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A Comparative Study of Global Power Grids and Global Fossil Energy Pipelines Using GIS Technology

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Abstract—This paper comprehensively investigates current development status of global power grids and fossil energy pipelines (oil and natural gas), proposes a standard visual platform of global power and fossil energy based on Geographic Information System (GIS) technology. In this visual platform, a series of systematic visual models is proposed with global spatial data, systematic energy and power parameters. Under this visual platform, the current Global Power Grids Map and Global Fossil Energy Pipelines Map are plotted within more than 140 countries and regions across the world. Using the multi-scale fusion data processing and modeling methods, the world's global fossil energy pipelines and power grids information system basic database is established, which provides important data supporting global fossil energy and electricity research. Finally, through the systematic and comparative study of global fossil energy pipelines and global power grids, the general status of global fossil energy and electricity development are reviewed, and energy transition in key areas are evaluated and analyzed. Through the comparison analysis of fossil energy and clean energy, the direction of relevant research is pointed out for clean development and energy transition.

Keywords—Energy Transition, geographic information system, fossil energy, power systems.

I. Introduction

THE Global Energy Interconnection Initiative (GEI) is proposed by China in September 2015, at the 70th UN Sustainable Development Summit. This initiative is to establish a global energy Interconnection Network to meet global electricity demand in a clean and green way. This global initiative is to promote the energy revolution, promote clean development and address climate change, and has opened a new era of sustainable energy development in the world, which has been widely praised and responded positively by the international community.

The GEI is a global energy allocation platform based on UHV transmission technology, smart grid and clean energy development [1]. More Safer, more reliable, more economical, cheaper electricity can be transmitted to thousands of households by developing wind, solar, hydro and other clean energy alternatives to replace fossil energy generation, utilizing Ultra-high Voltage Transmission Technology and smart distribution, through the domestic, continental and global power interconnection. In this way, a global clean energy consumption mechanism can be established to meet the energy needs of mankind. The concept of GEI can be summarized as that Smart Grid is the foundation, UHV grid is the key, clean energy is essence. GEI is a green low-carbon, interconnected, open and shared energy allocation system, with great economic, social and environmental benefits. GEI can help countries to share responsibilities of low-carbon emission, share the achievements of clean development, build a peaceful and harmonious world. Moreover, GEI is a sharing economic action in the field of energy innovation.

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Since the essence of GEI is clean energy development, energy transition should be firstly promoted to achieve that. GEI Development and Cooperation Organization (GEIDCO) proposed the strategy of Two Placements, One Increase, One Restore and One Conversion[1]. Two replacements means to use clean alternatives in energy production, replacing fossil fuels with hydro, solar, and wind energy, which is known as Clean replacement, and also to promote electricity replacement in energy consumption, replacing coal, oil, natural gas and firewood with electricity. One Increase is to improve electrification across all social sectors. One restore refers to the restoration of fossil energy to its basic attribute as industrial raw material to express more economic value. One conversion means that carbon dioxide, water and other substances will be converted to fuels and raw materials like hydrogen, methane and methanol by virtue of electricity to pave the way for future energy development and sustainable development of mankind[1][2].

Currently, establishing GEI process has already been at a new stage from concept promotion to Implementation with joint actions. To achieve the implementation actions, it is necessary to comparatively study the development status of global power sector and fossil energy sector in macro aspect with big data. Using GIS technology, the database of global power sector and fossil energy sector can be established and global maps of world's global fossil energy pipelines and power grids information can be plotted, which can contribute to review the development status of global power sector and fossil energy sector and support the research of GEI [3], [4]. In the current state of art, the data of global power grid and fossil energy are various in different countries and regions, all of which are incomplete, inconsistent, of multifarious standards and updated in different years. Hence, it is necessary to propose a unified model system to achieve visual data management of global power and fossil energy sector, including grid lines, substations, oil and gas pipelines with detail specification data. This unified system and visual platform can support to data collection, storage, processing, analysis of the entire value chain of global power sector and fossil energy sector, and further contribute to global energy transition analysis, power planning research, governmental policy decision-making and world wide technical support[5].

