | 1110.14 |
| Africa     | 66.13 | 25.02 | 13495.43 | 6974.61 | 2334.78 | 4226.49 |
| Oceania    | 17.85 | 16.38 | 2962.09 | 2831.12 | 586.46 | 598.42 |
| Global     | 1396.19 | 1094.96 | 354752.19 | 351737.17 | 34998.87 | 35914.87 |

In connection to fossil energy saving benefit, cumulative fossil energy saving by 2050 can be up to 30.1 billion ton of standard coal equivalent in interconnecting scenario, and it’s most significant mainly in Asia, North America, Africa and Europe, which is power receiver region or clean power resourceful region. In connection to water saving benefit, accumulated global water saving quantity in interconnecting scenario by 2050 can be up to 958.1 billion ton, and because of complement with South America and receive arctic wind power, the most significant region is North America. Asia’s water use increases 2.2 trillion ton in interconnecting scenario, it’s mainly because it’s significantly increased nuclear power capacity. In connection to land value saving, global land using saving of
interconnecting scenario in 2050 can be up to 91.6 billion square meters. Considering regional difference of land value, which Europe and North America are higher and Africa is lower, global land value accumulative saving of interconnecting scenario by 2050 can be $162.4 billion.

4.2. Atmospheric Pollutant Emission Reduction Benefits
According to formula (5) ~ (7), emission of SO2, NOx and primary PM from global and various continents is calculated. By 2050, interconnection scenario reduce SO2 emissions about 7.8 million ton, NOx emission about 144.8 billion ton, primary PM emission about 9 billion ton.

![Figure 3. Emission Accumulative Reduction Scale and Percentage from 2016 to 2050.](image)

The cumulative emission reduction and reduction percentage of conventional pollutants in different continents from 2016 to 2050 are shown in figure 3. As of 2050, regions with large emission reductions of conventional pollutants mainly include Asia, North America and Africa, and regions with large percentage reductions are mainly Africa, South America and North America. Asia as a whole generation larger scale, interconnection scenario for 2016-2050 coal gas and electricity cumulative output fell 68.1 trillion kilowatt-hour, interconnection scenario on SO2, NOx and fine particulate matter emissions from balance situation reduce 4.19 million ton, 7.55 million ton and 520000 ton respectively. Sending Africa as electricity, domestic solar energy resources are very abundant, networking scenario for 2016-2050 of coal gas and electricity cumulative output fell 16.8 trillion kilowatt-hour, solar capacity of interconnection scenario by 65.8 trillion kilowatt-hour, SO2, NOx and fine particulate matter emissions is relatively independent emissions scenarios to reduce 1.1 million ton, 1.97 million ton and 120000 ton, reduction percentage reached 38%, 48% and 48%, respectively.

4.3. Combating to Climate Change Benefits
Based on formula (8), global annual greenhouse gas emission is calculated as shown in figure 4. Before 2030, difference between two scenarios is not obvious, and after interconnection of Asia-Europe-Africa in 2030, global greenhouse gas emissions of interconnection scenario are significantly being lower. By 2050, after global interconnection, cumulative greenhouse gas emission by 2050 can be about 173 gigaton equivalent of carbon dioxide in interconnecting scenario.

![Figure 4. Greenhouse Gas Emission from Energy Sector.](image)
By use of MAGICC model, global temperature rise and sea level rise caused by greenhouse gas emissions are calculated as shown in figure 5 and figure 6. In disconnection scenario, global temperature rise is higher than 2 degree Centigrade in 2100 and global sea level rise is about 30 centimetre. In interconnection scenario, global temperature rise can be controlled within 2 degree Centigrade, but more than 1.5 degree Centigrade, and global sea level rise is about 25 centimetre.

![Figure 5. Global Temperature Change.](image)

![Figure 6. Global Sea Level Change.](image)

5. Conclusions

After global energy interconnecting, complementary characteristics of intercontinental resources and power loads can be taken full advantage of, on the other hand, clean energy with wind and solar power bases in "the Arctic and Equatorial" regions can be effectively used, which can comprehensively increase development and utilization of renewable energy and improve non-fossil energy consumption share, as well as save development and utilization of fossil energy to realize resource saving and pollutants emission reduction. By measuring, in 2050, by reducing power generation of thermal plants and increasing non-fossil energy generating, interconnection scenario can reduce fossil energy consumption about 30.1 billion ton of standard coal equivalent, water consumption about 301.5 billion ton, land value loss about $162.4 billion, and SO2, NOx and primary PM emissions about 7.8 million, 14.5 million and 0.9 million ton respectively.

GEI also has a positive impact on response to global climate change. It is estimated that interconnection scenario can reduce greenhouse gas emission about 173 gigaton equivalent of carbon dioxide. By use of MAGGIC model to simulate greenhouse gas emissions of interconnection scenario and disconnection scenario respectively, it’s found that interconnection scenario can achieve goal of 2 degree Centigrade global temperature rise control, and the other scenario cannot.

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