Science-Metrix

Canada-U.S. Collaborations in Clean Energy Research

A Scientometric Analysis (2005-2009)

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Executive Summary

The Canadian working group on expanding clean energy R&D collaboration is currently reviewing existing Canada-U.S. partnerships in order to identify prospective areas for long-term clean energy R&D collaborative initiatives as part of the framework mandated by the Clean Energy Dialogue Action Plan. The present scientometric study represents one of the sources this working group will draw on to develop a more robust understanding of the scientific production and collaborative landscape in the field of clean energy R&D and in three subfields of interest: future generation biofuels, clean energy vehicles and green buildings.

This scientometric study found that the scientific output in clean energy R&D and its three subfields increased dramatically during the 2005–2009 period, internationally, in the U.S. and in Canada. Both these countries are among the 15 leading countries in clean energy R&D, with the U.S. being the largest producer in the field overall and in the three subfields. Indicators of scientific impact, quality and specialization suggest that the strengths of leading countries vary across the subfields, but overall in clean energy R&D, Sweden and Turkey stand out as having levels of impact and specialization that are above the world level. Canada, Germany, the Netherlands, the U.S. and the U.K. all rank above the world average in impact but are not particularly specialized in this field. Note that the small number of publications in green buildings research limited the conclusions that could be drawn from the data for this subfield.

In terms of collaboration patterns, the analysis shows that, in over 60% of cases, the countries examined are collaborating less than expected by chance with their leading counterparts. In clean energy R&D and in the three subfields, Canada's strongest affinities are generally with the U.S., Turkey and China. Overall, with a few exceptions, papers published collaboratively with other countries are, on average, more highly cited than non-collaborative papers. In fact, this is the case for Canada in clean energy R&D overall.

In addition to the data presented at the country level, leading U.S. and Canadian institutions in these research areas were identified, as were those most active in terms of Canada/U.S. cross-border collaborations. The analysis of Canada/U.S. collaboration patterns at the institution level indicates that Canadian institutions tend to collaborate more with U.S. institutions than U.S. institutions do with Canadian organizations; this is actually not surprising given the relative size of organizations in these countries.

The reader is invited to consult Section 6, which provides additional details on the key findings with regard to the scientific performance of leading countries in the field of clean energy R&D, as well as to existing collaboration patterns in this field.

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Introduction

In February 2009, the U.S. and Canada established the Clean Energy Dialogue to identify ways to jointly reduce greenhouse gases and combat climate change.[1] In addition to environmental benefits, this initiative envisions bilateral efforts to build a new clean energy economy as a key element of both countries' broader economic recovery and reinvestment efforts. The Dialogue impelled the development of an Action Plan by joint Canada-U.S. working groups that incorporates innovative and applicational activities across three defined areas: the development of clean energy technology, the construction of a more efficient energy grid, and the expansion of research and development. These activities aim to optimize currently available modes of environmentally responsible energy production, minimize waste in energy transportation and delivery, and bring about the next generation of alternatives.

In the Report to Leaders presented on September 16, 2009, clean energy R&D was highlighted as one of the most promising areas for international action under the Dialogue.[2] The Canadian working group responsible for expanding clean energy R&D collaboration is comprised of high-ranking representatives from the key public sector science and energy bodies and includes senior officials from Environment Canada, NRCan, NRC, NSERC and AAFC. The group is reviewing existing Canada-U.S. partnerships in order to identify prospective areas for long-term clean energy R&D initiatives and, in particular, ways to expand research collaboration on future-generation biofuels, clean engines/vehicles, and energy efficiency (homes and buildings). It is also attentive to "big ideas" that may not fit in these categories but fall under its larger goal.

The Canadian working group is drawing on various sources of information to develop a robust understanding of the collaborative landscape and to best construct a framework for Canada-U.S. clean energy R&D collaboration, as mandated by the Clean Energy Dialogue Action Plan. These sources include stakeholder inputs from the private, academic and not-for-profit sectors, as well as the commissioning of this scientometric study, which considers research publication data across the key areas identified by the group. Research paper statistics provide a measure of innovative knowledge production and reveal the collaborative patterns and trends occurring in this field.

This study begins with an examination of clean energy R&D as a whole before moving to more focused examinations of scientific activity in three subfields: future generation biofuels, clean energy vehicles and green buildings. The data provide a picture of the relative strengths and weaknesses of Canada and the U.S. in these areas. In addition, collaboration patterns and the effect of collaboration on scientific impact and quality are described at the country level. Finally, leading Canadian and U.S. research institutions will be considered to better apprehend their contributions to these fields and to identify those that were the most active in terms of Canada/U.S. cross-border collaborations. Note that the methods used in this study are presented in Appendix 1.

[1] http://pm.gc.ca/eng/media.asp?id=2432

[2] http://pm.gc.ca/eng/media.asp?id=2821

1 Characterizing Clean Energy R&D

Section 1 presents data on clean energy publications – in Canada and internationally – from 2005 to 2009. Bibliometric data are first used to examine overall publication trends at the world level, followed by an assessment of output in the U.S. and in Canada (Section 1.1). Subsequently, the outputs of leading countries in the field are presented together with their level of specialization and scientific impact and quality (Section 1.2). Finally, data on international collaboration between these countries are presented in Section 1.3.

1.1 Publication trends in clean energy R&D

Figure 1 presents data for the five-year period extending from 2005 to 2009. It shows that the percentage of papers published in the area of clean energy R&D, relative to the overall number of papers in the Web of Science (WOS), has increased from about 6,400 to more than 13,600 papers. This represents a growth of 112% over only five years and confirms that clean energy is one of the hot research areas in science. Expressed as a proportion of the total world output, the production of clean energy papers has increased from 0.7% to 1.3%, indicating an overall growth in this field at the international level.[3]

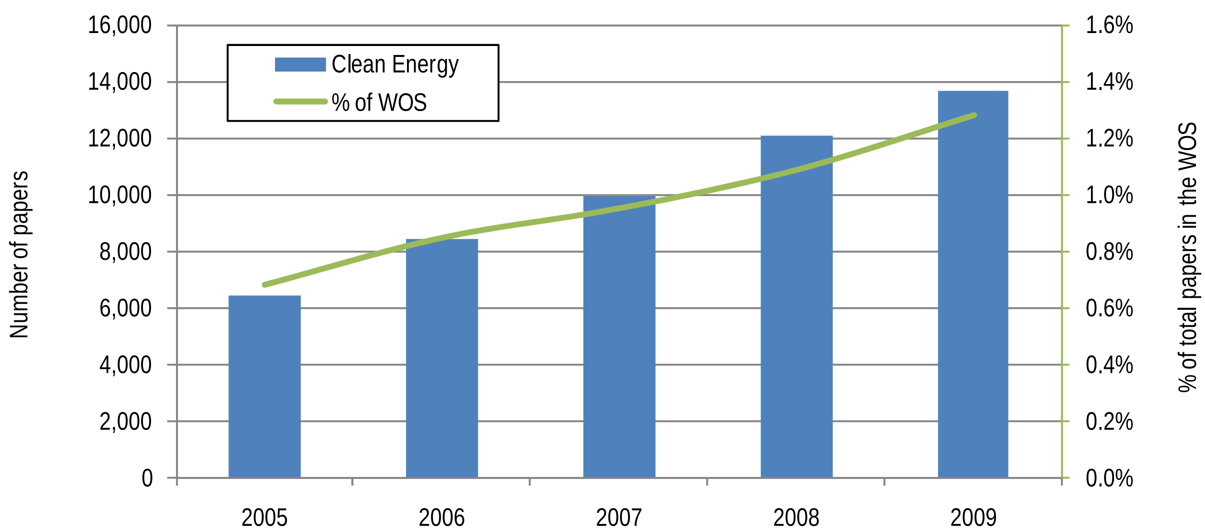


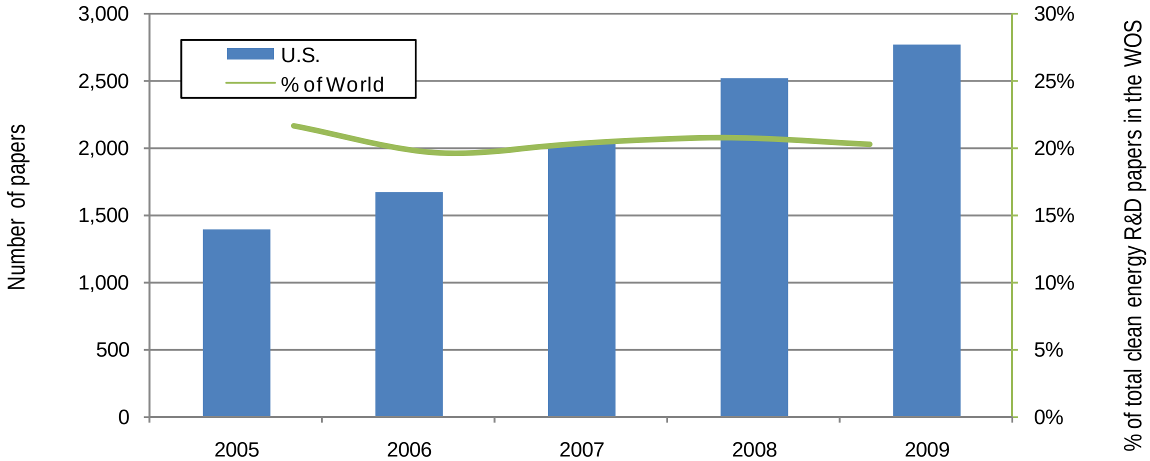
Figure 1 Number and percentage of clean energy papers, 2005–2009

Source: Compiled by Science-Metrix from WOS data

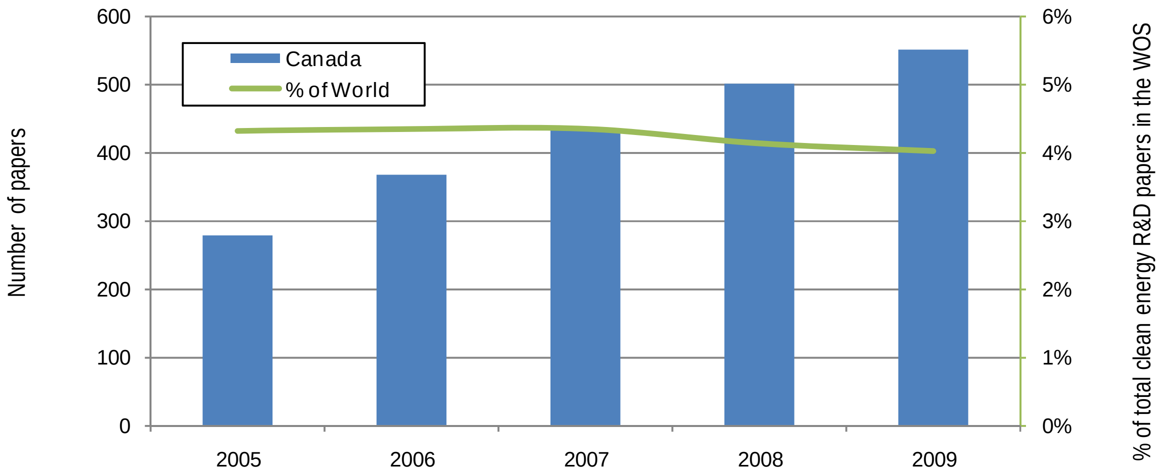
An examination of the relative production of papers in this field by both the U.S. and Canada reveals that the two countries have increased their production at a similar pace to that observed at the world level (green lines, Figure 2A and Figure 2B). Indeed, Figure 2 shows the number of clean energy

[3] Expressing the output as percentage of the world total is required in order to take into consideration the general expansion of science as well as that of the WOS database's coverage during the given time period. This metric indicates whether an area of research is gaining or losing ground compared to science as a whole.

papers from both countries has nearly doubled in the last five years. However, their growth remains about 12 percentage point slower than the world level, which means that both Canada and the U.S. have lost some ground to the competition in terms of their clean energy R&D output.



A



B

Figure 2 Number and percentage of clean energy papers produced by A) the U.S. and B) Canada, 2005–2009

Source: Compiled by Science-Metrix from WOS data

1.2 Leading countries in clean energy R&D

The top 15 producers of clean energy science at the international level were identified based on their total number of papers produced from 2005 to 2009 (Dashboard 1). These 15 same countries will be presented in subsequent sections of this report (i.e., Section 2 on future generation biofuels, Section 3 on clean energy vehicles and Section 4 on green buildings).

Dashboard 1 shows that the U.S. and China are by far the leading producers of research in this area: over 4,000 papers separate them from Japan, which ranks third. Interestingly, Asian countries represent three of the top five producers of clean energy papers, with Germany occupying 4th place.

Based on solely the number of papers produced, Canada ranks 9th in the world. With regard to the trends in their share of the world's clean energy papers ("Trend" column), countries whose share increased between 2005 and 2009 include China, the Republic of Korea, India and Turkey. Over the same period, this share has decreased most notably for Japan, the Netherlands and Sweden.

The top 15 countries were then examined more closely using three indicators: the specialization index (SI), the average of relative citations (ARC), and the average relative impact factor (ARIF). The SI indicates the intensity of research in a given field relative to the rest of the world; when a country has an SI score that is greater than 1, it published a greater proportion of its papers in that field than does the rest of the world. The ARC indicates the impact of a country's research, as it represents how often its papers are cited relative to the world's average paper in the same field. The ARIF indicates the quality of a country's research based on the impact factor of the journals in which its papers are published: the greater the impact factor of journal, the more selective the editors can be and, therefore, the greater the quality of the published papers. In both cases, a score above 1 means a country's score is higher than the world average. A combination of high numbers of papers and high levels of specialization and impact is the best-case scenario when assessing the strengths of a country or region in a given field.