In this paper, current development status of global power grids and fossil energy pipelines (oil and natural gas) are comprehensively investigated. A standard visual platform of global power and fossil energy is proposed using GIS technology. In this visual platform, a series of systematic visual models is proposed with global spatial data, systematic energy and power parameters. Under this visual platform, the current Global Power Grids Map and Global Fossil Energy Pipelines Map are plotted within more than 140 countries and regions across the world. Using the multi-scale fusion data processing and modeling methods, the world's global fossil energy pipelines and power grids information system basic database is established, which provides important data supporting global fossil energy and electricity research. Finally, through the systematic and comparative study of global fossil energy pipelines and global power grids, the general status of global fossil energy and electricity development are reviewed, and energy transition in key areas are evaluated and analyzed. Through the comparison analysis of fossil energy and clean energy, the direction of relevant research is pointed out for clean development and energy transition.

Firstly, this paper systematically summarized the structure of global power and fossil energy GIS platform by reviewing various raw data sources, modeling data attributes, applying visual modeling methods, and presenting the GIS visualization results. This paper further analyze global power grids and fossil energy pipelines by utilizing network analysis modeling methonds, including network density, network interconnection, network channel direction and other factors. Based on these, the comparative analysis of global power grids and fossil energy pipelines are conducted. Finally, key conclusions are made to contribute the promotion of GEI.

II. Structure of Global Power and Fossil Energy GIS Platform

First of all, considering the current data source of global fossil energy and power information are diverse and complex in standards, data formats, update years and other aspects, global fossil energy and power data are widely collected from different data source and formalized to research. A standard visualization method based on GIS technology is proposed, multi-standard fusion models are defined through the correlation between global spatial data and systematic parameters, and a standard graphical model system with latitude and longitude information is formed.

A. Data Source of Global Power and Fossil Energy

The data source of global power and fossil energy are collected from the following areas:

- Public documents issued by national power grids, oil and gas companies and research institutes in various countries.
- Public research results released by authoritative associations or organizations in energy sector of various countries.
- Public investigation results released by regional or international organizations and multilateral institutions.
- Open access reports and documents released by governments in various countries.
- Published academic journals and conference papers.
- Open access resources online.

B. Data Attributes and Visualization Modeling

To establish the platform and database of global power and fossil energy, it is necessary to construct visualization models of data attributes of global power grids and fossil energy pipelines.

1) Data Attributes: In power sector, the voltage levels of DC transmission lines are 400 kV, 500 kV, 660 kV, 800 kV, 1100 kV, 1100 kV and above. The voltage levels of AC transmission lines are 220 275 kV, 300 330 kV, 380 400 kV, 500 kV, 745 765 kV, 1000 kV and above. The attributes of power generation sites include name, type (Coal-fired thermal, Gas-fuel thermal, other thermal, hydropower, pumped storage, nuclear, PV, Photothermal, wind, and other), current status (existed or planning), country, continent, installed capacity, ownership, operation unit, and coordinate of latitude and longitude. The attributes of power substations include type (AC, DC and VSC-HVDC), current status (existed or planning), voltage level, country. In total, there are 11 types of power generation sites and each type has AC and DC subtype. Hence, there are 22 types of power generation sites. For the substations, there are 6 types in total. The attributes of transmission lines include two basic type DC and AC. In DC lines, the attributes include 400 kV below, 400 kV, 500 kV, 660 kV, 800 kV, 1100 kV, 1100 kV above and other type. In AC lines, the attributes include 110-161 kV below, 220-275 kV, 300-330 kV, 380-400 kV, 500kV, 745-765 kV, 1000 kV above and other type. With additional free line and planning line types, there are 32 types of transmission lines.

In fossil energy sector, the data attributes are finally classified after extensive collection of information and research the current status of the global fossil energy pipelines. The data attributes include fields (oil field, gas field), pipelines (crude oil pipelines, gas pipelines and oil product pipeline), stations (Oil refinery, gas processing station, gas storage station, and oil storage station), and corresponding factors to indicate the existing status or planning status.

