A dynamic analysis on global biomass energy trade network

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Abstract. In recent years, increasing attention has been paid to the development of biomass energy. Global biomass energy trade plays an important role in this development process. However, due to the uneven distribution of biomass energy supply and demand, as well as different policies in different regions, the development of biomass energy, to some extent, has been affected. Thus, it is essential to investigate the evolution mode of global biomass energy trade, so as to promote its balanced development and sustainable growth. In this paper, we analysed the dynamic evolution of global biomass energy trade from 2011 to 2017 based on complex network theory and some conclusions were given. Firstly, the results show that the overall volumes of biomass energy trade is on the rise, but its mode tends to be low density with a large volume of trade concentrated in some countries. Secondly, it is worth noting that European countries and the North America are more active in global biomass energy trade, while only a small number of developing countries, like Brazil, China and India, have certain influence on the biomass energy trade. Thirdly, it seems that most countries prefer to establish biomass energy trade export relationships with other countries rather than import. Finally, given the poor performance of both in-degree and out-degree in the Middle East and North African regions over time, more attention should be paid to the development of biomass energy in these areas. The main contribution of this paper is to understand the market evolution of global biomass energy trade in 2011-2017 from the perspective of complex networks, being a supplement to the existing researches on biomass energy trade.

1. Introduction
Biomass energy being a renewable energy has significant potential to producing fuels, chemicals, and polymeric materials to improve climate and ensure energy security [1]; for instance, bioethanol production from corn grain via the dry-grind process, where petrol is supplemented [2]. According to the statistics of IRENA (International Renewable Energy Agency), biomass energy accounted for about 10% of total final energy consumption and total trade of biomass for energy purposes is estimated as having increased twofold from around 780 PJ in 2004 to 1250 PJ in 2015 [3]. Furthermore, power generation of biomass energy is expected to reach 1,487 TWh in 2035 which is less than hydro and wind power, but more than other renewable energy like Solar PV [4]. It has been found that trade openness contributes to environmental pollution and the consumption of biomass energy is helpful to reduce the environmental pollution. However, due to the uneven distribution of biomass energy supply and demand, it is essential to observe the evolution of international biomass energy trade patterns.

Though many researches including verifying the relationship between the consumption of biomass energy and environmental pollution [5], or evaluating the economic and environmental cost through models [6] have been done, the research on international trade of biomass energy is insufficient.
Therefore, the goal of this paper is to investigate the characteristics of global biomass energy trade patterns from a complex network perspective and the dynamic evolution of biomass energy trade network, thus helping policy makers understand the distribution mode of global biomass energy trade and promoting the integrated development of biomass energy.

2. Methods and data source

The international biomass energy trade network model is a directed weighted network, and it can be represented by $G = (N, E)$, where $N = \{n_i, i=1, 2, ..., p\}$, $p$ is the number of nodes and $E = \{e_i, i=1, 2, ..., q\}$, $q$ is the number of edges. In this paper, nodes represent the countries, and edges represent the trade relationship between each of countries.

2.1. The measurement of biomass energy trade patterns

In this paper, three indicators are selected to analyze the evolution of biomass energy trade patterns, including the density, the average path length and the modularity measure. The density and the average path length are used to measure the overall tightness of biomass trade network. The larger the value of these two indicators, the closer the relationship among the countries in the biomass energy trade network. See formula (1) and formula (2). Modularity measure is used to detect the potential communities in the network, uncovering some close cooperation groups. See formula (3).

\[
\Delta = \frac{m}{n(n-1)} \quad (1)
\]

In the formula (1), $\Delta$ is the density of the biomass energy trade network, $n$ is the total number of nodes, and $m$ is the number of the actual relationships in the network.

\[
L = \frac{1}{N(N-1)} \sum_{i,j} l_{ij} \quad (2)
\]

In the formula (2), $L$ is the average path length of the biomass energy trade network, $N$ is the total number of nodes, and $l_{ij}$ is the shortest distance between node $i$ and node $j$. If $i=j$, $l_{ij}=0$.

\[
Q = \frac{1}{2m} \sum_{i,j} \left[ w_{ij} - \frac{k^{in}_i k^{out}_j}{2m} \right] \delta(c_i, c_j) \quad (3)
\]

In the formula (3), $Q$ is the modularity measure, $m = \frac{1}{2} \sum_{i,j} w_{ij}$, $w_{ij}$ is the weight of edges between node $i$ and node $j$, $k^{in}_i$ is the total inflow weight of node $i$, $k^{out}_j$ the total outflow weight of node $j$. $\delta(c_i, c_j)$ is a 0/1 control variable, and if $k^{in}_i = k^{out}_j$, $\delta(c_i, c_j) = 1$; otherwise $\delta(c_i, c_j) = 0$.