	Papers			SI		ARC		ARIF	
Country	N	Rank	Trend	Score	Rank	Score	Rank	Score	Rank
United States	10,355	*(1)*			*(13)*		*(2)*		*(3)*
China	9,071	*(2)*			*(2)*		*(13)*		*(15)*
Japan	4,854	*(3)*			*(5)*		*(12)*		*(11)*
Germany	3,589	*(4)*			*(9)*		*(7)*		*(7)*
Rep. of Korea	2,821	*(5)*			*(1)*		*(11)*		*(12)*
United Kingdom	2,603	*(6)*			*(15)*		*(3)*		*(2)*
India	2,195	*(7)*			*(3)*		*(15)*		*(14)*
France	2,140	*(8)*			*(12)*		*(10)*		*(6)*
Canada	2,130	*(9)*			*(10)*		*(6)*		*(10)*
Spain	1,913	*(10)*			*(7)*		*(8)*		*(8)*
Italy	1,785	*(11)*			*(11)*		*(14)*		*(9)*
Netherlands	1,176	*(12)*			*(8)*		*(1)*		*(1)*
Turkey	1,168	*(13)*			*(4)*		*(4)*		*(13)*
Sweden	1,075	*(14)*			*(6)*		*(5)*		*(5)*
Australia	1,011	*(15)*			*(14)*		*(9)*		*(4)*
World	50,568								

Dashboard 1 Benchmarking of leading countries in clean energy R&D, 2005–2009

Note: The Trend column indicates the variation in the share of world papers in clean energy. SI, ARC and ARIF: a black dot in the green area indicates a score above the world average; when the black dot is in the red area, the score is below the world average.

Source: Compiled by Science-Metrix from WOS data

An examination of specialization, impact and quality indicators reveals several interesting features. First, it is readily seen that, as well as being in the top five producers of research in this area, China, Japan and the Republic of Korea are also among the top five in the world in terms of specialization (with rankings of 2nd, 5th and 1st respectively). This is especially significant because only six countries among these 15 leaders are specialized (SI > 1.0) in clean energy research; the other three are India (ranked 3rd), Turkey (4th) and Sweden (6th). Canada ranks 10th in terms of specialization among these leading countries, its SI score being just below the world average.

The Netherlands ranks first in both scientific impact (ARC) and quality (ARIF). The U.S. and the U.K. rank respectively 2nd and 3rd in scientific impact (and 3rd and 2nd for quality); thus, even though these countries are not specialized in this field, they are producing highly cited and high quality clean energy research relative to the other leading countries, as well as relative to the world (ARC and ARIF > 1.0, 1.0 being the world average). Sweden and Germany are the only remaining countries of the top 15 for which both impact and quality scores are above the world average. Canada ranks 6th for impact (ARC score slightly above world average) and 10th for quality (ARIF score at the world average). This indicates that while Canadian research in this field tends to be cited slightly more than world average, it is being published in average journals compared to the overall output in this field.

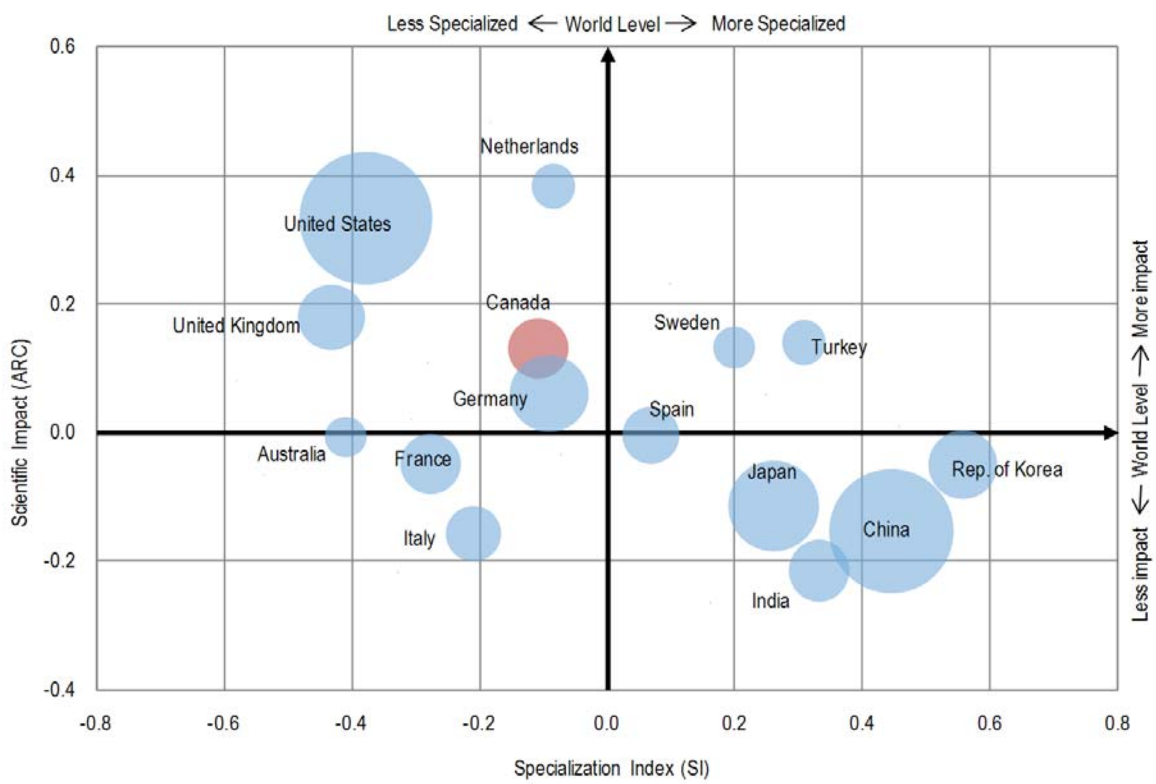


Figure 3 Positional analysis of leading countries in clean energy R&D
Source: Compiled by Science-Metrix from WOS data

Specialization and impact indicators, in combination with paper counts, can also be used to generate a positional analysis graph, which allows for several fields or subfields to be assessed at a glance (Figure 3). The horizontal axis of the positional analysis graph corresponds to the SI and the vertical axis to the ARC, whereas the size of the bubbles is proportional to the number of papers published in this field by each country. The performance of countries can therefore be interpreted based on the size of their bubble and its position within the four quadrants, with the top right quadrant being synonymous with excellence (i.e., high levels of specialization and impact).

Figure 3 shows that only two of the most active countries in clean energy research are currently positioned in the top right quadrant – i.e., Turkey and Sweden. As mentioned above, China, Japan, the Republic of Korea and India are all highly specialized, but their research has yet to become recognized in terms of citations, as shown by their impact position below the world average. Canada, the U.S., the U.K., Germany and the Netherlands are all positioned in the upper left quadrant, indicating an overall lack of specialization but levels of scientific impact above the world average.

1.3 International collaboration patterns and affinity indices

At the international level, a paper is deemed to be produced in collaboration when there are at least two different countries appearing in the address field of a paper. For example, if a paper is co-authored by two researchers from Canada and one from the U.S., the paper will count as one collaboration for Canada and one for the U.S. The collaboration rate is calculated by dividing the number of papers written in collaboration by a given entity by its total number of papers. This ratio is use to determine the proportion of papers that a country produces with international collaborators, and is especially useful to examine trends over time.

However, its use for comparing collaboration across countries is limited, as it is very sensitive to scale. Indeed, the larger the country, the more likely scientists will find national collaborators in the same field – in other words, without resorting to international collaboration. In very small countries, it is less likely than another researcher in the same field will be found locally; hence, the percentage of international collaboration increases as country size decreases. Because of this, Science-Metrix has developed an indicator of "propensity to collaborate," which takes into account the country's size and the specific collaboration dynamics in a system (see Methods).

Table I shows that for the 2005–2009 period, the five leading countries in terms of propensity to collaborate were France, Germany, the U.K., Australia and the Netherlands. Based on this indicator, Canada ranks 9th among the 15 leading producers of clean energy R&D. Note that the U.S. and China have the two highest *numbers* of collaborations, but because their overall output is also very large, they only collaborate on 25% and 17%, respectively, of their total clean energy papers. Overall trends in collaboration rates ("Trend" column) vary considerably by country, with the most marked increases from 2005 to 2009 occurring in Sweden, Japan and China.

Table I International collaboration of leading countries in clean energy R&D, 2005–2009

Country	Collaborations	All Papers	Collaboration Rate	Trend	Propensity to Collaborate	Ranking
France	1,002	2,140	47%		1.55	(1)
Germany	1,453	3,589	40%		1.44	(2)
United Kingdom	1,100	2,603	42%		1.44	(3)
Australia	470	1,011	46%		1.38	(4)
Netherlands	523	1,176	44%		1.35	(5)
Sweden	455	1,075	42%		1.27	(6)
Italy	611	1,785	34%		1.11	(7)
Spain	632	1,913	33%		1.08	(8)
Canada	672	2,130	32%		1.05	(9)
United States	2,551	10,355	25%		1.02	(10)
Rep. of Korea	642	2,821	23%		0.78	(11)
Japan	977	4,854	20%		0.75	(12)
India	478	2,195	22%		0.72	(13)
China	1,578	9,071	17%		0.71	(14)
Turkey	187	1,168	16%		0.49	(15)

Source: Compiled by Science-Metrix from WOS data

Table II presents data on the effect of collaboration on the impact and quality of the scientific output of leading countries in clean energy R&D. An examination of the ARC values reveals that with the exception of two countries – the U.S. and the Netherlands – papers published collaboratively with other countries are, on average, more highly cited than papers without international co-authors. The two most substantial increases in ARC scores associated with international collaboration were seen for the Republic of Korea (from 0.82 to 1.43) and Turkey (from 1.03 to 1.64). Other countries where international collaborations resulted in a notable increase in scientific impact are: China (from 0.81 to 1.10), Germany (from 0.96 to 1.21), Japan (from 0.83 to 1.18), Spain (from 0.87 to 1.26), Italy (from 0.72 to 1.08), Australia (from 0.86 to 1.15) and Sweden (from 1.02 to 1.32).[4] The only country where international collaboration appears to be associated with a notable decrease in ARC score was the Netherlands (from 1.70 to 1.21).

An analysis of the effect of international collaboration on ARIF scores shows a less dramatic effect overall, with 10 of the 15 countries exhibiting little to no change in quality when comparing collaborative versus non-collaborative papers (Table II).The five countries where notable increases in ARIF scores were observed are: China (from 0.89 to 1.07), Germany (from 1.00 to 1.17), Japan (from 0.93 to 1.08), the Republic of Korea (from 0.91 to 1.10), and Turkey (from 0.89 to 1.09). No countries exhibited a notable decrease in their ARIF score in association with international collaboration.

A comparison of the effect of international collaboration on ARC and ARIF scores reveals five countries for which collaboration increases both their ARC and ARIF scores: China, Germany, Japan, the Republic of Korea and Turkey. Interestingly, except for Germany, all these countries had low propensity to perform research in international collaboration. With the exception of India, all

[4] Notable differences in ARC and/or ARIF scores were defined as a change (be it positive or negative) of 0.15 or greater.

countries having ARC and ARIF scores below the world average for their papers without international collaboration achieved scores above the world average (for both indicators) for their papers written with international co-authors.

Table II Effect of collaboration on the output of leading countries in clean energy R&D, 2005–2009

Country	With international collaboration			Without international collaboration			All Papers		
	Papers	ARC	ARIF	Papers	ARC	ARIF	Papers	ARC	ARIF
United States	2,551	1.40	1.18	7,804	1.42	1.14	10,355	1.41	1.15
China	1,578	1.10	1.07	7,493	0.81	0.89	9,071	0.85	0.92
Germany	1,453	1.21	1.17	2,136	0.96	1.00	3,589	1.06	1.07
United Kingdom	1,100	1.28	1.18	1,503	1.14	1.14	2,603	1.20	1.15
France	1,002	1.03	1.09	1,138	0.89	1.06	2,140	0.95	1.07
Japan	977	1.18	1.08	3,877	0.83	0.93	4,854	0.89	0.96
Canada	672	1.22	1.06	1,458	1.10	0.97	2,130	1.14	1.00
Rep. of Korea	642	1.43	1.10	2,179	0.82	0.91	2,821	0.95	0.96
Spain	632	1.26	1.15	1,281	0.87	1.02	1,913	0.99	1.07
Italy	611	1.08	1.10	1,174	0.72	1.00	1,785	0.85	1.04
Netherlands	523	1.21	1.17	653	1.70	1.22	1,176	1.50	1.20
India	478	0.82	0.98	1,717	0.80	0.90	2,195	0.80	0.92
Australia	470	1.15	1.15	541	0.86	1.07	1,011	0.99	1.11
Sweden	455	1.32	1.16	620	1.02	1.06	1,075	1.14	1.10
Turkey	187	1.64	1.09	981	1.03	0.89	1,168	1.15	0.93

Source: Compiled by Science-Metrix from WOS data

Another collaboration indicator, the probabilistic affinity index (PAI) indicates the intensity of scientific collaboration between two countries: it compares the observed number of bilateral collaborations between two countries with the number expected, given their individual share of world bilateral collaborations. A positive PAI value means that two countries collaborate more than expected, whereas a negative index value means the opposite. Note that the PAI is based on the number of *bilateral* collaborations of countries and not on the absolute number of papers written in international collaboration (see Methods for more details).

Figure 4 presents the PAI scores for the 15 leading producers of clean energy R&D. In over 60% of cases, these countries exhibit negative PAI scores, which means that they collaborate less than expected by chance with their leading counterparts. The country pairings with the strongest affinity index are Canada/Turkey and India/Republic of Korea: both have PAI scores of 0.95. Spain, Italy and France all exhibit relatively high (i.e., 0.5 or higher) affinity indices for collaboration with one another. Generally, affinity patterns of E.U. countries reveal a strong tendency towards intra-E.U. collaboration but little with their Asian or North American counterparts.

