Profile of developments in biomass-based bioenergy research: a twenty-year perspective

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Available at: https://works.bepress.com/li_tang/27/
Profile of developments in biomass-based bioenergy research: a 20-year perspective

Weishu Liu · Mengdi Gu · Guangyuan Hu · Chao Li · Huchang Liao · Li Tang · Philip Shapira

Received: 22 June 2013 / Published online: 10 December 2013
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Abstract In an era of energy crisis, biomass-based bioenergy research has attracted the attention of R&D managers and policy makers around the world. This study explores the structural and dynamic patterns of biomass-based bioenergy research. We measure the profile of biomass research on both macro scales (nations) and meso level (institutions) in an international context. We find that biomass publications are intensively distributed in developed regions and some emerging economies. The U.S. leads in this emerging field as evidenced by research quantity, impact, and international collaboration links. China is developing rapidly in this domain in terms of publication volume and collaborative links but suffers from low research visibility. The study also finds strong interactions are taking place both within macro-disciplines and between macro-disciplines. Research limitations are presented.

Keywords Biomass-based bioenergy · Bibliometric analysis · Research profile · Information visualization

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Introduction

Resource scarcity and energy crisis are major concerns of sustainable economic development around the world. According to the U.S. Energy Information Administration, global consumption of energy has increased over 25% from 400 Quadrillion Btu in 2000 to 511 Quadrillion Btu in 2010 (EIA 2013). Among all energy sources, traditional fossil fuels including coal, petroleum, and natural gas, account for 85% of global consumption. Yet renewable energy has started to play an increasingly important role in the world energy supply system (Dincer 2008).

Biomass is among the most important sources of renewable energy. As a biological material derived from living or recently living organisms (Wang and Zhao 2009), it includes three main source types: energy crops, agriculture & forestry residues, and waste biomass (Steubing et al. 2010). Today, biomass has become the fourth largest source of energy and provides about 14% of the world’s primary energy consumption (Saxena et al. 2009). In sharp contrast to fossil fuels’ finite storage and serious environmental problems, biomass-based energy is potentially more environmental friendly and renewable, and thus has attracted the attention of R&D managers and policy makers (Huber et al. 2006; Tuck et al. 2012). From 2007 to 2011, $60.2 billion has been invested in biomass all over the world with an average of $12 billion per year (Bloomberg 2013). However, research profiling studies on renewable energy, particularly biomass-based bioenergy, are still underdeveloped. To fill in the research gap, this paper utilizes a customized global biomass research dataset, and combines text mining and information visualization techniques to profile the research trajectory and dynamics of biomass research activities across the globe.

Literature review

Bibliometric analysis is increasingly recognized as a useful tool for research evaluation (Wallin 2005; Van Leeuwen et al. 2003). In past scholarship, researchers have applied a variety of bibliometric methods to depict the status quo and dynamics of different research fields, including traditional domains (Bhattacharya 1997; Sengupta 1986; Kim 2001) and emerging fields such as nanotechnology and graphene (Youtie et al. 2011; Shapira et al. 2012). More recently, analysts have begun to combine information visualization techniques and funding acknowledgements to profile research trajectories and understand the drivers behind research growth (Rafols et al. 2010; Hu et al. 2012; Shapira and Wang 2010).

Alongside growing industry investment and rising academic interest, an emerging literature has started to evaluate research activities in the renewable energy research field. For instance, Tsay (2008) analyzed hydrogen energy publications during the period of 1965–2005 and found a rapid growth of global publications in the latter period and the U.S. dominating role in this field. Echoing Tsay’s findings, Dong et al. (2012) conducted a bibliometric analysis of solar power research in the period 1991–2010. They discovered a significant growth of publications along with an increasing number of countries involved. They argue that similar to the hydrogen energy field, solar power research is dominated by the U.S., but China is playing an increasingly important role in this domain. Using solar photovoltaic patent data, Jang et al. (2013) investigated the divergence between the innovative capability and production capacity of certain countries. Wind power has also attracted scientists’ attention, as evidenced by the boom in publications (Sanz-Casado et al. 2013). After the U.S. and the EU, China ranks third in terms of the number of wind energy papers.
In contrast, bibliometric research on biomass appears to be under-investigated, with some exceptions. One interesting study in biomass was conducted by Kajikawa and Takeda (2008). These two Japanese scientists used citation network analysis to probe the global structure of biomass and bio-fuels research. Targeting the taxonomic structure of emerging technologies, they found that bio-fuel and bio-energy related studies are the main focuses of biomass research. In another study, Konur (2011) adopted a bibliometric method to analyze research on algae and bioenergy, and identified key players at country, institutional, and individual levels. He has also explored the characteristics of the literature on the production of bioenergy from biomass from 1980 to 2010 (Konur 2012). These previous studies are insightful, however important aspects for understanding the development of biomass-based bioenergy are left unexplored, including patterns of growth and collaboration.