2) Visualization Modeling: With the systematically modeled data attributes, to visually model the multi-source-collected GIS data, a differentiated mapping method is proposed and applied to a global map covering more than 140 countries worldwide. A data stratification

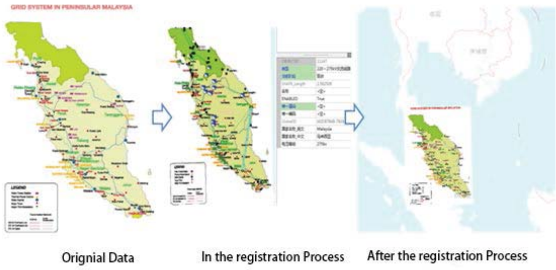

Fig. 1 Geographical information registration process

simplification algorithm is proposed and applied in order to achieve global fossil energy and power data visualization display, and clarified different current developing status of power and fossil energy in various countries. Finally, Global Power Grids Map and Global Fossil Energy Pipelines Map are plotted based in the platform.

In the data process procedure, because the raw data are collected from multiple sources in various languages, the first procedure is to standardize all the raw data with unified language and systematic symbols. Then, the data are processed with geographical information registration, as Fig. 1 shows. The geographic coordinates (longitude, latitude) of the corresponding grid points can be obtained after registration. The next step is to emerge all the data from different sources and map the registered data in unified WGS-84 coordination system. Before finally displaying the data, it is necessary to apply graphic grid vectorization management of all registered data.

From a macro perspective within a small scale, a large number of sites, substations (point features) and power grids (line elements) need to be displayed within the same view range. In particular, for line features, because they contain a large amount of coordinate information, in the visual display process to render them often need to consume a large amount of computing resources. At the same time, because the map scale is small and the view range is large, the observer often gets only the approximate outline of the line, and area zooming is required to see the details of the specific line. After the vectorization, the massive amount of energy and power data collected, using the data layering simplification algorithm proposed in [6], can be used to achieve a five-stage display mode display,as shown in Fig. 2.

After data construction of the global power and fossil energy GIS database and visualization platform, Global Power Grids Map and Global Fossil Energy Pipelines Map are plotted based in the platform, as shown in Figs. 3 and 4 respectively. The Global Power Grids Map collects and Global Fossil Energy Pipelines Map covers 149 countries around the world, establishing a global database of global power and fossil energy information. In this database, for the global power sector has a total of 51131 lines, 20572 substations, 16263 power supply sites. For global fossil energy sector, there are currently 30850 oil and gas pipelines, including 907 crude oil pipelines, 29280 natural gas pipelines, 663 refined oil pipelines, 4978 oil and gas fields, of which 2945 in oil fields and 2033 gas fields, and 3,697 oil and gas sites of