Overall, the U.S. and the U.K. tend to have relatively high preference affinities for a larger number of their counterparts than do other leading countries (Figure 4). Japan, China, and the Republic of Korea have relatively high affinity for at least three other countries. Outside of collaboration with Asian countries and the U.S., however, the Republic of Korea exhibits the least overall degree of affinity with its remaining counterparts. There is also considerable affinity amongst Australia, Japan and China. Canada and U.S. both have strong affinities for one another, China and Turkey; as mentioned, the U.S. also has preferential ties with the Republic of Korea.

Country	U.S.	China	Japan	Germany	R. of Korea	U.K.	India	France	Canada	Spain	Italy	Netherlands	Turkey	Sweden	Australia
U.S.		0.56	0.02	-0.10	0.75	-0.11	0.28	-0.50	0.57	-0.44	-0.02	-0.44	0.71	-0.33	-0.03
China	0.56		0.74	-0.38	0.30	-0.24	-0.03	-0.51	0.63	-0.99	-0.89	-0.82	-1.00	0.36	0.59
Japan	0.02	0.74		-0.48	0.69	-0.34	0.61	-0.68	-0.20	-0.79	-0.50	-0.75	-0.75	-0.90	0.63
Germany	-0.10	-0.38	-0.48		-0.74	-0.03	-0.53	0.20	-0.74	0.39	0.09	0.49	0.10	-0.34	0.30
R. of Korea	0.75	0.30	0.69	-0.74		-0.32	0.95	-0.96	-0.39	-0.98	-0.90	-1.00	-0.95	-0.98	-0.19
U.K.	-0.11	-0.24	-0.34	-0.03	-0.32		-0.27	-0.41	-0.12	0.45	0.37	0.47	0.09	-0.16	0.29
India	0.28	-0.03	0.61	-0.53	0.95	-0.27		-0.22	-0.28	-0.93	-0.25	-0.50	-0.92	-0.92	-0.29
France	-0.50	-0.51	-0.68	0.20	-0.96	-0.41	-0.22		-0.14	0.62	0.57	-0.10	-0.80	-0.16	-0.50
Canada	0.57	0.63	-0.20	-0.74	-0.39	-0.12	-0.28	-0.14		-0.89	-0.82	-0.46	0.95	-0.41	-0.68
Spain	-0.44	-0.99	-0.79	0.39	-0.98	0.45	-0.93	0.62	-0.89		0.53	0.29	-0.41	0.02	-0.74
Italy	-0.02	-0.89	-0.50	0.09	-0.90	0.37	-0.25	0.57	-0.82	0.53		0.28	-0.74	0.11	-0.78
Netherlands	-0.44	-0.82	-0.75	0.49	-1.00	0.47	-0.50	-0.10	-0.46	0.29	0.28		-0.85	0.33	0.08
Turkey	0.71	-1.00	-0.75	0.10	-0.95	0.09	-0.92	-0.80	0.95	-0.41	-0.74	-0.85		-0.76	-1.00
Sweden	-0.33	0.36	-0.90	-0.34	-0.98	-0.16	-0.92	-0.16	-0.41	0.02	0.11	0.33	-0.76		-0.68
Australia	-0.03	0.59	0.63	0.30	-0.19	0.29	-0.29	-0.50	-0.68	-0.74	-0.78	0.08	-1.00	-0.68	

Figure 4 Probabilistic affinity indices (PAI) between leading producers of clean energy R&D, 2005–2009
Source: Compiled by Science-Metrix from WOS data

2 Characterizing Scientific Activity on Future Generation Biofuels

Section 2 presents publication data on future generation biofuels – in Canada and internationally – from 2005 to 2009. Publication trends at the world level are examined first, followed by an assessment of the papers by the U.S. and in Canada (Section 2.1). The output of leading countries in the future generation biofuels is then presented along with their specialization and scientific impact scores (Section 2.2) and followed by an examination of international collaboration between these countries (Section 2.3).

2.1 Publication trends in future generation biofuels research

Figure 5 presents the number of papers published in the subfield of future generation biofuels research, as well as this area's share of the overall number of papers in the WOS for the 2005–2009 period. During this period, the published output increased from about 500 to close to 1900 papers. This represents an increase from 0.05% to 0.17% of papers in the WOS, indicating real growth of this subfield relative to science as a whole. Although the number of future generation biofuels papers was relatively small in 2005, the observed growth is also very strong in absolute terms: there are now more than 2.7 times more papers being published in this subfield than five years ago.

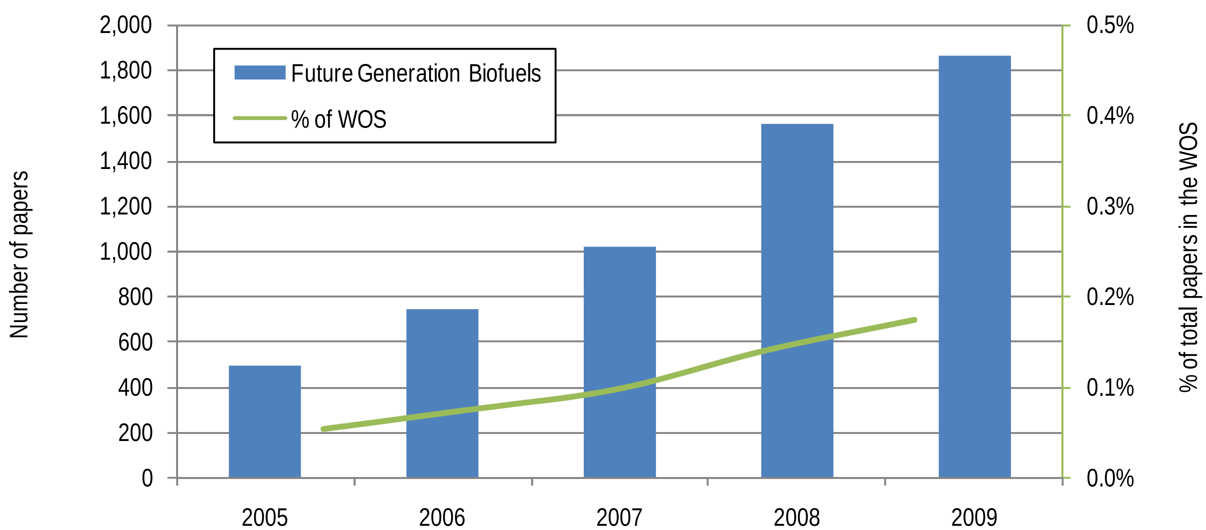
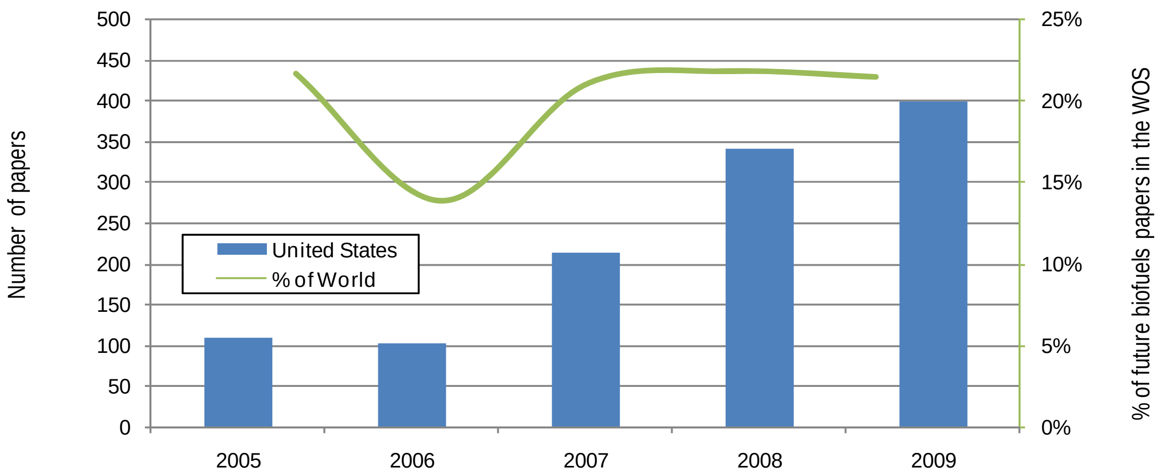


Figure 5 Number and percentage of future generation biofuels papers, 2005–2009

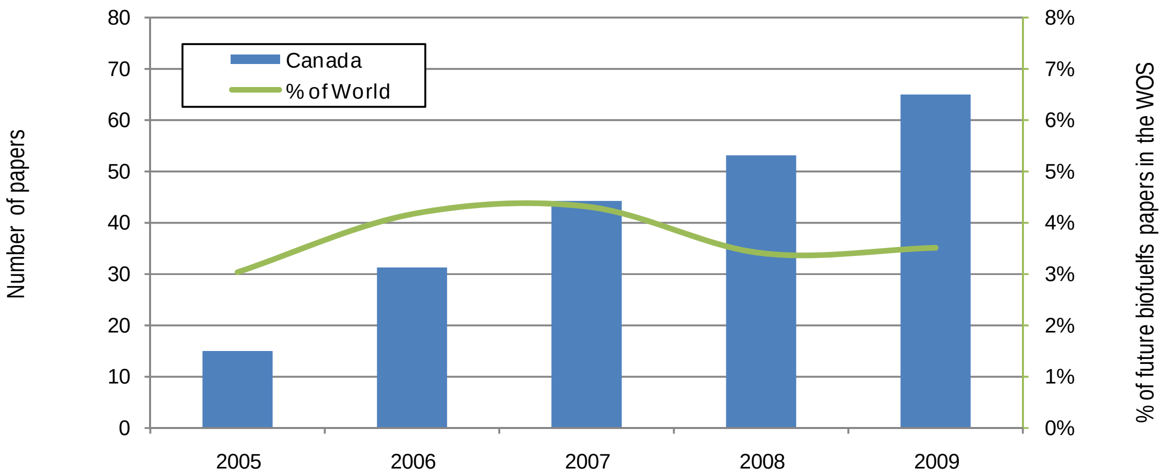
Source: Compiled by Science-Metrix from WOS data

An examination of the relative output of papers in this subfield by the U.S. and Canada indicate that these two countries contributed to a somewhat variable share of the world's future generation biofuels papers between 2005 and 2009 (green lines, Figure 6A and Figure 6B). Nonetheless, both countries have increased their output steadily over this period. In fact, the growth of the Canadian output in this subfield was particularly strong: there are now 3.3 times the number of future generation biofuels papers being published by Canadian researchers than was the case in 2005. In the

U.S., production of future generation biofuels papers dipped slightly in 2006, but returned to approximately 22% of the world's output in this subfield by 2009.



A



B

Figure 6 Number and percentage of future generation biofuels papers produced by A) the U.S. and B) Canada, 2005–2009

Source: Compiled by Science-Metrix from WOS data

2.2 Leading countries in future generation biofuels research

Dashboard 2 presents the scientific production of selected countries in future generation biofuels research for the 2005–2009 period (these are the same countries as those presented in Section 1). The U.S. is by far the leading producer of research in this subfield, with nearly twice as many papers as China (ranked 2nd) and more than three times as many papers as India (3rd). Following India are five countries that produced a similar number of papers over the past five years (i.e., approximately 300). Among these countries, Turkey – which ranked 13th for the size of its overall scientific production in clean energy R&D – ranks 5th in future generation biofuels; this is a higher ranking than four of the main producers in clean energy R&D, namely Germany (6th in future generation biofuels), the UK

(7th), Canada (11th), and France (13th). Interestingly, the strongest increases in terms of the share of the world's production in this subfield (as illustrated in the "Trend" column) belong to China and France. In contrast, the share of the world's papers held by Japan, Spain and Sweden clearly decreased over the 2005–2009 period.

The specialization and impact scores of selected countries in future generation biofuels reveal several interesting features (Dashboard 2). First, along with being among top producers of research in this area, China, India and Turkey are also among the top six in the world in terms of specialization (ranked 6th, 3rd and 1st, respectively). The other countries that have high SI scores are Sweden (2nd), the Netherlands (4th) and Spain (5th). The intensity of future generation biofuels research in Canada is below the world average, and Canada ranks 7th based on its SI score.

	Papers			SI		ARC		ARIF	
Country	N	Rank	Trend	Score	Rank	Score	Rank	Score	Rank
United States	1,165	*(1)*			*(11)*		*(3)*		*(5)*
China	686	*(2)*			*(6)*		*(4)*		*(6)*
India	370	*(3)*			*(3)*		*(6)*		*(12)*
Japan	323	*(4)*			*(8)*		*(10)*		*(9)*
Turkey	317	*(5)*			*(1)*		*(2)*		*(11)*
Germany	295	*(6)*			*(12)*		*(13)*		*(14)*
United Kingdom	294	*(7)*			*(14)*		*(5)*		*(2)*
Spain	287	*(8)*			*(5)*		*(7)*		*(4)*
Sweden	240	*(9)*			*(2)*		*(12)*		*(10)*
Netherlands	218	*(10)*			*(4)*		*(1)*		*(3)*
Canada	208	*(11)*			*(7)*		*(9)*		*(13)*
Italy	190	*(12)*			*(9)*		*(14)*		*(7)*
France	178	*(13)*			*(15)*		*(8)*		*(8)*
Australia	131	*(14)*			*(10)*		*(11)*		*(1)*
Rep. of Korea	113	*(15)*			*(13)*		*(15)*		*(15)*
World	5,690								

Dashboard 2 Benchmarking of selected countries in future generation biofuels research, 2005–2009

Note: The Trend column indicates the variation in the share of world papers in clean energy. SI, ARC and ARIF: a black dot in the green area indicates a score above the world average; when the black dot is in the red area, the score is below the world average.