The rest of the paper is organized as follows. In the next section we describe the dataset. Then we use multiple scientometric indicators to gauge the patterns and dynamics of biomass research in the past two decades along three aspects, (1) key actors at both macro level (countries) and meso level (institutions); (2) research content; and (3) collaborative links. In the final section, we summarize key conclusions and point out limitations of this study.

Methods

Data

Thomson Reuters Web of Science (WoS) is the chosen data source in this study. This database provides essential data that covers over 12,000 research journals worldwide, including open access journals, and over 150,000 conference proceedings spanning more than 250 disciplines (Thomson Reuters 2013). As one of the most authoritative publication databases, a large number of extant studies have selected WoS for large scale research evaluations in a variety of research domains (Porter et al. 2008), including studies of biomass research outputs (Kajikawa and Takeda 2008; Konur 2012).

The most extensive bibliometric analyses of biomass-based bioenergy was carried out by Konur (2012). Taking both high recall and high precision into consideration, he developed the following searching queries to retrieve relevant publications.

\[ \text{ti=biomass and ts=(biofuel* or “bio-fuel*” or fuel* or bioenergy or “bio-energy” or energy or biomethan* or “bio-methan*” or methan* or bioethanol* or “bio-ethanol*” or ethanol* or biodiesel* or “biodiesel*” or diesel* or biogas* or “bio-gas*” or gas or biooil* or “bio-oil*” or oil* or biohydrogen* or hydrogen* or synfuel* or syngas* or synoil* or “syn-gas” or “syn-fuel*” or “syn-oil*” or “renewable energy” or “green energy” or “biorefin*” or “bio-refin*” or refinery) Database=SCI-EXPANDED, SSCI, time period=1993-2012} \]

This paper adopts Konur’s search strategy. All data were accessed using WoS 5.0 version\(^1\) in May 2013. The publication records with full bibliographic information\(^2\) were

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\(^1\) Please note since that Thomson Reuters released version 5 of SSCI in the Web of Science (WoS) in August 2011, the old original 222 subject categories in WoS 4.0 were renamed and extended to 225 Web categories. In this study, we draw overlay maps based on newly modified toolkit developed by Leydesdorff and his colleagues. For more details please refer to Leydesdorff et al. (2013).

\(^2\) These include paper title, author name(s), author affiliations, source, publication year, cited times and other information.
accessed in the format of plain texts and then cleaned and analyzed using the text mining software VantagePoint. As WoS was designed primarily for information retrieval as opposed to research evaluation, downloaded data were cleaned and standardized in the VantagePoint software through a series of thesauri and manual checking. After a thorough cleaning, we identified 8,524 biomass publications covering the period 1993–2012.

Analyses

Research quantity

Country level

Our data shows that over 120 countries took part in knowledge production of biomass in the last 20 years, with over half of papers contributed by the five top publishing nations. English is the primary language for communication: about 97 % articles were written in English. Unsurprisingly, the U.S. is the dominant player in this research domain. About 27 % of research on the production of bioenergy from biomass involves at least one researcher from the U.S. China is the second most active nation, contributing 8.5 % of the world’s papers. The UK ranks third with a share of 6.3 % in the worldwide output. Other highly active countries include Germany, accounting for 6.0 % of the scientific publications related to biomass-based bioenergy research, followed by Spain (5.1 %), Canada (4.6 %), and India (4.5 %).

To demonstrate the growth of biomass research, we further split the study period into two phases 1993–2002 and 2003–2012 (Table 1). Our analysis shows that publications of the key players grew dramatically during the two periods. Almost all top 20 countries in the first 10-year period have at least tripled their publications with the exception of Russia, whose publications increased from 21 during the first 10-year period to 34 in 2003–2012. The U.S. still dominated in this research field but with a declining share of world publications. China, the most rapidly rising country, jumped from a position of 16th in the earlier period to second in the later period.