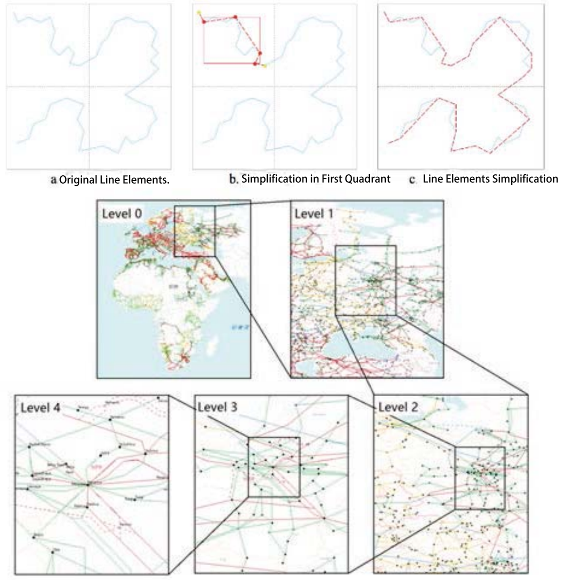

Fig. 2 Data layering display

Fig. 3 Global Power Grids Map

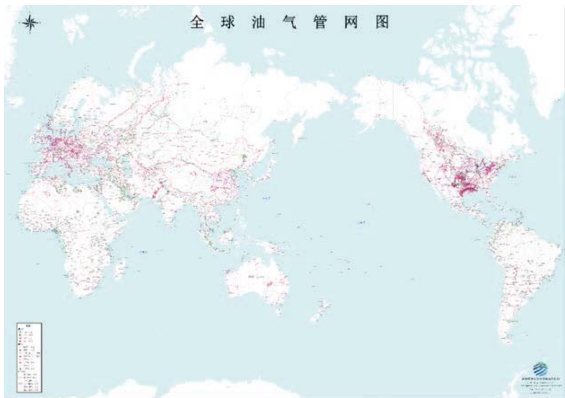

Fig. 4 Global Fossil Energy Pipelines Map

various types, including 2203 oil refineries and 624 natural gas processing plants and 541 gas storage stations.

From the distribution characteristics of global power grids and fossil energy pipelines, the development status of power and fossil energy in different regions are not balanced, especially there are significant unbalanced distribution of fossil energy pipeline networks. There are many reasons to cause this status, the first reason is due to the non-uniformity distribution of the world's energy resources, especially fossil energy. The second reason is due to the unbalanced energy industry development in different countries. Moreover, other reason is the transparency of public energy information in different countries is not the same, such as in Europe and United States energy information is more transparent, reflecting the number lines and elements in the maps are more intense.

III. Modeling and Analysis of Global Power Grids and Fossil Energy Pipelines

After plotting the Global Power Grids Map collects and and Global Fossil Energy Pipelines Map, the comparative analysis is conducted by modeling from line density, interconnection, and corridor perspectives for global power and fossil energy.

A. Grids and Pipelines Density Modeling

In order to evaluate the density of global power and fossil energy, i.e. grids and pipeline density, a large-scale network density analysis model is applied to power lines and pipelines in global maps [7], [8], [9]. The density can be calculated with data using (1).

$$D_i =< \frac{\sum_i N_{ii}}{S_i} > \quad (1)$$

where D_i is the density value of line elements, N_{ii} is the number of line elements which the starting point and ending point are both in region i, S_i is area value of region i, < Ꞁ > is normalization calculation, which can be calculated using (2).

$$< \mathbf{a} >= \frac{a}{\max \mathbf{a} - \min \mathbf{a}} > \quad (2)$$

Through the calculation of density value, the powerline and pipeline density in different regions can be effectively and comparatively analyzed and evaluated. Moreover, through the normalization calculation, the effects brought by area differences of countries can be eliminated that the development status can be fairly evaluated between different countries.

B. Grids and Pipelines Interconnection Modeling

After the analysis of density, the interconnection status is further analyzed by interconnection modeling in different regions. By adopting the modeling methods in [7], [8], [9], the cross-border energy interconnection between different regions can be calculated and analyzed using (3).

$$I_i =< \frac{\sum_{i \neq j} N_{ij}}{S_{ij}} > \quad (3)$$

where I_i is the interconnection value in region i, N_{ij} is the number of line elements that starts in region i and ends in region j, S_{ij} is the area value of region i and j, and ¡•¿ is the normalization calculation.

C. Grids and Pipelines Corridor Modeling

The long transmission distance and large capacity corridor is always a key issue in energy development. Using the the modeling methods in [7], [8], [9], the Grids and Pipelines Corridor can also be modeled by using (4).

$$C_i =< \frac{\sum_{i \neq j} N_{ij} | (D_{ij} > T)}{S_{ij}} > \quad (4)$$

where C_i is the corridor value of region i, N_{ij} is the number of line elements that starts in region i and ends in region j, D_{ij} is the distance of direct line between region i and j, T is the threshold value of distance for corridor, S_{ij} is the area value of region i and j, and ¡•¿ is the normalization calculation.

IV. Comparative Analysis of Global Power Grids and Fossil Energy Pipelines

Through the data collected in global power and fossil energy GIS platform, after data analyses in density, interconnection, and corridor, the development status of global power sector and fossil energy sector can be comparatively analyzed.