Source: Compiled by Science-Metrix from WOS data

The Netherlands ranks highly for both impact and quality indicators (1st in ARC, 3rd in ARIF, respectively) and its future generation biofuels papers are highly cited, as well as being published in journals that are cited more than the world level. The U.S. and the U.K. also have relatively high impact and quality scores (i.e., above the world level) despite their overall lack of specialization. While Turkey ranks 2nd in ARC (and has an impact score above the world level), its ARIF score indicates that it does not publish papers in journals that are more cited than the world average. Canada ranks 9th in ARC and 13th in ARIF and falls below the world average for both indicators, which means that Canadian future generation biofuels research is, on average, neither particularly highly cited, nor is it being published in highly cited journals.

The positional analysis of selected countries in future generation biofuels research clearly shows five countries occupying the top right quadrant, which represents excellence: Turkey, India, the Netherlands, Spain and China. The U.S. and the U.K. are positioned in the upper left quadrant, indicating an overall lack of specialization but impact scores above the world average. Canada, along with Japan, France, Australia, Germany, Italy and the Republic of Korea are situated in the bottom left quadrant because both their levels of specialization and impact are below the world average.

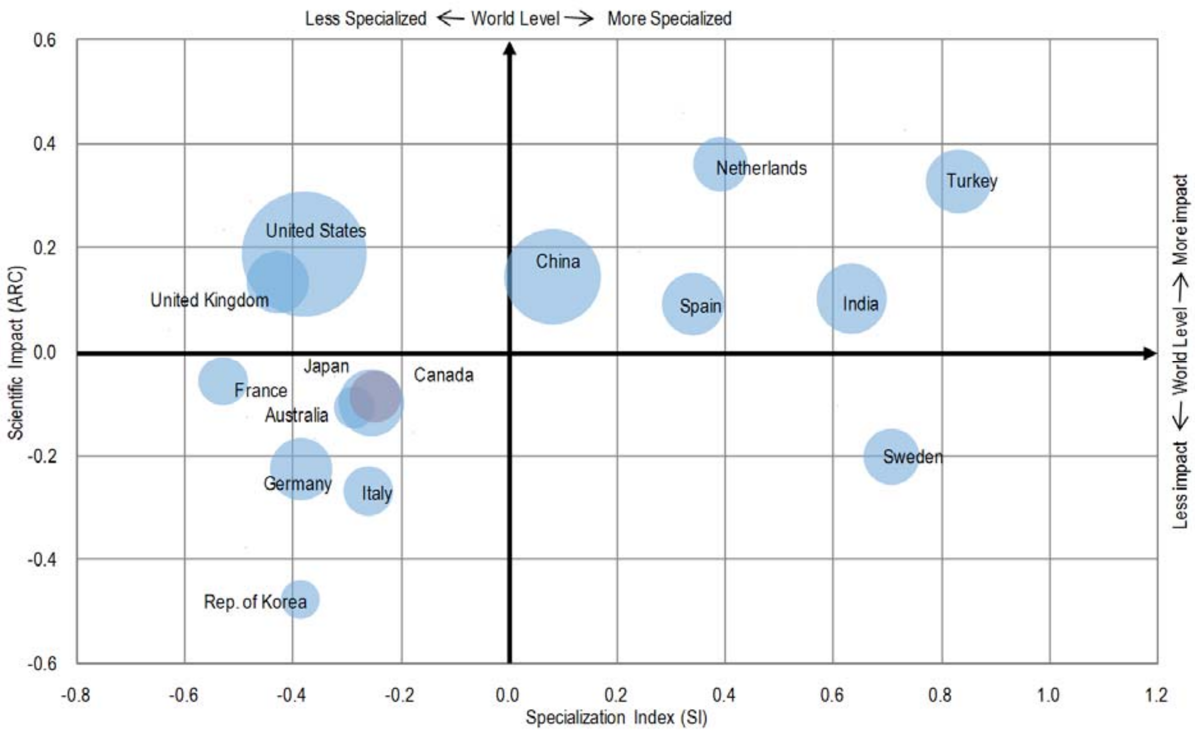


Figure 7 Positional analysis of selected countries in future generation biofuels research

Source: Compiled by Science-Metrix from WOS data

2.3 International collaboration patterns and affinity indices

The international collaboration patterns in future generation biofuels research are shown in Table III for selected countries over the 2005–2009 period. Based on their propensity to collaborate, the five leading countries are all E.U. members: France, the Netherlands, the U.K., Sweden and Germany. Canada ranks 8th, behind Australia and the U.S. Looking at trends in each country's collaboration rate, Sweden, China and Spain generally increased the proportion of papers they published with international co-authors from 2006 to 2009.

Table III International collaboration of selected countries in future generation biofuels research, 2005–2009

Country	Collaborations	All Papers	Collaboration Rate	Trend	Propensity to Collaborate	Ranking
France	78	178	44%		1.54	(1)
Netherlands	91	218	42%		1.54	(2)
United Kingdom	113	294	38%		1.52	(3)
Sweden	93	240	39%		1.46	(4)
Germany	108	295	37%		1.45	(5)
Australia	55	131	42%		1.38	(6)
United States	270	1,165	23%		1.26	(7)
Canada	71	208	34%		1.25	(8)
Japan	99	323	31%		1.24	(9)
Italy	60	190	32%		1.13	(10)
Rep. of Korea	39	113	35%		1.10	(11)
China	149	686	22%		1.04	(12)
Spain	70	287	24%		0.96	(13)
India	68	370	18%		0.77	(14)
Turkey	27	317	9%		0.34	(15)

Source: Compiled by Science-Metrix from WOS data

Table IV presents data on the effect of international collaboration on selected countries in future generation biofuels research. An examination of the ARC values (where available[5]) reveals that – with the exception of the U.K. and the Netherlands – papers published in collaboration with other countries are, on average, more highly cited than papers without international co-authors. The most substantial increases in ARC scores were seen for the U.S. (from 1.12 to 1.58) and China (from 1.12 to 1.39). As mentioned above, ARC scores only decreased in association with international collaboration for the Netherlands (from 1.79 to 0.97) and the U.K. (from 1.17 to 1.11).

The effect of international collaboration was much less dramatic with regard to quality: the ARIF scores of 11 of the 14 countries exhibited little to no change when comparing collaborative versus non-collaborative papers in future generation biofuels research (Table IV).[6] Notable increases in ARIF scores were observed for Canada (from 0.85 to 1.01), Germany (from 0.82 to 1.03) and Australia (from 1.06 to 1.22). No countries exhibited a notable decrease in ARIF score in association with international collaboration. Note that Turkey published only 27 papers with international co-authors between 2005 and 2009, which is not a sufficient number to enable the calculation of a reliable ARIF score.

Overall, international collaboration increased both the ARC and ARIF scores of four countries: the U.S., Germany, Japan and Sweden (Table IV). Furthermore, with the exception of the Republic of Korea, all countries exhibiting ARC and ARIF scores below the world average for their papers without international collaboration increased their position to above the world average (for both

[5] The ARC cannot be reliably calculated when the total number of papers for 2005, 2006 and 2007 is less than 30, as is the case for several countries in future generation biofuels research. See Methods for more details.

[6] Notable differences in ARC and/or ARIF scores were defined as a change (be it positive or negative) of 0.15 or greater.

indicators) for their papers written with international co-authors. Conversely, the scientific impact of Dutch papers written without international collaboration was the highest seen in Table IV (ARC of 1.79), but dropped below the world average for its international collaborations. Finally, it is worth noting that while international collaboration was associated with increases in the scientific impact of future generation biofuels papers (i.e., increases in ARC between 0.16 to 0.46), the effect on the ARIF was constricted to a much smaller range (between 0.02 to 0.22).

Table IV Effect of collaboration on selected countries in future generation biofuels research, 2005–2009

	With international collaboration			Without international collaboration			All Papers		
Country	Papers	ARC	ARIF	Papers	ARC	ARIF	Papers	ARC	ARIF
United States	270	1.58	1.11	895	1.12	1.09	1,165	0.67	1.09
China	149	1.39	1.07	537	1.12	1.08	686	1.09	1.08
United Kingdom	113	1.11	1.08	181	1.17	1.15	294	0.63	1.12
Germany	108	0.92	1.03	187	0.74	0.82	295	0.67	0.89
Japan	99	1.02	1.03	224	0.86	1.00	323	0.77	1.01
Sweden	93	0.97	1.04	147	0.74	0.92	240	2.42	0.97
Netherlands	91	0.97	1.11	127	1.79	1.09	218	1.51	1.10
France	78	n.a.	1.06	100	0.98	1.03	178	0.56	1.04
Canada	71	n.a.	1.01	137	0.84	0.85	208	0.78	0.90
Spain	70	n.a.	1.13	217	1.08	1.08	287	1.43	1.09
India	68	n.a.	1.00	302	1.01	0.89	370	2.12	0.91
Italy	60	n.a.	0.95	130	0.72	1.09	190	0.77	1.05
Australia	55	n.a.	1.22	76	n.a.	1.06	131	0.75	1.13
Rep. of Korea	39	n.a.	0.87	74	n.a.	0.86	113	0.67	0.86
Turkey	27	n.a.	n.a.	290	1.45	0.92	317	3.32	0.93

Source: Compiled by Science-Metrix from WOS data

Figure 8 presents PAI values for the selected countries in future generation biofuels research between 2005 and 2009. In two-thirds of cases, country pairs have negative PAI scores, which indicates that they are collaborating with one another less than expected by chance. The country pairings with the strongest affinity index are India/Republic of Korea, Australia/Japan and Germany/Turkey: all three have PAI scores above 0.90. The U.S. also has several high-affinity pairings (i.e., 0.7 or higher), notably with China, Korea, Canada and Turkey. Moreover, China and Japan share a high affinity for collaboration.

Looking at the degree to which countries listed in Figure 8 have affinities for collaborating with a broad range of their counterparts, the U.S. and the U.K. both tend to have more relatively high positive affinities with the other countries. Canada's strongest affinities lie with the U.S., Turkey and China, but it also collaborates more than expected based on chance with India and France. Note that, as seen in clean energy R&D as a whole, affinity patterns of European countries reveal a strong tendency towards intra-E.U. collaboration but little affinity with their Asian or North American counterparts. Similarly, considerable affinity exists amongst Australia, Japan and China, but these countries have no prominent linkages with their European counterparts.

Country	U.S.	China	Japan	Germany	R. of Korea	U.K.	India	France	Canada	Spain	Italy	Netherlands	Turkey	Sweden	Australia
U.S.		0.75	-0.01	-0.68	0.82	-0.08	0.54	-0.13	0.78	-0.52	-0.08	-0.44	0.71	-0.32	0.24
China	0.75		0.73	-0.45	0.05	-0.86	-0.54	-0.59	0.34	-1.00	-0.63	-0.81	-1.00	-0.45	0.52
Japan	-0.01	0.73		-0.62	0.66	-0.68	0.49	-1.00	-0.52	-0.89	-0.60	-0.38	-1.00	-1.00	0.94
Germany	-0.68	-0.45	-0.62		-0.70	-0.01	-0.40	0.20	-0.42	-0.76	-0.04	0.62	0.92	-0.48	-0.22
R. of Korea	0.82	0.05	0.66	-0.70		-0.28	0.97	-1.00	-0.31	-1.00	-1.00	-1.00	-1.00	-1.00	-0.10
U.K.	-0.08	-0.86	-0.68	-0.01	-0.28		-0.02	0.39	-0.74	0.53	0.49	0.03	0.09	0.06	-0.05
India	0.54	-0.54	0.49	-0.40	0.97	-0.02		0.30	0.13	-0.81	-0.37	-0.66	-1.00	-0.87	-1.00
France	-0.13	-0.59	-1.00	0.20	-1.00	0.39	0.30		0.06	0.62	0.47	-0.82	-1.00	-0.53	-0.39
Canada	0.78	0.34	-0.52	-0.42	-0.31	-0.74	0.13	0.06		-1.00	-1.00	-0.38	0.64	-0.25	-0.08
Spain	-0.52	-1.00	-0.89	-0.76	-1.00	0.53	-0.81	0.62	-1.00		0.60	0.40	-1.00	0.28	-0.73
Italy	-0.08	-0.63	-0.60	-0.04	-1.00	0.49	-0.37	0.47	-1.00	0.60		0.18	-1.00	0.14	-0.71
Netherlands	-0.44	-0.81	-0.38	0.62	-1.00	0.03	-0.66	-0.82	-0.38	0.40	0.18		-1.00	0.21	-0.86
Turkey	0.71	-1.00	-1.00	0.92	-1.00	0.09	-1.00	-1.00	0.64	-1.00	-1.00	-1.00		-1.00	-1.00
Sweden	-0.32	-0.45	-1.00	-0.48	-1.00	0.06	-0.87	-0.53	-0.25	0.28	0.14	0.21	-1.00		-0.81
Australia	0.24	0.52	0.94	-0.22	-0.10	-0.05	-1.00	-0.39	-0.08	-0.73	-0.71	-0.86	-1.00	-0.81	

Figure 8 Probabilistic affinity indices (PAI) between producers of future generation biofuels research, 2005–2009

Source: Compiled by Science-Metrix from WOS data

3 Characterizing Scientific Activity on Clean Energy Vehicles

The section presents data on the scientific output on clean energy vehicles – in Canada and internationally – from 2005 to 2009. Overall publication trends are examined at the world level, followed U.S. and Canadian trends (Section 3.1). Country-level data on clean energy vehicles papers are then presented, including the countries' specialization and scientific impact levels (Section 3.2), as well as the patterns of international collaboration amongst selected countries (Section 3.3).

3.1 Publication trends in clean energy vehicles research

Figure 9 presents data on the growth of the scientific output in clean energy vehicles research during the last five years. The total number of clean energy vehicles papers increased from about 2,800 to 4,900 (73% growth) and their proportion of the total world output rose from 0.3% to almost 0.5%.