2.2. The spatial-temporal analysis of biomass energy trade network

Generally, countries with sufficient resources are more likely to attract other importing countries to trade with them. Thus, this paper focuses on the temporal and spatial changes of trading partners and trade volume. The in-degree and out-degree are selected to analyze the number of import and export trading partners of biomass energy trade, while the weight degree represent the trade volume of the connecting edges in the network. See from formula (4) to formula (6).

\[
K^{in}_i = \sum_j e_{ij} \quad (4)
\]

\[
K^{out}_i = \sum_j e_{ij} \quad (5)
\]

In the formula (4) and (5), $K^{in}_i$ and $K^{out}_i$ are the in-degree and out-degree of country $i$ respectively, $e_{ij}=1$ when node $i$ flows to node $j$, and $e_{ij}=0$ otherwise.

\[
S_i = \sum_j e_{ij} w_{ji} + \sum_j e_{ij} w_{ij} \quad (6)
\]

In the formula (6), $\sum_j e_{ij} w_{ji}$ and $\sum_j e_{ij} w_{ij}$ are the weight in-degree and weight out-degree of country $i$ respectively, $w_{ji}$ or $w_{ij}$ is the trade volume between node $i$ and node $j$.

2.3. Data source

Data used in this paper comes from the UN Commodity Trade Database. Table 1 shows the HS code and records of each biomass energy product selected in the database.
Table 1. Selected biomass energy records in UN Comtrade.

| HS code | Records | Description |
|---------|---------|-------------|
| 220710  | 28208   | Undenatured ethyl alcohol; of an alcoholic strength by volume of 80% vol. or higher |
| 382600  | 7241    | Biodiesel and mixtures thereof; not containing or containing less than 70% by weight of petroleum oils or oils obtained from bituminous minerals |
| 440130  | 12698   | Wood; sawdust, waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms |

3. Results and discussion

3.1. The evolution characteristics of biomass energy trade patterns
As shown in Figure 1, despite the decline during 2013-2015, the total volume of global biomass energy trade shows the overall upward trend which is consistent with [7]. We can see that the total volume of biomass energy export trade is always greater than that of import, which means that some countries have a favorable balance of trade in biomass energy trade. Policy makers can take changing tariff into account to keep the balance of trade in international biomass energy trade activities. Furthermore, incentive policies should be established to encourage the development of biomass energy, like attracting foreign investment.

Figure 1. The volume of biomass energy trade from 2011 to 2017.

The density, average path length and number of communities of the international biomass energy trade network are calculated through the software of Gephi-0.9.2 to analyze the evolution of biomass energy trade patterns, showing in Figure 2. Firstly, the average path length maintain a steady state from 2010 to 2017, keeping between 2 and 3. Secondly, the density of biomass energy trade network shows an overall downward trend, namely the red line in Figure 2. These two indicators comprehensively indicate that the density of network is relative low. This may be due to the fact that biomass energy trade is mainly conducted in the import and export countries directly, rarely through other countries. Meanwhile, a large number of biomass energy products are traded among several significant countries, namely the bigger nodes in the graph, like Netherlands, Germany, etc. However, the number of communities presents a different changing states. The number of communities of biomass energy trade network increased from 2010 to 2013, which means that at that time, more and more countries joined the global biomass energy trade, forming more potential communities. Nevertheless, as time goes on, the volumes of biomass energy trade are mainly concentrated in a few
communities and their members, then the number of communities has been declining since 2013. We can see that there are increasing red arrows in the network holding a large part of trade volume. In general, a large number of connections in the network are increasingly held by a few nodes, presenting the characteristics of scale-free network. In the real world, trade barrier or even trade monopolies should be avoided in biomass energy trade, and emerging technologies or good policies should be introduced to other countries, especially those agriculture intensive ones.

Figure 2. The trade pattern evolution of the international biomass energy trade during 2010-2017.