A. Density Analysis

Through the calculation results from (1), in Fig. 5 the density index results of power grids show the density of the European grids is much higher than that of the rest of the world, mainly because of the large number of European countries and the development of European grid is well advanced. Secondly, power grid density in North America ranks the second, mainly because the United States and Canada are the world's two largest developed countries, the development of the power grid is quite perfect, especially the United States is the world's energy consuming center. However, due to the overall population of North America, although the total number of line in North America is higher than in Europe, the overall density index is lower than that of Europe. Oceania region includes Australia, New Zealand and other countries, of which grid construction is good. But the land area in Australian mainland is widely open with few population, resulting the density level of the power grid is low. Most of Asia (East, South, Southeast Asia, etc.) is dominated by developing countries, but the power grids are developing rapidly and the density of the power grids is relatively high. The Arab region and most of Africa have the lowest overall grid density levels.

For fossil energy sector, in Fig. 6 results show that compared with power sector, fossil energy in different region is very diverse in development and utilization status. Oil and gas pipelines in Europe and the United States are much denser than in the rest of the world. In particular, United States has the highest number of oil and gas pipelines in the world, Europe due to the large number of countries and smaller areas, its oil and gas pipeline density level is leading in the world. In other regions, the Arab region and Central Asia, as the export region of traditional oil and gas resources, export a large number of oil and gas resources, although the construction level of the oil and gas pipeline network is not as high as that of developed countries, but still higher than the rest of the world.