Institutional level

By institutional affiliation, the U.S. National Renewable Energy Laboratory is the leading producer of papers with 179 papers (Table 2). The Chinese Academy of Sciences (CAS) produced 177 articles. This is followed by the U.S. Forest Service, the U.S. Agricultural Research Service (ARS), the University of Wisconsin, and Iowa State University, which are all in the United States. The number of U.S. entities among the world’s top 20 institutions reflects a prolific yet decentralized research structure. The dominance of CAS in China’s output reflects the high centralization of China’s scientific research system.

GIS software MapInfo 11.0 was used to visualize the global distribution of publications in the above sequential periods. From Fig. 1 we can see that biomass publications mainly concentrate in developed regions such as North America, Western Europe and some...
emerging economies. The U.S., as the ‘superpower’, plays a dominant role in this research domain. By far the strongest growth occurs in China evidenced by the shade changes, while the UK and Germany also occupy important positions in both periods. Eastern Europe, Africa and South America (with the exception of Brazil) have not been significantly involved in knowledge production in this emerging area. The geographic development path is different from that of nanotechnology and graphene research (Youtie et al. 2008; Lv et al. 2011), with a stronger biomass research role for emerging economies such as India, Turkey and Brazil.

### Research impact

Citation count is a widely adopted indicator of research impact. Higher citations suggest greater research influence (Youtie et al. 2013; Tang 2013). We use three citation indicators to gauge key players’ research impacts.

#### Country level

Over the 20 year study period, U.S. biomass research attracted 58,187 (or about 37% of) citations, which is significantly higher than the UK with 12,686 (8.1%) and Germany with 12,610 (8.0%). China, the second most prolific country by publication output, was ranked
Table 2 Most productive research institutions

<table>
<thead>
<tr>
<th>Institution</th>
<th>Country</th>
<th>Publications</th>
<th>CPP</th>
<th>HCP</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natl Renewable Energy Lab</td>
<td>USA</td>
<td>179</td>
<td>42.7</td>
<td>37</td>
<td>20.7</td>
</tr>
<tr>
<td>Chinese Acad Sci</td>
<td>China</td>
<td>177</td>
<td>13.3</td>
<td>13</td>
<td>7.3</td>
</tr>
<tr>
<td>US Forest Serv</td>
<td>USA</td>
<td>110</td>
<td>30.7</td>
<td>25</td>
<td>22.7</td>
</tr>
<tr>
<td>USDA ARS</td>
<td>USA</td>
<td>105</td>
<td>21.9</td>
<td>19</td>
<td>18.1</td>
</tr>
<tr>
<td>Univ Wisconsin</td>
<td>USA</td>
<td>86</td>
<td>56.4</td>
<td>20</td>
<td>23.3</td>
</tr>
<tr>
<td>Iowa State Univ</td>
<td>USA</td>
<td>79</td>
<td>14.0</td>
<td>4</td>
<td>5.1</td>
</tr>
<tr>
<td>Max Planck Soc</td>
<td>Germany</td>
<td>74</td>
<td>54.8</td>
<td>24</td>
<td>32.4</td>
</tr>
<tr>
<td>Swedish Univ Agr Sci</td>
<td>Sweden</td>
<td>70</td>
<td>15.2</td>
<td>5</td>
<td>7.1</td>
</tr>
<tr>
<td>Texas A&amp;M Univ</td>
<td>USA</td>
<td>70</td>
<td>46.1</td>
<td>10</td>
<td>14.3</td>
</tr>
<tr>
<td>Univ of Leeds</td>
<td>UK</td>
<td>70</td>
<td>21.8</td>
<td>8</td>
<td>11.4</td>
</tr>
<tr>
<td>Univ of Minnesota</td>
<td>USA</td>
<td>70</td>
<td>19.7</td>
<td>3</td>
<td>4.3</td>
</tr>
<tr>
<td>Tech Univ Denmark</td>
<td>Denmark</td>
<td>68</td>
<td>21.1</td>
<td>4</td>
<td>5.9</td>
</tr>
<tr>
<td>Univ of São Paulo</td>
<td>Brazil</td>
<td>64</td>
<td>23.9</td>
<td>9</td>
<td>14.1</td>
</tr>
<tr>
<td>Delft Univ of Tech</td>
<td>Netherlands</td>
<td>62</td>
<td>20.0</td>
<td>7</td>
<td>11.3</td>
</tr>
<tr>
<td>Utrecht Univ</td>
<td>Netherlands</td>
<td>61</td>
<td>42.5</td>
<td>14</td>
<td>23.0</td>
</tr>
<tr>
<td>Oak Ridge Natl Lab</td>
<td>USA</td>
<td>60</td>
<td>20.4</td>
<td>9</td>
<td>15.0</td>
</tr>
<tr>
<td>CSIC</td>
<td>Spain</td>
<td>58</td>
<td>20.4</td>
<td>6</td>
<td>10.3</td>
</tr>
<tr>
<td>Indian Inst Technol</td>
<td>India</td>
<td>58</td>
<td>18.9</td>
<td>6</td>
<td>10.3</td>
</tr>
<tr>
<td>Imperial College London</td>
<td>UK</td>
<td>56</td>
<td>18.0</td>
<td>5</td>
<td>8.9</td>
</tr>
<tr>
<td>Oregon State Univ</td>
<td>USA</td>
<td>56</td>
<td>53.4</td>
<td>19</td>
<td>33.9</td>
</tr>
<tr>
<td>Total</td>
<td>World</td>
<td>8524</td>
<td>18.5</td>
<td>860</td>
<td>10.1</td>
</tr>
</tbody>
</table>