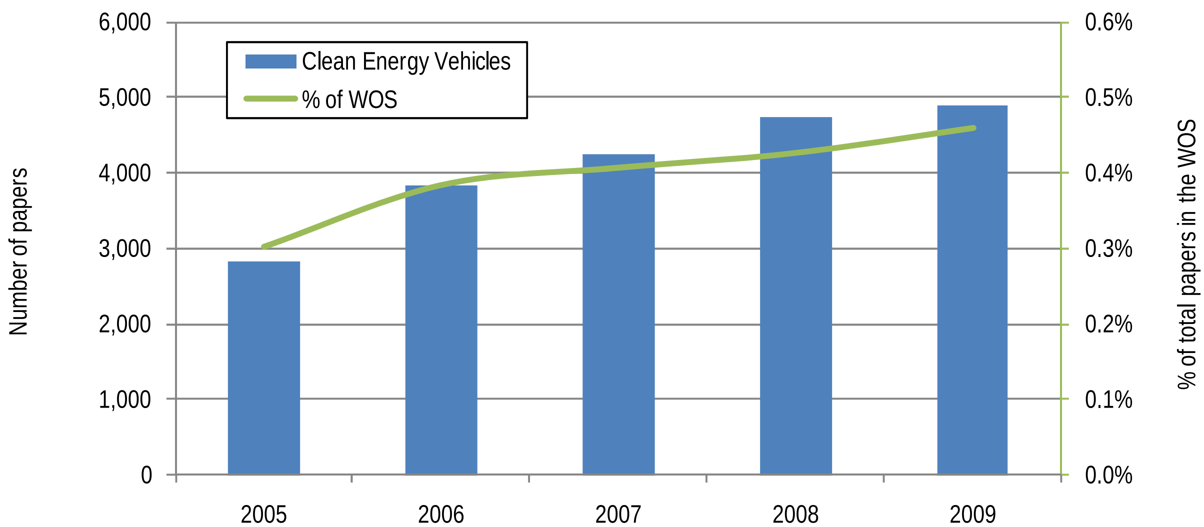
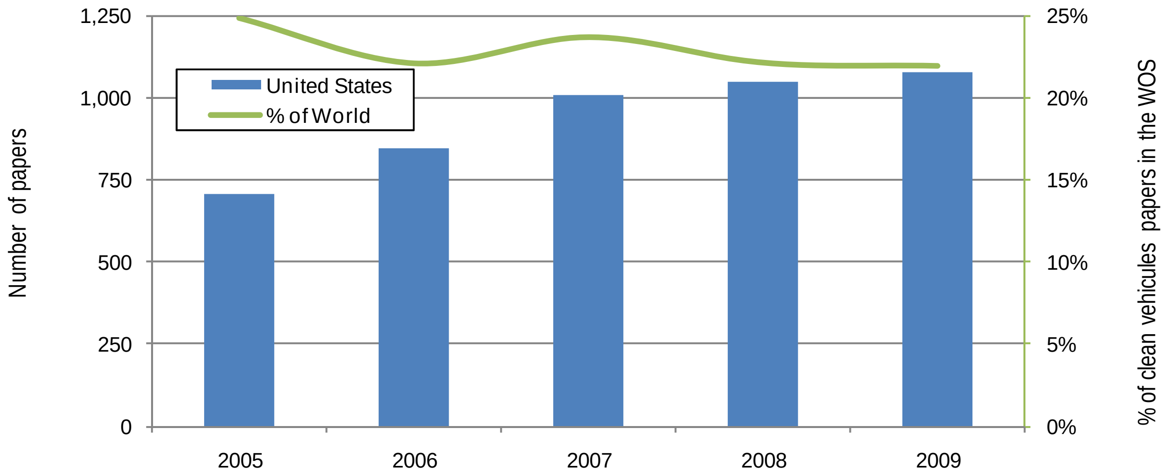


Figure 9 Number and percentage of clean energy vehicles papers, 2005–2009
Source: Compiled by Science-Metrix from WOS data

Examining the production of papers in this subfield by the U.S. and Canada reveals that the two countries have been slowly losing ground compared to the world's output (Figure 10). In both cases, the absolute number of papers has steadily increased, but this growth has been slower than that observed at the world level; thus, both countries have a decreasing share of papers in that area. More specifically, the U.S. share of clean energy vehicles papers dropped from almost 25% in 2005 to 22% in 2009, whereas the Canadian share dropped by one percentage point – to 4.7% – between 2005 and 2009.



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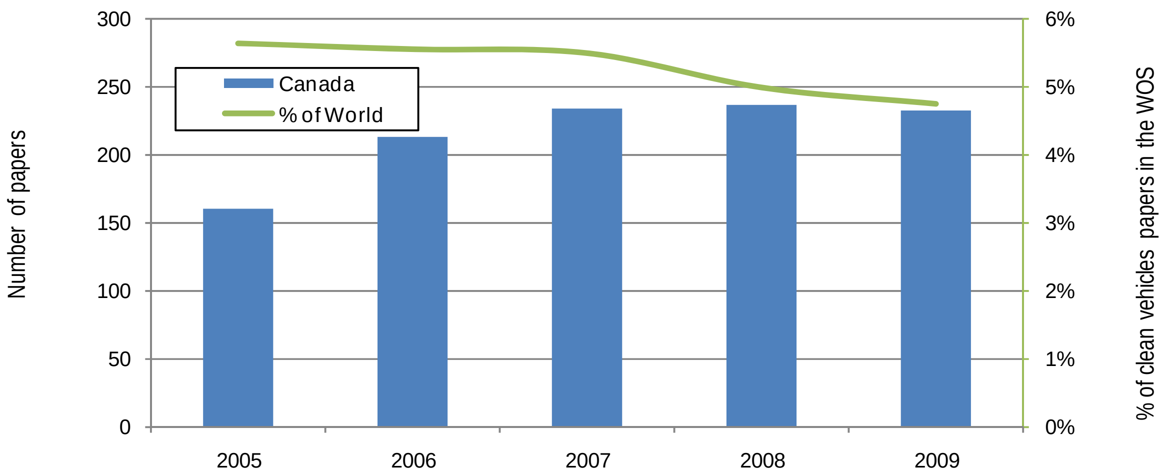


B

Figure 10 Number and percentage of clean energy vehicles papers produced by A) the U.S. and B) Canada, 2005–2009

Source: Compiled by Science-Metrix from WOS data

3.2 Leading countries in clean energy vehicles research

Dashboard 3 presents the scientific production of selected countries in clean energy vehicles research for the 2005–2009 period (these are the same countries as those presented in Section 1). The U.S. and China are by far the leading research producers in this area, with over 2,500 papers separating them from third-ranked Japan. China actually overtook the U.S. in 2007 based on annual output in this subfield, and now produces more scientific papers annually on clean energy vehicles than any other country. Including China, Asian countries represent three of the top five producers of clean energy vehicles papers, whereas Canada is in 6th place. China's rapid growth in this subfield is also reflected by its growing share of the world's papers (see "Trend" column). Other countries whose share of the world's output has increased over the period include India, Australia and Turkey, while notable decreases are clearly occurring for Japan, the Netherlands and Sweden.

	Papers			SI		ARC		ARIF	
Country	N	Rank	Trend	Score	Rank	Score	Rank	Score	Rank
United States	4,683	*(1)*			*(11)*		*(3)*		*(4)*
China	4,629	*(2)*			*(2)*		*(15)*		*(15)*
Japan	2,107	*(3)*			*(3)*		*(10)*		*(12)*
Rep. of Korea	1,517	*(4)*			*(1)*		*(14)*		*(13)*
Germany	1,323	*(5)*			*(8)*		*(7)*		*(7)*
Canada	1,073	*(6)*			*(5)*		*(6)*		*(10)*
France	904	*(7)*			*(10)*		*(8)*		*(6)*
United Kingdom	870	*(8)*			*(14)*		*(4)*		*(2)*
Italy	784	*(9)*			*(6)*		*(12)*		*(8)*
India	748	*(10)*			*(4)*		*(13)*		*(14)*
Spain	576	*(11)*			*(9)*		*(9)*		*(9)*
Australia	309	*(12)*			*(15)*		*(5)*		*(5)*
Netherlands	295	*(13)*			*(13)*		*(2)*		*(1)*
Turkey	290	*(14)*			*(7)*		*(1)*		*(11)*
Sweden	261	*(15)*			*(12)*		*(11)*		*(3)*
World	20,540								

Dashboard 3 Benchmarking of selected countries in clean energy vehicles research, 2005–2009

Note: The Trend column indicates the variation in the share of world papers in clean energy. SI, ARC and ARIF: a black dot in the green area indicates a score above the world average; when the black dot is in the red area, the score is below the world average.

Source: Compiled by Science-Metrix from WOS data

An examination of the SI reveals that the Republic of Korea, China and Japan occupy the top three ranks among selected countries in terms of specialization (Dashboard 3). Interestingly, only 5 of the 15 countries in this Dashboard are specialized in clean energy vehicles research, with India ranking 4th and Canada 5th.

The Netherlands has the highest combined ranking when considering the scientific impact and quality indicators (1st in ARIF, 2nd in ARC; Dashboard 3). Meanwhile, Turkey is ranked 1st in ARC but 11th in ARIF, suggesting its papers have a much higher citation frequency than is suggested by the average impact factor of the journals in which they are published. The U.S. and the U.K. have high ARC and ARIF rankings, indicating that despite their overall lack of specialization, these countries are producing highly cited, high-quality research compared to their counterparts in Dashboard 3. Australia and Germany represent the only other countries in this list where both impact and quality scores (i.e., ARC and ARIF) fall above the world average in clean energy vehicles research. Canada ranks 6th in ARC (slightly above world average) and 10th in ARIF (at the world average), which indicates that while Canadian research in this subfield tends to be well cited, it is not (on average) being published in the journals with the highest impact factors.

Nonetheless, the positional analysis presented in Figure 11 clearly shows that Canada is the only country occupying the top right quadrant (i.e., both impact and specialization above the world level) in clean energy vehicles research. As mentioned above, Republic of Korea, China, Japan and India are specialized in this subfield but their research is, on average, not highly cited relative to the world's average paper. A number of countries, including the U.S., the U.K., Germany, Australia, Turkey and the Netherlands are positioned in the upper-left quadrant, indicating an overall lack of specialization yet high levels of scientific impact. However, Spain, Italy, France, and Sweden are not specialized in clean energy vehicles researcher, nor are their impact scores in this subfield above the world level.

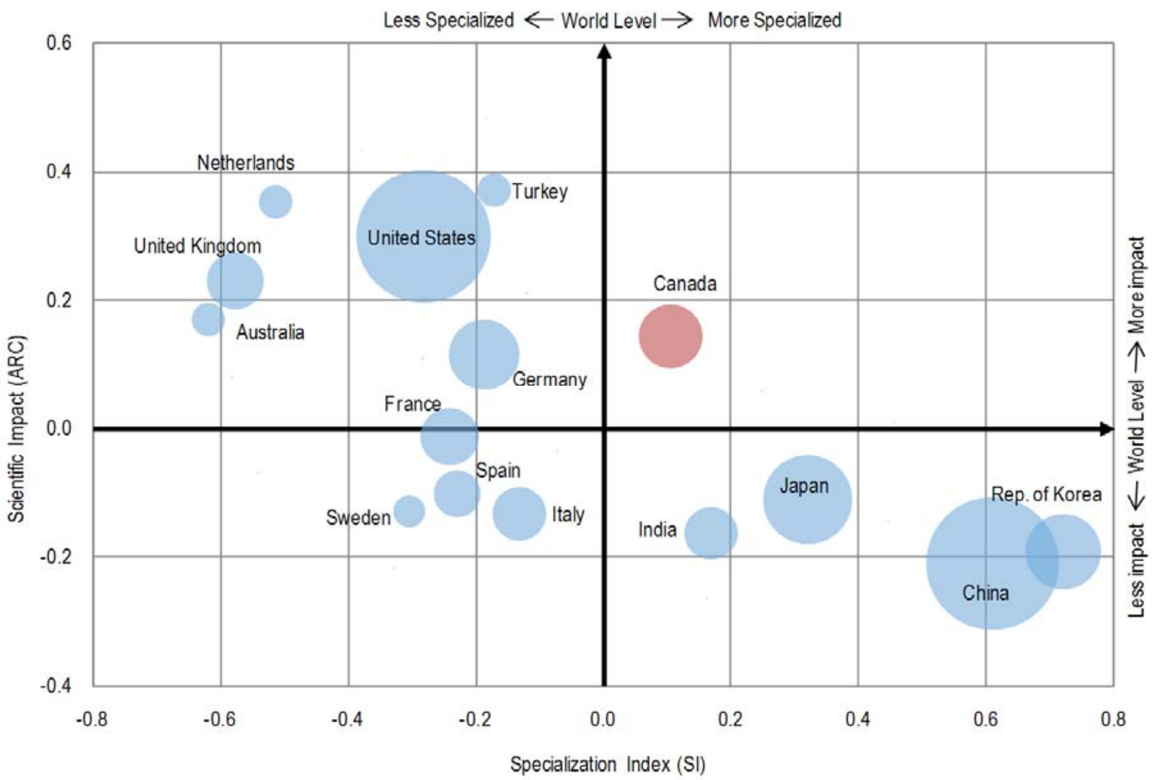


Figure 11 Positional analysis of selected countries in clean energy vehicles research

Source: Compiled by Science-Metrix from WOS data

3.3 International collaboration patterns and affinity indices

Table V shows that over the 2005–2009 period, the five countries with the highest propensity to collaborate were Australia, Sweden, France, Germany and the U.K. Based on this indicator, Canada ranks 7th. Overall trends in collaboration rates differ by country, with only four countries – Sweden, France, the U.S. and Japan – exhibiting a general increase in their collaboration rate between 2005 and 2009.