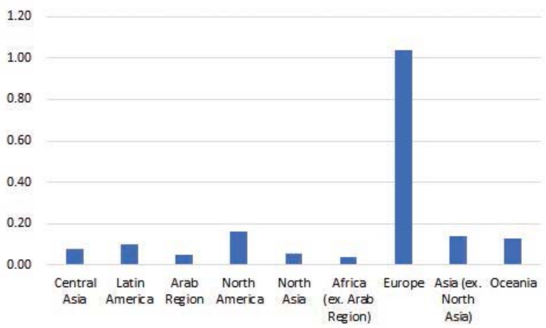

Fig. 5 Density index of power grids in different regions

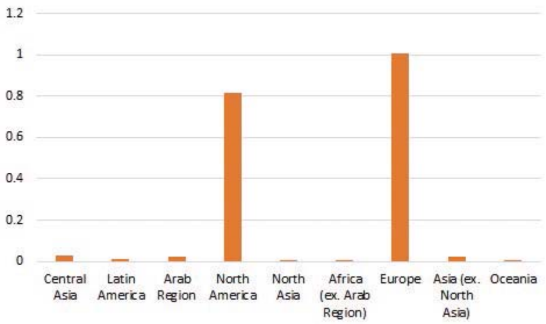

Fig. 6 Density index of fossil energy pipelines in different regions

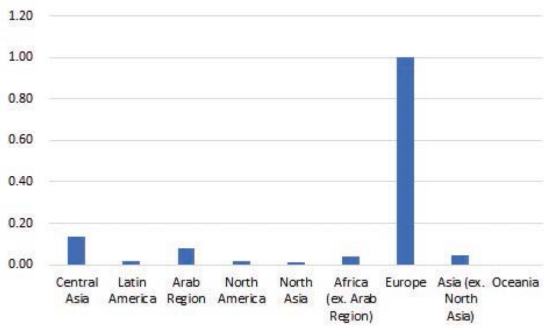

Fig. 7 Interconnection index of power grids in different regions

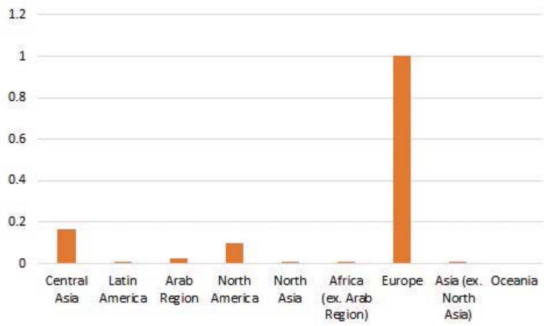

Fig. 8 Interconnection index of fossil energy pipelines in different regions

B. Interconnection Analysis

Through the calculation, in Fig. 7 results from (3), the interconnection index in power sector results shows that Europe still has the world leading level in the interconnection index. In Europe, due to the establishment of a power transmission grid ENTSO - E, the index of interconnection between countries is much higher than other parts of the world. In North America, although the grid density is higher, but United States and Canada is relatively independent, hence the power grid interconnection between the two countries is lower. Central Asia are greatly influenced by Russia, interconnect index is higher between central Asia and Russia. Moreover, Kazakhstan and other central Asian countries also have certain interconnected between each other. Hence, central Asias interconnection index s relatively higher. In Oceania, because between countries are not adjacent to each other, the interconnection index is very low.The interconnection index of power grid in north Asia is also very low due to its large area and sparse population.

For fossil energy sector, in Fig. 8 the interconnection index results is similar to power sector. The interconnection index in Europe is significantly higher than that in central Asia. That's because the fossil energy pipeline network in central Asia is widely connected with Russia. Therefore, the interconnection index of central Aisa is relatively high. Moreover, there is no cross-border pipeline interconnection in North America or Oceania due to geographical reasons.

C. Corridor Analysis

Through the calculation results from (eq: corridor), in Fig. 9 the corridor index for power sector results shows that long-distance power transmission corridor are mainly in Asia, including China and India. Because of its wide land area, power generation and power consuming center are located far away from each other, hence the transmission corridor index is higher in Asia. Secondly, power grid construction in north America is well advanced, and large-scale transmission corridors are built to connect the consuming center in east and west coasts. Hence the corridor index in north America is also high, while in central Aisa, north Asia and Oceania corridor index is low.

For fossil energy sector, the large-scale transmission corridors mainly exist in areas with advanced pipeline networks like north America and Europe, where corridor index is high. Besides that, central Aisa and north Asia is also with long-distance transmission corridors, where the index is also high, as shown in Fig. 10.

V. Conclusion

Due to the necessity of energy transition, this paper comprehensively investigates current development status of global power sector and fossil energy sector. This work proposes a standard visual platform of global power and fossil energy based on GIS technology. In this visual platform, a series of systematic visual models is proposed with global spatial data, systematic energy and power parameters. Under this visual platform, the current Global Power Grids Map and Global Fossil Energy Pipelines Map are plotted within more than 140 countries and regions across the world. Using the multi-scale fusion data processing and modeling methods, the world's global fossil energy pipelines and power grids information system basic database is established,

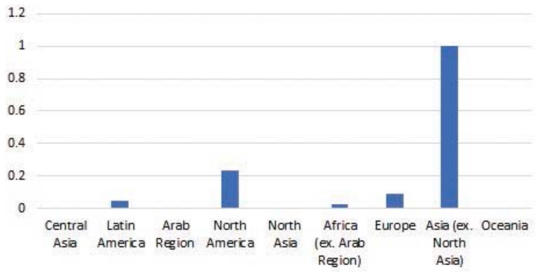

Fig. 9 Corridor index of power grids in different regions

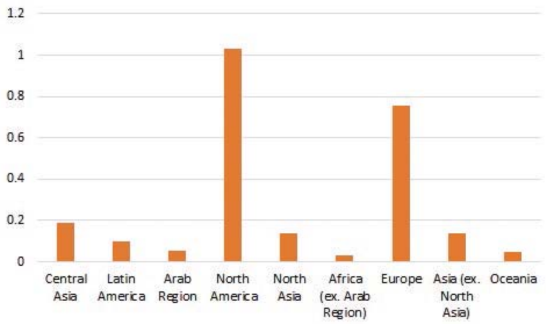

Fig. 10 Corridor index of fossil energy pipelines in different regions

which provides important data supporting global fossil energy and electricity research. Finally, through the systematic and comparative study of global fossil energy pipelines and global power grids, the general status of global fossil energy and electricity development are reviewed, and energy transition in key areas are evaluated and analyzed. Through the comparison analysis of fossil energy and clean energy, important conclusion are made for clean development and energy transition.

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