3.2. The spatial-temporal analysis of biomass energy trade network

3.2.1. In-degree and out-degree distribution. A region that play an important role in the global trade network undoubtedly has a large amount of demand or supply, which is crucial for establishing various trade relations. Degree represents the number of direct trade partnerships in a country or region. What’s more, in this paper, the in-degree and the out-degree are the number of import links and export links of a country respectively. The higher the value of in-degree or out-degree, the greater the influence of a country in the global biomass energy trade network.

The in-degree and out-degree spatial-temporal distribution of global biomass energy trade uncover the evolution trend of biomass energy market. Since the change of each year is not particularly striking, this paper displays the evolution of in-degree and out-degree every three years during 2011-2017, showing in Figure 3. Firstly, in terms of evolution of in-degree, there has been little difference in each country over time. Showing in the Figure 3(a) (c) (e), Europe and North America maintain a high level of participation in importing biomass energy during 2011-2017. This is partly related to the past and expected future EU demand developments in the industrial segment, i.e. large-scale use of wood pellets in co- and mono-firing installations [8]. Furthermore, The United States has maintained a high influence in biomass energy import, holding a large number of biomass energy import partners globally. Biomass energy, to some extent, is an important contributor to U.S. climate change mitigation efforts [9], and given the local policies of environmental protection, biomass energy is more dependent on import trade there. Although the above analysis shows that the overall trade volume of biomass energy is increasing, this imbalance of import trading relationships needs to be taken seriously. Policies should be made in those regions with poor import trading activities to encourage using biomass energy so as to promote the integration and in-depth development of global biomass energy.

By contrast, more countries are keen to export biomass energy products to others, especially the area of Europe and North America. See Figure 3(b) (d) (f). The United States, for example, Furthermore, those countries that do not possess too much import relationships of biomass energy...
trade, like China, India and Brazil, are actively exporting domestic biomass energy products to other countries. This may be related to the fact that they already have sufficient biomass energy and the development of other renewable energy sources. However, more attention should be focused on the Middle East and North African regions because of the poor performance in both in-degree and out-degree over time. These two regions have experienced rapid economic development as consequence of natural resources in the last decade, while their economies have transitioned from agricultural-driven economies to industrial-driven economies and finally to service-driven ones with increase in foreign direct investment [10], which leads to the great decline of agricultural development as well as the slow development of local biomass energy. Taking the Middle East as an example, since 2009, the energy consumption in this region has greatly increased [11], and these countries have good potential in developing renewable energy. Thus, more countries should actively establish biomass energy trade relations with them and more investment in biomass energy can be considered for the development of local biomass energy.

Figure 3. In-degree and out-degree spatial distribution in 2011, 2014 and 2017.

Figure 4. The weighted degree ranking evolution for countries of biomass energy trade.
3.2.2. Weight degree analysis. Due to the constraints of geographical conditions and local policies, the importing and exporting sources of biomass energy show regional characteristics. Here, we introduce the weight degree, which takes the trade volume of each country into account, to reflect the influence intensity of each country. As shown in Figure 4, it can be seen that the rankings of European countries are relatively high and stable as a result of having been emphasizing the use of biomass energy recent years. This is similar to previous study, which shows that 48% of the annual biomass potential (157 Mtoe for biomass excluding biodegradable waste) is currently used in the EU-24 and Norway [12]. This is, to some extent, also related to many projects carried out in Europe dedicating to solutions to biomass trade and market barriers. However, some developed countries, such as Denmark, have been reducing biomass energy trade during 2011-2017, showing in the Figure 4.

On the other hand, though the overall participation and influence of developing countries in biomass energy trade is relatively low, some developing countries like Brazil, China and India are actively participating in biomass energy trade. The ranking changes for countries with consideration of volume of biomass energy trade are displayed in the Figure 4. China and India, for example, both show an upward trend. Although these countries are not as influential as European countries globally, they are gradually increasing the strength of influence in the biomass energy trade. Furthermore, it is worth noting that Brazil keep a high ranking in the international biomass energy trade, because Brazil has been vigorously developing bioethanol and is one of the leaders in bioethanol production globally [13]. Finally, there is a slightly decline for China during 2014-2017, because China was in the process of traditional energy transformation during 2014-2015 and then vigorously promoted the development of renewable energy including biomass energy after signing the Paris Agreement in 2016. Although investment of biomass energy in China is not as much as that of photovoltaic power generation and wind power generation, industrial roundwood has greatly developed [13]. Meanwhile, more measures should be taken to promote the diversified development of biomass energy in China, including encouraging research and development of biofuels, improving the recycling rate of wood chips and particles, etc.