Table V International collaboration of selected countries in clean energy vehicles research, 2005–2009

Country	Collaborations	All Papers	Collaboration Rate	Trend	Propensity to Collaborate	Ranking
Australia	178	309	58%		1.69	(1)
Sweden	146	261	56%		1.59	(2)
France	398	904	44%		1.56	(3)
Germany	523	1,323	40%		1.49	(4)
United Kingdom	363	870	42%		1.47	(5)
Netherlands	136	295	46%		1.34	(6)
Canada	327	1,073	30%		1.11	(7)
Italy	248	784	32%		1.09	(8)
United States	1,084	4,683	23%		1.09	(9)
Spain	188	576	33%		1.07	(10)
China	798	4,629	17%		0.81	(11)
Rep. of Korea	298	1,517	20%		0.76	(12)
Japan	366	2,107	17%		0.71	(13)
India	147	748	20%		0.67	(14)
Turkey	63	290	22%		0.63	(15)

Source: Compiled by Science-Metrix from WOS data

Table VI presents data on the effect of collaboration in clean energy vehicles research on selected countries. The comparison of ARC values with and without international collaboration show that with the exception of three countries – the Netherlands, Turkey, and India – papers published with international co-authors are, on average, more highly cited than those without. The most substantial increases in ARC scores were seen for Italy (from 0.72 to 1.20), France (from 0.81 to 1.26) and the Republic of Korea (from 0.74 to 1.14). Other countries where international collaborations have resulted in a notable increase in ARC value are China (from 0.76 to 1.06), Japan (from 0.84 to 1.21) Spain (from 0.80 to 1.10) and Australia (from 1.07 to 1.27).[7] As mentioned above, there are three examples of international collaborations resulting in depressed ARC scores: the Netherlands (from 1.49 to 1.38), Turkey (from 1.52 to 1.37) and – albeit to a small extent – India (from 0.85 to 0.83).

International collaboration in clean energy vehicles research has a more muted effect on ARIF scores, with 10 of the 15 countries exhibiting little to no change in impact scores when comparing collaborative versus non-collaborative papers (Table VI). The three countries where notable increases in ARIF scores were observed were China (from 0.88 to 1.06), Japan (from 0.94 to 1.11), the Republic of Korea (from 0.90 to 1.06) and Turkey (from 0.95 to 1.15). Only Sweden exhibited a notable decrease in its ARIF score for papers with international collaboration compared to those without (from 1.27 to 1.10).

The positive effect of international collaboration was observed on both ARC and ARIF scores in 11 countries: the U.S., China, Germany, France, the U.K., Canada, Japan, the Republic of Korea, Italy, Spain and Australia (Table VI). Furthermore, all countries exhibiting ARC scores below the world average for their papers without international co-authors increased their position to above the world

[7] Notable differences in ARC and/or ARIF scores were defined as a change (be it positive or negative) of 0.15 or greater.

average when they collaborated internationally, except for India and Sweden; India, however, did increase its ARIF scores to 1.0 or greater with collaboration.

Table VI Effect of collaboration on selected countries in energy vehicles research, 2005–2009

Country	With international collaboration			Without international collaboration			All Papers		
	Papers	ARC	ARIF	Papers	ARC	ARIF	Papers	ARC	ARIF
United States	1,084	1.39	1.21	3,599	1.36	1.11	4,683	1.36	1.14
China	798	1.06	1.06	3,831	0.76	0.88	4,629	0.81	0.91
Germany	523	1.20	1.13	800	1.07	1.02	1,323	1.12	1.07
France	398	1.26	1.14	506	0.81	1.09	904	0.99	1.12
Japan	366	1.21	1.11	1,741	0.84	0.94	2,107	0.89	0.97
United Kingdom	363	1.29	1.19	507	1.25	1.17	870	1.26	1.18
Canada	327	1.16	1.09	746	1.15	0.98	1,073	1.16	1.01
Rep. of Korea	298	1.14	1.06	1,219	0.74	0.90	1,517	0.82	0.93
Italy	248	1.20	1.10	536	0.72	0.98	784	0.87	1.02
Spain	188	1.10	1.11	388	0.80	0.97	576	0.90	1.02
Australia	178	1.27	1.16	131	1.07	1.09	309	1.18	1.13
India	147	0.83	1.02	601	0.85	0.91	748	0.85	0.93
Sweden	146	0.94	1.10	115	0.80	1.27	261	0.88	1.17
Netherlands	136	1.38	1.31	159	1.49	1.25	295	1.44	1.28
Turkey	63	1.37	1.15	227	1.52	0.95	290	1.48	0.99

Source: Compiled by Science-Metrix from WOS data

Figure 12 presents the PAI values for the selected countries in energy vehicles research, and indicates that over 60% of the time, these countries exhibit negative PAI scores; thus, they are collaborating less than expected by chance with their counterparts. The country pairings with the strongest affinity are the Republic of Korea/India and the U.S./Turkey (PAI scores of 0.91 and 0.85, respectively). Japan, China and Australia all have relatively high affinity for collaboration amongst themselves, as do Spain, the U.K. and the Netherlands.

Overall, the affinity for collaboration is relatively high for a large number of countries in the U.S and in the U.K., while Turkey exhibits the least overall degree of affinity with its remaining counterparts. Canada's strongest affinities lie with Turkey, China and the U.S. The same is observed for the U.S. – noting the reciprocal affinity for Canada and additional ties with the Republic of Korea. Generally, E.U. countries have a strong affinity for collaboration with other E.U. partners, and less so for Asian or North American counterparts.

Country	U.S.	China	Japan	Germany	R. of Korea	U.K.	India	France	Canada	Spain	Italy	Netherlands	Turkey	Sweden	Australia
U.S.		0.44	0.06	-0.29	0.76	-0.14	0.15	-0.47	0.42	-0.45	0.08	-0.39	0.85	-0.42	-0.48
China	0.44		0.53	-0.43	0.25	-0.04	-0.32	-0.47	0.59	-1.00	-0.92	-0.90	-1.00	-0.01	0.75
Japan	0.06	0.53		-0.63	0.39	-0.49	0.78	-0.38	-0.03	-0.95	-0.19	-0.98	-0.86	-0.54	0.58
Germany	-0.29	-0.43	-0.63		-0.55	-0.07	-0.06	0.40	-0.78	0.59	0.13	0.46	-0.16	-0.45	0.03
Rep. of Korea	0.76	0.25	0.39	-0.55		-0.34	0.91	-0.93	-0.65	-1.00	-0.95	-1.00	-0.77	-0.90	-0.47
U.K.	-0.14	-0.04	-0.49	-0.07	-0.34		0.10	-0.58	0.23	0.72	0.51	0.57	-0.88	-0.38	0.02
India	0.15	-0.32	0.78	-0.06	0.91	0.10		-0.66	-0.61	-1.00	-0.65	-0.89	-1.00	-0.91	-0.67
France	-0.47	-0.47	-0.38	0.40	-0.93	-0.58	-0.66		-0.37	0.76	0.64	0.13	-0.65	0.18	0.00
Canada	0.42	0.59	-0.03	-0.78	-0.65	0.23	-0.61	-0.37		-1.00	-0.69	0.00	0.81	-0.58	-0.82
Spain	-0.45	-1.00	-0.95	0.59	-1.00	0.72	-1.00	0.76	-1.00		0.39	0.65	-1.00	-0.18	-0.94
Italy	0.08	-0.92	-0.19	0.13	-0.95	0.51	-0.65	0.64	-0.69	0.39		0.10	-0.25	0.02	-0.58
Netherlands	-0.39	-0.90	-0.98	0.46	-1.00	0.57	-0.89	0.13	0.00	0.65	0.10		-0.47	0.59	0.44
Turkey	0.85	-1.00	-0.86	-0.16	-0.77	-0.88	-1.00	-0.65	0.81	-1.00	-0.25	-0.47		0.10	-1.00
Sweden	-0.42	-0.01	-0.54	-0.45	-0.90	-0.38	-0.91	0.18	-0.58	-0.18	0.02	0.59	0.10		-0.93
Australia	-0.48	0.75	0.58	0.03	-0.47	0.02	-0.67	0.00	-0.82	-0.94	-0.58	0.44	-1.00	-0.93	

Figure 12 Probabilistic affinity indices (PAI) between producers of clean energy vehicles research, 2005–2009

Source: Compiled by Science-Metrix from WOS data

4 Characterizing Scientific Activity on Green Buildings

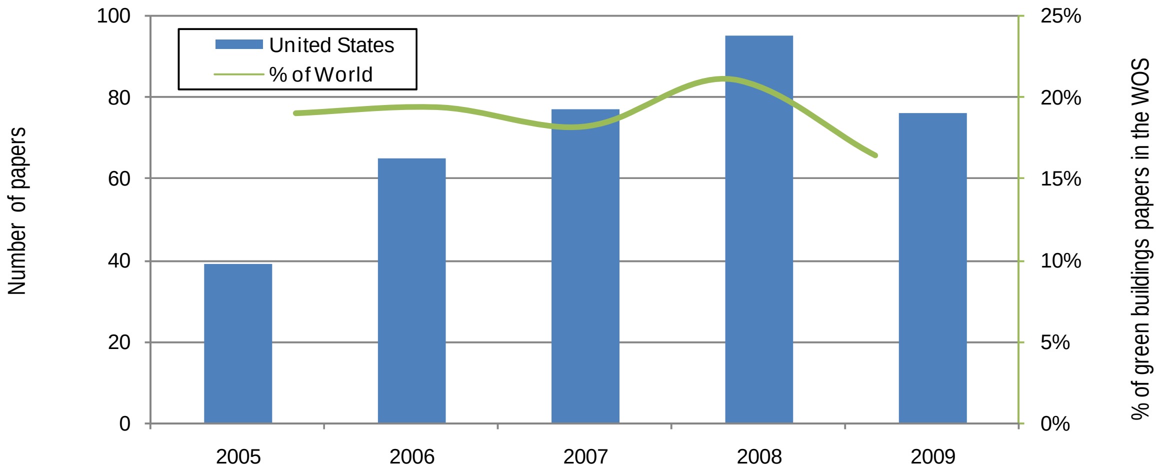
The section presents data on green buildings papers – in Canada and internationally – from 2005 to 2009. Bibliometric data is first used to examine overall publication trends at the world level, followed by an assessment of the U.S. and Canadian trends (Section 4.1). Next, the output of selected countries in this subfield is examined along with their level of specialization and scientific impact (Section 4.2). Finally, the pattern of international collaboration between these countries is described in Section 4.3.

4.1 Publication trends in green buildings research

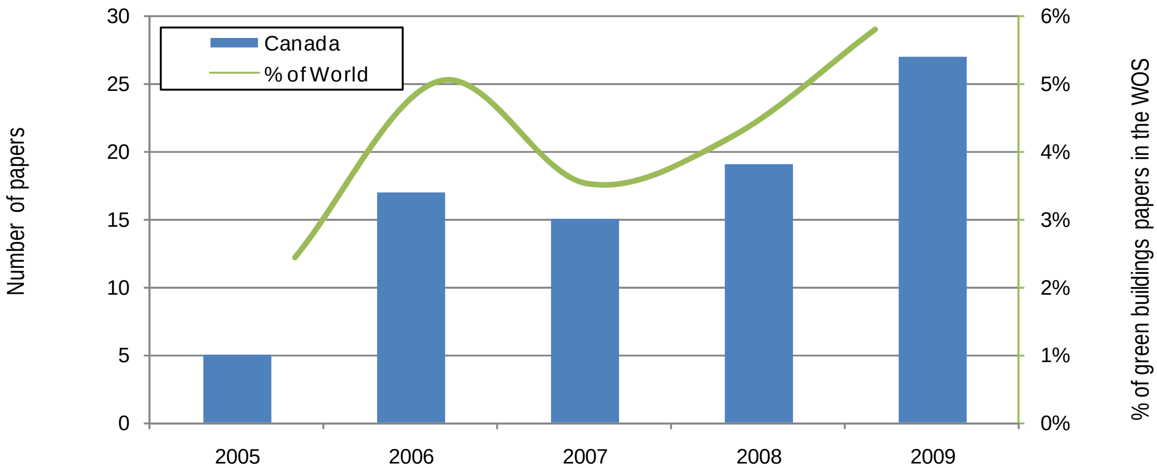
Figure 13 presents the number of papers published in green buildings research and the percentage of these papers in the WOS as a whole over the 2005–2009 period. During this period, the number of papers increased from about 200 to over 450 – an increase of 125%. This represents a rise from 0.02% to over 0.04% of the total world's scientific output.

Figure 13 Number and percentage of green buildings papers, 2005–2009
Source: Compiled by Science-Metrix from WOS data

The production of papers on green buildings by the U.S. and Canada is fairly limited: the U.S. output peaked at less than 100 papers (in 2008), whereas that of Canada is about one quarter of that of the U.S. (Figure 14). The very small size of the Canadian output means that conclusions based on these data should be made with great care; nonetheless, growth in this subfield is clearly indicated by the five-fold increase in output during the last five years, as well as by the fact that the world's share of papers in this subfield by Canadian researchers has more than doubled during this same period.



A



B

Figure 14 Number and percentage of green buildings papers produced by A) the U.S. and B) Canada, 2005–2009

Source: Compiled by Science-Metrix from WOS data

4.2 Leading countries in green buildings research

Dashboard 4 presents the scientific production of selected countries in green buildings research for the 2005–2009 period (these are the same countries as those presented in Section 1). Once again, the U.S. is the international leader in this area, with over 100 papers separating it from the second-ranked U.K., and over 140 from third-ranked China. However, while the U.S. share of the world's output in this subfield may be declining, that of China is growing very rapidly. Japan and Turkey round out the top five countries as ranked by the number of published papers, with at least 100 papers each during the last five years. Based on its number of green buildings papers, Canada ranks 8th in the world.