1. Total citations: accumulative citation counts, i.e. the number of times the research was cited from its publication date until May 2013. Self-citations are not removed.
2. CPP: citation per publication.
3. HCP: highly cited publications (in top 10% of publications by citations).

6th globally by citations. Table 3 shows the citation profiles of top 20 most productive countries in biomass field in two phases. As illustrated in Table 3 when measured by CPP, the average research impact of U.S. biomass studies is lower than that of Austria, Brazil, Greece, Germany and Canada in 1993–2002. Significant changes occurred in the second phase: none of the top 5 in the previous period were able to remain on the list. The new top 5 countries were the Netherlands, Spain, Austria, the U.S., and Turkey. In both phases, China’s citation per publication was outside the top 15 and far below the average citation per article at a global level.

One caveat of total citations and CPP is that individual papers can skew citation results. So we also adopt another commonly used citation-based indicator—highly cited publications (HCP) to measure one country’s relative competitive advantage in a particular research area (King 2004). In this article, we set the threshold 10% of the most cited documents in each phase under study. This threshold corresponds to receiving 79 citations or above for the first period publications (1993–2002), and at least 35 citations for articles published in the second period (2003–2012).

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5 The first column of counties in Table 3 is listed in descending order based on the total publications from 1993 to 2012.
The U.S. easily leads the list of HCP in both phases. The U.S. takes up 48.0 % and 35.1 % of the world HCPs in two periods respectively. It is interesting to note the position of countries in the HCP ranking did not change as significantly as that in CPP ranking. Similar to the indicator of CPP, the percentage of HCP of China is lower than the world
average in both phases. It indicates that the publications of China still suffer from relatively low research citation influence despite the rapid increase in number of publications. Yet there is growth in China’s influence in absolute terms: by top 10% cited articles, China moved from only one article in the earlier period to 67 articles in the later period.

**Institution level**

The research impact of national outputs can be disaggregated to the institutional level. As shown in Table 2, the University of Wisconsin possesses the highest CPP of 56.4, followed by the Max Planck Society (54.8) and Oregon State University (53.4). The CPP of the Chinese Academy of Sciences ranks the last among the top 20. Similar to the CPP ranking, most of the institutions topping the list of HCP are located in the U.S. or Western Europe.