4. Conclusions

In this paper, complex network theory is introduced to investigate the evolutionary characteristics of global biomass energy trade and conclusions are as follows:

(1) The density of biomass energy trade network is generally low and present a downward trend from the perspective of the evolution of the biomass energy trade network, which shows that the trade relationships of biomass energy among countries are relatively loose. More measures should be taken by international organizations, such as the EU and WTO, to encourage regions to establish close trade relations in biomass energy.

(2) The number of communities increases first and then decreases continuously during 2011-2017, showing that biomass energy trade activities and most of the biomass energy volumes are increasingly concentrated in some countries. On the one hand, these countries should establish a solid supply chain and market structure related to biomass energy to reduce structural risks. On the other hand, better communication strategies on the opportunities of biomass energy development should be established by other governments and local enterprises.

(3) In terms of in-degree and out-degree spatial distribution, Europe and the North America are the most active participants in global biomass energy trade whose advanced technology and incentive policies can be introduced in other countries. It is worth noting that, according to the weighted degree, some developing countries, such as Brazil and China, have also been involved in global trade of biomass energy in recent years. For the remaining developing countries, biomass energy should be appropriately developed according to their own agricultural and ecological characteristics.

(4) The Middle East and North African regions have great potential to develop biomass energy trade for their huge energy demand in the future and the deficiency in developing biomass energy.

Overall, this paper simply explore the evolution of the complex biomass energy trade network, and given the limited data, further research will be carried out in the future.
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References
[1] Bahar R, Mukund K, Sabrina S 2018 Renewable Rubber and Jet Fuel from Biomass: Evaluation of Greenhouse Gas Emissions and Land Use Tradeoffs in Energy and Material Markets ACS Sustainable Chemistry & Engineering acssuschemeng 8b03098-
[2] Čuček L, Klemč JJ, Kravanja Z 2012 Carbon and nitrogen trade-offs in biomass energy production Clean Technologies & Environmental Policy 14(3) 389-397
[3] Proskurina S, Junginger M, Jussi Heinimö, et al. 2019 Global biomass trade for energy – Part 1: Statistical and methodological considerations Biofuels, Bioproducts and Biorefining 13(2)
[4] Ellabban O, Abu-Rub H, Blaabjerg F 2014 Renewable energy resources: Current status, future prospects and their enabling technology Renewable and Sustainable Energy Reviews 39 748-764
[5] Danish, Wang Z 2019 Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries Sci Total Environ 670 1075-1083
[6] Shahbaz M, Balsalobre-Lorente D, Sinha A 2019 Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption Journal of Cleaner Production 217 603-614
[7] Proskurina S, Junginger M, Heinimö J, et al. 2017 Trade of energy biomass - An overview of the global status European Biomass Conference and Exhibition Proceedings 2017 1439-1448
[8] Lamers P, Marchal D, Jussi Heinimö, et al. 2014 Global Woody Biomass Trade for Energy Springer Netherlands
[9] Wise M.A., McJeon H.C., Calvin K.V., etal. 2014 Assessing the interactions among U.S. climate policy, biomass energy, and agricultural trade Energy Journal 35 165-180
[10] Charfeddine L, Mrabet Z 2017 The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries Renewable and Sustainable Energy Reviews 76 138-154
[11] Nematollahi O, Hoghooghi H, Rasti M, et al. 2016 Energy demands and renewable energy resources in the Middle East Renewable and Sustainable Energy Reviews 54 1172-1181
[12] Alakangas E, Junginger M, Dam J V, et al. 2012 EUBIONET III—Solutions to biomass trade and market barriers Renewable and Sustainable Energy Reviews 16(6) 4277-4290
[13] Proskurina S, Junginger M, Heinimö J, et al. 2018 Global biomass trade for energy- Part 2: Production and trade streams of wood pellets, liquid biofuels, charcoal, industrial roundwood and emerging energy biomass Biofuels Bioproducts & Biorefining