Interestingly, few of the top producers of research in this area have high specialization, impact or quality scores. In fact, only four countries among these leaders in clean energy R&D overall are clearly specialized in this subfield: Turkey, Sweden, the U.K. and India. In terms of ARC scores, only

Turkey's ARC score is well above the world average. Meanwhile, no country has an ARIF score that is markedly above the world average, indicating that, as a whole, these countries are not publishing in high-impact journals within the subfield of green buildings research. Canada falls below the world average for all three of these indicators. Note that, because of the low scientific output in this subfield, too few reliable data points were available to produce a positional analysis of countries in green buildings research.

	Papers			SI		ARC		ARIF	
Country	N	Rank	Trend	Score	Rank	Score	Rank	Score	Rank
United States	352	(1)			(13)		(5)		(9)
United Kingdom	234	(2)			(3)		(4)		(1)
China	208	(3)			(6)		(3)		(8)
Japan	115	(4)			(8)		(7)		(5)
Turkey	107	(5)			(1)		(1)		(7)
Germany	93	(6)			(12)		(2)		(13)
India	84	(7)			(4)		(6)		(2)
Canada	83	(8)			(7)		(8)		(14)
Spain	67	(9)			(5)	n.a			(3)
France	58	(10)			(15)	n.a			(4)
Italy	58	(10)			(9)	n.a			(11)
Sweden	58	(10)			(2)	n.a			(12)
Australia	41	(13)			(10)	n.a			(10)
Rep. of Korea	38	(14)			(11)	n.a			(6)
Netherlands	28	(15)			(14)	n.a		n.a	
World	1,885								

Dashboard 4 Benchmarking of selected countries in green buildings research, 2005–2009

Note: The Trend column indicates the variation in the share of world papers in clean energy. SI, ARC and ARIF: a black dot in the green area indicates a score above the world average; when the black dot is in the red area, the score is below the world average.

Source: Compiled by Science-Metrix from WOS data

4.3 International collaboration patterns and affinity indices

The collaboration rates for selected countries in green buildings research for the 2005–2009 period are shown in Table VII; note that the propensity to collaborate could not be reliably computed for this subfield. In terms of collaboration rates, the six leading countries are all European: the Netherlands (46%), France (41%), Germany (41%), Spain (33%), Sweden (31%) and the U.K. (26%). Canada ranks 11th among these countries based on collaboration rates but the absence of large numbers suggest that any conclusion based on these data are tenuous. China, Canada, Japan, Sweden and Turkey all showed a general increase in their collaboration rates during the 2005–2009 period. Again, the relatively small number of collaborative papers for each country makes the determination of statistically significant trends difficult, and contributes to the volatility of the results. Notably, the lack of a sufficient sample size prevents the calculation of ARC and ARIF values for the collaborative papers of several countries, and so no conclusions can be drawn regarding the effects of collaboration.

Table VII International collaboration of selected countries in green buildings research, 2005–2009

Country	Collaborations	All Papers	Collaboration Rate	Ranking	Trend
Netherlands	13	28	46%	(1)	
France	24	58	41%	(2)	
Germany	38	93	41%	(3)	
Spain	22	67	33%	(4)	
Sweden	18	58	31%	(5)	
United Kingdom	60	234	26%	(6)	
Australia	9	41	22%	(7)	
Japan	20	115	17%	(8)	
United States	57	352	16%	(9)	
Rep. of Korea	6	38	16%	(10)	
Canada	13	83	16%	(11)	
Italy	8	58	14%	(12)	
India	11	84	13%	(13)	
China	24	208	12%	(14)	
Turkey	12	107	11%	(15)	

Source: Compiled by Science-Metrix from WOS data

The PAI values for selected countries in green buildings research are presented in Figure 15. The country pairings with the strongest affinity index are the Republic of Korea/India (PAI of 0.98), China/India (PAI of 0.96), Canada/Republic of Korea (PAI of 0.96), and Canada/Turkey (PAI of 0.95); Canada also has a high PAI with Japan (0.86). Generally, Asian countries exhibit very high (0.90 or above) affinity indices amongst themselves, whereas E.U. countries also have greater affinity with their European counterparts than those in Asia or North America. Compared to other subfields analyzed in this report, countries are more likely to show very high affinity indices with certain partners, and little or no activity with others.

Country	U.S.	China	Japan	Germany	R. of Korea	U.K.	India	France	Canada	Spain	Italy	Netherlands	Turkey	Sweden	Australia
U.S.		0.04	0.57	-0.43	-1.00	0.02	0.36	-0.86	0.09	-0.11	0.61	-0.75	0.84	-0.03	-0.02
China	0.04		0.91	-1.00	0.90	0.77	0.96	-1.00	0.47	-1.00	-1.00	-1.00	-1.00	-0.02	0.80
Japan	0.57	0.91		-1.00	0.92	-0.28	-1.00	-0.11	0.86	-0.01	-1.00	-1.00	-1.00	0.06	0.83
Germany	-0.43	-1.00	-1.00		-1.00	-0.25	-1.00	0.11	-1.00	0.62	0.55	0.42	-0.07	-0.12	0.29
Rep. of Korea	-1.00	0.90	0.92	-1.00		-1.00	0.98	-1.00	0.96	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
U.K.	0.02	0.77	-0.28	-0.25	-1.00		-1.00	-1.00	-0.55	-0.48	0.28	0.11	0.60	-0.42	-1.00
India	0.36	0.96	-1.00	-1.00	0.98	-1.00		0.50	-1.00	0.57	-1.00	0.71	-1.00	-1.00	-1.00
France	-0.86	-1.00	-0.11	0.11	-1.00	-1.00	0.50		-1.00	0.33	0.44	-0.11	-1.00	0.40	-1.00
Canada	0.09	0.47	0.86	-1.00	0.96	-0.55	-1.00	-1.00		-1.00	-1.00	-1.00	0.95	0.41	-1.00
Spain	-0.11	-1.00	-0.01	0.62	-1.00	-0.48	0.57	0.33	-1.00		0.85	-0.01	0.51	-1.00	-1.00
Italy	0.61	-1.00	-1.00	0.55	-1.00	0.28	-1.00	0.44	-1.00	0.85		-1.00	-1.00	-1.00	-1.00
Netherlands	-0.75	-1.00	-1.00	0.42	-1.00	0.11	0.71	-0.11	-1.00	-0.01	-1.00		-1.00	-1.00	-1.00
Turkey	0.84	-1.00	-1.00	-0.07	-1.00	0.60	-1.00	-1.00	0.95	0.51	-1.00	-1.00		-1.00	-1.00
Sweden	-0.03	-0.02	0.06	-0.12	-1.00	-0.42	-1.00	0.40	0.41	-1.00	-1.00	-1.00	-1.00		-1.00
Australia	-0.02	0.80	0.83	0.29	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	

Figure 15 Probabilistic affinity indices (PAI) between producers of green buildings research, 2005–2009
Source: Compiled by Science-Metrix from WOS data

5 Leading Canadian and U.S. Institutions

Section 5 of this report examines publication data in clean energy R&D, as well as in the three subfields, at the institutional level for the 2005–2009 period. In each case, the leading Canadian and U.S. producers of research papers are identified and characterized based on the number of papers produced; their ARC and ARIF scores are also provided (Sections 5.1 to 5.4). In Section 5.5, the scientific collaboration patterns of leading institutions are presented with an emphasis on those institutions with the highest instances of cross-border (Canada/U.S.) collaborations.

5.1 Clean energy R&D

The top 20 U.S. producers of research in the field of clean energy R&D are presented in Table VIII. With the exception of the University of Connecticut, the overall trends show an increase in output (to varying degrees) in their number of papers over the 2005–2009 period.

Table VIII Scientific benchmarking of leading U.S. institutions in clean energy R&D, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
DOE - National Renewable Energy Laboratory	432	*(1)*		1.99	*(7)*	1.28	*(10)*
Pennsylvania State University	366	*(2)*		2.82	*(2)*	1.17	*(15)*
University of California, Berkeley	311	*(3)*		2.44	*(3)*	1.73	*(3)*
United States Department of Agriculture	264	*(4)*		1.35	*(16)*	0.98	*(20)*
Georgia Institute of Technology	258	*(5)*		1.19	*(19)*	1.16	*(16)*
University of Michigan	228	*(6)*		1.50	*(12)*	1.20	*(14)*
DOE - Pacific Northwest National Laboratory	220	*(7)*		1.34	*(17)*	1.12	*(17)*
DOE - Lawrence Berkeley National Laboratory	216	*(8)*		2.03	*(6)*	1.76	*(1)*
University of Illinois, Urbana-Champaign	181	*(9)*		1.40	*(15)*	1.22	*(13)*
University of Connecticut	178	*(10)*		1.27	*(18)*	1.02	*(19)*
University of California, Los Angeles	170	*(11)*		3.25	*(1)*	1.61	*(4)*
Stanford University	169	*(12)*		1.84	*(9)*	1.76	*(2)*
DOE - Argonne National Laboratory	158	*(13)*		1.55	*(11)*	1.55	*(5)*
University of Minnesota	157	*(14)*		2.03	*(5)*	1.29	*(9)*
Massachusetts Institute of Technology	153	*(15)*		1.88	*(8)*	1.47	*(6)*
DOE - Oak Ridge National Laboratory	153	*(16)*		1.62	*(10)*	1.22	*(12)*
DOE - Sandia National Laboratories	152	*(17)*		2.32	*(4)*	1.31	*(8)*
Virginia Polytechnic Institute and State University	149	*(18)*		1.42	*(14)*	1.03	*(18)*
University of California, Davis	147	*(19)*		0.99	*(20)*	1.24	*(11)*
California Institute of Technology	141	*(20)*		1.46	*(13)*	1.36	*(7)*

Source: Compiled by Science-Metrix from WOS data

Nearly all institutions in Table VIII also exhibit ARC and ARIF scores that are above the world average (or nearly at the world level, as seen for the University of California (UC), Davis). Pennsylvania State University and UC Berkeley are the only institutions in the top five in terms of number of papers which also rank in the top five in terms of ARC scores. The remaining top three institutions by impact (ARC) are: UC Los Angeles (UCLA), DOE – Sandia National Laboratories, and the University of Minnesota. Remarkably, the top five U.S. institutions with the highest impact levels produce clean energy papers that are cited more than twice as often as the world average. The ARIF rankings place the DOE – Lawrence Berkeley National Laboratory in first place, followed by Stanford University, UC Berkley, UCLA, and DOE – Argonne National Laboratory.

Most top 20 Canadian institutions demonstrate a similar pattern in growth trends as do U.S. institutions (i.e., overall positive) (Table IX). Not surprisingly, however, their total number of papers is smaller than for their U.S. counterparts. In fact, compared to the list of top U.S. institutions, only 4 Canadian institutions would rank among the top 20 U.S. producers based on number of papers. The small size of the Canadian output also prevents the calculation of an ARC value for half of the Canadian organizations in this field.

Although 8 of the 10 Canadian institutions Table IX for which the ARC could be calculated are well above the world level, Canada's top-ranked institution based on impact (University of Toronto, ARC of 1.57) would place 11th for impact among the top 20 U.S. institutions. Other institutions with high scientific impact are the National Research Council Canada, the University of British Columbia and the University of Ontario Institute of Technology. In terms of ARIF, only 7 of 19 Canadian institutions place above the world average, most notably Université Laval, the University of Toronto, and Simon Fraser University.

Table IX Scientific benchmarking of leading Canadian institutions in clean energy R&D, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
National Research Council Canada	270	*(1)*		1.56	*(2)*	1.02	*(7)*
University of British Columbia	187	*(2)*		1.49	*(3)*	0.94	*(14)*
University of Waterloo	165	*(3)*		1.11	*(8)*	1.03	*(5)*
University of Toronto	144	*(4)*		1.57	*(1)*	1.36	*(2)*
University of Alberta	123	*(5)*		0.69	*(10)*	0.84	*(18)*
University of Ontario Institute of Technology	103	*(6)*		1.45	*(4)*	1.03	*(6)*
McGill University	85	*(7)*		0.88	*(9)*	0.95	*(11)*
University of Victoria	82	*(8)*		1.33	*(5)*	0.95	*(13)*
University of Calgary	74	*(9)*		n.a.	n.a.	0.95	*(10)*
University of Saskatchewan	65	*(10)*		1.27	*(6)*	0.91	*(16)*
Simon Fraser University	65	*(11)*		1.24	*(7)*	1.25	*(3)*
Queen's University	60	*(12)*		n.a.	-	1.00	*(8)*
University of Ottawa	56	*(13)*		n.a.	-	0.95	*(12)*
University of Western Ontario	56	*(14)*		n.a.	-	0.87	*(17)*
Université Laval	56	*(15)*		n.a.	-	1.46	*(1)*
Institut national de la recherche scientifique	55	*(16)*		n.a.	-	1.07	*(4)*
Dalhousie University	53	*(17)*		n.a.	-	0.91	*(15)*
École Polytechnique de Montréal	52	*(18)*		n.a.	-	0.75	*(19)*
Natural Resources Canada	42	*(19)*		n.a.	-	0.95	*(9)*
University of Manitoba	31	*(20)*		n.a.	-	n.a.	-

Source: Compiled by Science-Metrix from WOS data

5.2 Future generation biofuels

Table X and Table XI present the top six producers of research papers in the subfield of future generation biofuels for the U.S. and Canada, respectively. In general, similar trends to those observed in clean energy R&D are seen here as well. For instance, the number of papers produced by top Canadian institutions (13 to 22 papers in total) is much lower than for top U.S. institutions (36 to 136 papers in total). In addition, the U.S. institutions fairly consistently increased their production over the 2005–2009 period, while their Canadian counterparts display slightly more variable trends. This may be an artefact associated with the number of papers in the dataset, however, in that a change by 1-2 papers in a pool of 20 produces far more dramatic results then it would in a pool of 50 or 100. In both cases, the small size of the dataset for this particular subfield prevented a detailed analysis of impact based on citations, with only one U.S. institution (and no Canadian ones) proving amenable to ARC calculation. In terms of ARIF, only the U.S. values could be calculated, with five out of six of the institutions ranking above the world average.