**Research disciplines**

The data shows that biomass-based bioenergy is interdisciplinary with a changing research landscape. Thomson Reuters WoS provides 225 WoS disciplinary subject categories (Leydesdorff et al. 2013). In our first period (1993–2002), biomass publications covered

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**Table 3** Summary of the citation analysis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total citation</td>
<td>CPP</td>
</tr>
<tr>
<td>USA</td>
<td>23,147(40.2)</td>
<td>40.4</td>
</tr>
<tr>
<td>China</td>
<td>559(1.0)</td>
<td>20.0</td>
</tr>
<tr>
<td>UK</td>
<td>5,908(10.3)</td>
<td>39.4</td>
</tr>
<tr>
<td>Germany</td>
<td>5,544(9.6)</td>
<td>40.8</td>
</tr>
<tr>
<td>Japan</td>
<td>1,515(2.6)</td>
<td>23.0</td>
</tr>
<tr>
<td>Spain</td>
<td>3,110(5.4)</td>
<td>37.0</td>
</tr>
<tr>
<td>Canada</td>
<td>3,634(6.3)</td>
<td>40.8</td>
</tr>
<tr>
<td>India</td>
<td>1,627(2.8)</td>
<td>16.9</td>
</tr>
<tr>
<td>Sweden</td>
<td>2,575(4.5)</td>
<td>26.3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1,989(3.5)</td>
<td>34.9</td>
</tr>
<tr>
<td>Turkey</td>
<td>1,874(3.3)</td>
<td>37.5</td>
</tr>
<tr>
<td>Italy</td>
<td>2,468(4.3)</td>
<td>39.2</td>
</tr>
<tr>
<td>France</td>
<td>1,925(3.3)</td>
<td>32.1</td>
</tr>
<tr>
<td>Australia</td>
<td>2,104(3.7)</td>
<td>37.6</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,901(3.3)</td>
<td>47.5</td>
</tr>
<tr>
<td>Finland</td>
<td>1,632(2.8)</td>
<td>32.6</td>
</tr>
<tr>
<td>Denmark</td>
<td>645(1.1)</td>
<td>33.9</td>
</tr>
<tr>
<td>Greece</td>
<td>1,212(2.1)</td>
<td>44.9</td>
</tr>
<tr>
<td>Poland</td>
<td>176(0.3)</td>
<td>19.6</td>
</tr>
<tr>
<td>Austria</td>
<td>1,252(2.2)</td>
<td>48.2</td>
</tr>
<tr>
<td>World</td>
<td>57,627(100)</td>
<td>32.2</td>
</tr>
</tbody>
</table>

Data were retrieved in May 2013. Numbers in parentheses represent the world share.
104 categories. From 2003 to 2012, the number of subject categories of biomass research extended to 135 WoS categories (hereinafter SCs). This echoes earlier findings of a dynamic research landscape in the biomass domain (Konur 2012). Energy & Fuels ranks first in both two periods with shares of 35.1% and 38.1% respectively. In the second period, we can see growth in the category of Engineering, Chemical, which indicates increasing engineering attention to biomass-based bioenergy.

To provide a dynamic visualization of the changing scale and scope of biomass studies, we used science overlay maps developed by Rafols and his colleagues (Leydesdorff et al. 2013; Rafols et al. 2010). Figure 2 illustrates two snapshots of the research landscape of biomass-based bioenergy papers. The science overlay map allocates all the 225 SCs into 19 macro-disciplines. Pajek software version 3.11 is used to generate the science overlay map based on the SCs of all the publications. In the science overlay map, each node represents one SC and the size of each node is proportional to the number of publications of each SC. The arcs indicate the degree of similarity between two SCs, with thicker arcs demonstrating stronger similarity.

The maps reveal some interesting results. The nodes of the collaborative fields have increased in both size and complexity. The growth is particularly significant in Environment Science & Technology, Biomedical Science, Mechanical Engineering, and Agricultural Science. In the first phase of 1993–2002, biomass publications covered 15 macro-disciplines. By 2012, the number of macro-disciplines had risen to 17, with the emergence of two new macro-disciplines: Business & Management and Psychological Science. It is notable that many more interactions between different macro-disciplines have been generated, evidenced by the closeness and overlaying of nodes of different fields (Hu et al. 2012).

Research links-collaboration analysis

International co-authorship has been used as an indicator in many previous studies to investigate international collaboration (Bhattacharya et al. 2012; Guan and Ma 2007; Tang and Shapira 2011b). We analyzed international collaborative links through joint research papers. 89.7% of all the biomass-based bioenergy publications are accomplished by collaborative work, with a mean of 3.9 authors per publication. A total of 1,431 internationally co-authored papers are indexed in the WoS dataset. Table 4 shows the range of rates of international collaboration among the most productive countries. Over half of Austrian biomass research has international co-authors. This is followed by Australia with an international collaboration rate of 47.4%, Netherlands (43.9%), and Germany (42.9%). The international collaboration rates of Austria, Australia, France, Netherlands, Germany, and Finland are twice that of the world average. Two exceptions among the top 20 most prolific countries are Turkey (9.8%) and Poland (13.9%)—both with international collaboration rates that are far below the average of top 20 and the world as well.

The analysis shows that academic joint research in biomass has doubled in the last decade as reflected in the growing share of internationally coauthored papers. Additionally there is a trend of growing multi-nationality in research. In 1993, the average number of countries per article was 1.02; by 2012, it had increased to 1.24. Figure 3 depicts this pattern. It shows that global co-authorships in biomass have been consistently rising over the last 20 years. Yet in sharp contrast to the linear growth of international collaboration, domestic publication grew exponentially. The number of domestic publications outgrew international papers after 2002. That is to say, in terms of quantity, international research collaboration in biomass so far is but one element in knowledge production. An increasing
number of countries have participated in biomass-based bioenergy research. As shown in Fig. 3, in the first decade 80 countries contributed to knowledge production in this domain. The number increased to 112 in the second decade. The percentage of international publications grew rapidly from 12.0% during the first phase to 18.1% in the second phase.

In order to further probe the patterns of international collaboration, the social network analysis program UCINET was used to map international scientific co-authorship among the top 20 most productive countries.\(^6\) Again we aggregate internationally co-authored publication years into two periods (see Fig. 4). The sizes of nodes is proportional to the

\(^6\) Developed by Steve Borgatti, Martin Everett, and Lin Freeman, a free trial version of UCINET can be downloaded from http://www.analytictech.com/ucinet/trial.htm.
There are no isolated nodes in both periods. During the first phase of 1993–2002, there were about 160 international co-authorship linkages. The U.S. was notable as the leading international collaboration hub, demonstrating collaboration relationships with all other productive countries, including especially strong relationships with Canada, Brazil, and Germany. The UK and Germany also co-authored with almost all the productive European countries.

In the second period of 2003–2012, the number of joint research linkages rose to 310, with the remarkable increase in collaboration density. The U.S. was again the leading international collaboration hub. China started to build strong collaborations with the U.S. along with its rapid rise of publications. The UK and Germany, the two most productive European countries, maintained their positions as major European collaboration hubs in this phase.

### Conclusion and discussion

This study combines multiple bibliometric indicators and data visualization to explore the patterns and dynamics of global biomass-based bioenergy research. Our analyses show that...
academic research publications in this area have grown dramatically over the last two decades. Although international scientific collaboration has strongly intensified, publication activity in most countries is still dominated by domestic research.

As might be anticipated, our analyses consistently shows the U.S. leading by volume of publications, research impacts, and collaborative links with other nations. The U.S. strength in emerging scientific fields is not limited to biomass, as has been witnessed in the nanotechnology domain (Youtie et al. 2008). The study also finds that more countries are becoming involved in biomass knowledge production and that it is becoming more geographically distributed. China’s rise into the biomass research domain is not surprising considering its huge investment in this research field and its highly centralized science policy. However, although Chinese biomass research has relatively low citation impact in relationship to its total output, the absolute number of highly cited papers has grown. More disciplines have became involved in biomass-based bioenergy research. Strong interactions took place both within macro-disciplines and between macro-disciplines during the second period of 2003–2012.

This research has limitations. The WoS database favors English-language journals (Lin and Zhang 2007; Tang and Shapira 2011a). In our data, only 3 % of biomass research was written in languages other than English. This may underestimate the research activities of non-English-speaking countries, including China, Japan, and Russia. Additionally, the rationale and limitations of bibliometric analyses have been widely discussed in previous studies (Lawani and Baye 1983). We are aware that co-authorship is an approximate but imperfect barometer of collaborative research activities. Citation analysis also has limitations and may favor early entrants.

Acknowledgments This work is supported by National Natural Science Foundation of China (#71132006, #71003054, and #71303147) and China Scholarship Council. The authors are grateful to Abdullah Gok, Penghui Lv, Long Chen, and Oliver Shackleton for their helpful discussions and suggestions. The authors would also like to thank the chief editor of Scientometrics and anonymous reviewers for their constructive comments.
Fig. 4  International collaboration in biomass research among top 20 countries

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