Table X Scientific benchmarking of leading U.S. institutions in future generation biofuels, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
United States Department of Agriculture	136	*(1)*		0.88	*(1)*	0.95	*(6)*
DOE - National Renewable Energy Laboratory	62	*(2)*		n.a	-	1.16	*(3)*
Iowa State University	51	*(3)*		n.a	-	1.07	*(5)*
Michigan State University	45	*(4)*		n.a	-	1.13	*(4)*
Pennsylvania State University	41	*(5)*		n.a	-	1.27	*(1)*
DOE - Oak Ridge National Laboratory	36	*(6)*		n.a	-	1.19	*(2)*

Source: Compiled by Science-Metrix from WOS data

Table XI Scientific benchmarking of leading Canadian institutions in future generation biofuels, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
University of Toronto	22	*(1)*		n.a	-	n.a	-
University of British Columbia	18	*(2)*		n.a	-	n.a	-
University of Ottawa	15	*(3)*		n.a	-	n.a	-
University of Saskatchewan	15	*(4)*		n.a	-	n.a	-
University of Alberta	14	*(5)*		n.a	-	n.a	-
University of Western Ontario	13	*(6)*		n.a	-	n.a	-

Source: Compiled by Science-Metrix from WOS data

5.3 Clean energy vehicles

Table XII and Table XIII present the top 10 producers of research papers in the subfield of clean energy vehicles for the U.S. and Canada, respectively. Output trends by U.S. institutions are more varied in this subfield: four of the ten entities demonstrate a fluctuating or decreasing trend in paper production over the 2005–2009 period. In Canada, this variability is more prominent, with only four institutions demonstrating an overall positive growth trend in this area during the period. Top producers in both countries (i.e., Pennsylvania State University and the National Research Council of Canada) are very comparable in their total output, with 240 and 239 papers, respectively. Yet the similarities end quickly as one descends through the remaining top institutions in each country.

The dataset for clean energy vehicles research papers was sufficiently large as to permit the calculation of both ARC and ARIF values for most of the institutions listed in Table XII and in Table XIII, except for the five Canadian institutions with the lowest number of papers. In the U.S., all 10 institutions ranked above or close to the world average for both impact (ARC) and quality (ARIF). Among Canadian institutions, available ARC scores were also above the world average, except for the University of Alberta, whereas ARIF scores were more variable.

Table XII Scientific benchmarking of leading U.S. institutions in clean energy vehicles, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
Pennsylvania State University	240	(1)		2.33	(1)	1.05	(8)
University of Connecticut	157	(2)		1.18	(10)	0.98	(10)
DOE - Pacific Northwest National Laboratory	150	(3)		1.37	(6)	1.08	(6)
University of Michigan	132	(4)		1.29	(8)	1.13	(4)
Georgia Institute of Technology	129	(5)		1.18	(9)	1.13	(5)
University of California, Berkeley	126	(6)		2.21	(2)	1.51	(2)
University of South Carolina	114	(7)		1.34	(7)	1.04	(9)
University of Illinois, Urbana-Champaign	100	(8)		1.48	(5)	1.21	(3)
DOE - Argonne National Laboratory	93	(9)		1.51	(4)	1.79	(1)
Virginia Polytechnic Institute and State University	87	(10)		1.54	(3)	1.07	(7)

Source: Compiled by Science-Metrix from WOS data

Table XIII Scientific benchmarking of leading Canadian institutions in clean energy vehicles, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
National Research Council Canada	239	(1)		1.53	(1)	1.01	(5)
University of British Columbia	112	(2)		1.53	(2)	0.95	(9)
University of Waterloo	92	(3)		1.37	(3)	1.06	(4)
University of Alberta	69	(4)		0.57	(5)	0.87	(10)
University of Victoria	65	(5)		1.24	(4)	0.99	(6)
Simon Fraser University	48	(6)		n.a.	-	1.31	(1)
University of Ontario	47	(7)		n.a.	-	1.15	(2)
Institut national de la recherche scientifique	46	(8)		n.a.	-	1.08	(3)
University of Calgary	38	(9)		n.a.	-	0.95	(8)
Queen's University	36	(10)		n.a.	-	0.98	(7)

Source: Compiled by Science-Metrix from WOS data

5.4 Green buildings

Table XIV and Table XV present the top five producers of research papers on green buildings by the U.S. and Canada, respectively. However, the small output for this particular subfield prevents any meaningful comparison between the two countries, or the calculation of impact and quality indicators.

Table XIV Scientific benchmarking of leading U.S. institutions in green buildings, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
DOE - Lawrence Berkeley National Laboratory	32	(1)		n.a.	-	n.a.	-
University of California, Berkeley	22	(2)		n.a.	-	n.a.	-
Michigan State University	15	(3)		n.a.	-	n.a.	-
Virginia Polytechnic Institute and State University	11	(4)		n.a.	-	n.a.	-
University of Michigan	9	(5)		n.a.	-	n.a.	-

Source: Compiled by Science-Metrix from WOS data

Table XV Scientific benchmarking of leading Canadian institutions in green buildings, 2005–2009

				ARC		ARIF	
Institutions	N	Rank	Trend	Score	Rank	Score	Rank
University of British Columbia	9	(1)		n.a.	-	n.a.	-
University of Toronto	8	(2)		n.a.	-	n.a.	-
Dalhousie University	6	(3)		n.a.	-	n.a.	-
University of Waterloo	5	(4)		n.a.	-	n.a.	-
Queen's University	5	(5)		n.a.	-	n.a.	-

Source: Compiled by Science-Metrix from WOS data

5.5 Collaboration Patterns

Bibliometric data was also compiled for the institutions in Canada and the U.S. that had the largest number of cross-border collaborations: this section presents lists of the top Canada/U.S. collaborators, as determined by their number of co-authored papers comprising at least one Canadian and one U.S. co-author. The institutions' overall number of papers, number of collaborative papers, number of Canada/U.S. collaborative papers and the percentage of papers written as Canada/U.S. collaborations are provided for clean energy R&D, as well as for the three subfields. It should be noted that these tables are not representative of existing collaboration networks (i.e., the top institutions in the U.S. do not necessarily collaborate with the top Canadian institutions, and links with other international institutions are not considered); such an analysis would need to be conducted separately.

Overall, in clean energy R&D, Canadian entities tend to collaborate more often with U.S. institutions – ranging from 5 to 24% of their total clean energy papers – than U.S. institutions do with Canadian organizations – ranging from 2 to 18% of their total papers (Table XVI). Actually, this is not surprising given the overall size of organizations in both countries. This observation holds for all three subfields. In terms of leading collaborators, the U.S. institutions appearing most frequently in the tables are Michigan State University and various DOE national laboratories. On the Canadian front, the three of the most frequent U.S. collaborators the University of British Columbia, the University of Toronto, and the National Research Council of Canada. It is also worth nothing the collaborative efforts of two firms, Ballard Power Systems and the General Motors R&D Center, (with 12 and 6 Canada/U.S. papers, respectively) in the subfield of clean energy vehicles (Table XVIII). Note that Table XV to Table XIX list the leading 10 institutions for both countries in terms of their number of Canada/U.S. collaborations in the three subfields.[8]

Table XVI Scientific collaboration of leading institutions (by number of Canada/U.S. collaborative papers) in clean energy R&D, 2005–2009

	Clean Energy R&D			
Institutions	Tot # Papers	Tot # Collab Papers	# Collab Papers U.S./Can	% Collab U.S./Can
Top 10 U.S. Institutions				
Michigan State University	120	28	20	17%
DOE - Los Alamos National Laboratory	123	38	10	8%
University of Illinois, Urbana-Champaign	181	42	8	4%
University of California, Los Angeles	170	40	8	5%
Auburn University	74	19	8	11%
University of California, Berkeley	311	66	6	2%
University of Texas, Austin	131	24	6	5%
University of Wisconsin, Madison	112	35	6	5%
Columbia University	67	16	6	9%
General Motors R&D Center	33	8	6	18%
Top 10 Canadian Institutions				
University of British Columbia	187	60	33	18%
University of Toronto	144	60	27	19%
National Research Council Canada	270	100	25	9%
University of Calgary	74	23	13	18%
Dalhousie University	53	24	12	23%
Ballard Power Systems	51	13	12	24%
University of Alberta	123	24	10	8%
University of Waterloo	165	43	8	5%
Simon Fraser University	65	20	7	11%
University of Western Ontario	56	17	7	13%

Source: Compiled by Science-Metrix from WOS data

[8] In the case of green buildings, only two U.S. and one Canadian institution are listed. These are the only institutions where collaborations were observed between the two countries for this subfield.

Table XVII Scientific collaboration of leading institutions (by number of Canada/U.S. collaborative papers) in future generation biofuels, 2005–2009

Institutions	Future Generation Biofuels Tot # Papers	Tot # Collab Papers	# Collab Papers U.S./Can	% Collab U.S./Can
Top 10 U.S. Institutions				
Michigan State University	45	9	6	13%
Texas A&M University	25	6	5	20%
United States Department of Agriculture	136	16	3	2%
DOE - National Renewable Energy Laboratory	62	11	3	5%
DOE - Oak Ridge National Laboratory	36	7	3	8%
Auburn University	13	8	3	23%
University of Wisconsin, Madison	26	7	2	8%
Washington State University	19	10	2	11%
Purdue University	19	4	2	11%
Dartmouth College	19	9	2	11%
Top 10 Canadian Institutions				
University of Toronto	22	15	11	50%
University of British Columbia	18	10	5	28%
Dalhousie University	10	4	2	20%
University of Calgary	7	3	2	29%
University of Windsor	3	2	2	67%
University of Alberta	14	1	1	7%
University of Western Ontario	13	5	1	8%
McGill University	8	1	1	13%
Agriculture and Agri-Food Canada	7	3	1	14%
Université de Sherbrooke	5	2	1	20%

Source: Compiled by Science-Metrix from WOS data

Table XVIII Scientific collaboration of leading institutions (by number of Canada/U.S. collaborative papers) in clean energy vehicles, 2005–2009

Institutions	Clean Energy Vehicles			
	Tot # Papers	Tot # Collab Papers	# Collab Papers U.S./Can	% Collab U.S./Can
Top 10 U.S. Institutions				
Michigan State University	47	18	14	30%
DOE - Los Alamos National Laboratory	81	20	8	10%
University of Texas, Austin	80	17	6	8%
General Motors R&D Center	29	8	6	21%
University of South Carolina	114	29	4	4%
University of Illinois, Urbana-Champaign	100	24	4	4%
University of California, Berkeley	126	25	3	2%
University of Massachusetts, Amherst	27	5	3	11%
Columbia University	24	6	3	13%
Pennsylvania State University	240	57	2	1%
Top 10 Canadian Institutions				
National Research Council Canada	239	86	21	9%
University of British Columbia	112	24	16	14%
Ballard Power Systems	51	13	12	24%
Dalhousie University	24	14	9	38%
Simon Fraser University	48	15	7	15%
University of Waterloo	92	29	4	4%
University of Western Ontario	17	7	4	24%
University of Calgary	38	6	3	8%
University of Toronto	32	9	3	9%
Université Laval	24	14	3	13%

Source: Compiled by Science-Metrix from WOS data

Table XIX Scientific collaboration of leading institutions (by number of Canada/U.S. collaborative papers) in green buildings, 2005–2009

Institutions	Green Buildings			
	Tot # Papers	Tot # Collab Papers	# Collab Papers U.S./Can	% Collab U.S./Can
Top U.S. Institutions				
DOE - Lawrence Berkeley National Laboratory	32	7	1	3%
University of Florida	4	1	1	25%
Top Canadian Institution				
University of Toronto	8	3	1	13%

Source: Compiled by Science-Metrix from WOS data

6 Summary of Key Findings

This section summarizes the key findings with regard to the scientific performance of leading countries in the field of clean energy R&D and three subfields (Future Generation Biofuels, Clean Energy Vehicles, and Green Buildings) during the 2005–2009 period.

***Overall trends in clean energy R&D output**:* The number and percentage of papers published in the area of clean energy R&D has increased substantially during the 2005–2009 period – by more than double. Canada and the U.S. have also nearly doubled their output during this time, but are losing some ground to their competitors in terms of growth. Within the three specified subfields, a similar phenomenon is observed: the world output grows steadily yet the Canadian and U.S. shares of this output remain relatively stable, as other countries increase their share to a greater extent. One notable exception is seen for Canada in green buildings research, where for the past two years there has been a marked increase in the percentage of the world's share; however, the number of papers is so low that it would be imprudent to make strong inferences from this statistic.

Leading countries in clean energy R&D: The 15 leading producers (based on the number of papers) in the field of clean energy R&D are ranked as follows: the U.S., China, India, Japan, Turkey, Germany, the U.K., Spain, Sweden, the Netherlands, Canada, Italy, France, Australia and the Republic of Korea. When assessed in terms of both their impact and specialization indices, only Sweden and Turkey stand out as having positive scores for both indicators in clean energy R&D. Canada, Germany, the Netherlands, the U.S. and the U.K. all score above the world average in impact but are not particularly specialized in this area. In contrast, Japan, the Republic of Korea, China and India are all highly specialized but are below the world average in terms of scientific impact.

Future Generation Biofuels: Five countries rank above the world average for impact and specialization in this subfield: Turkey, India, the Netherlands, Spain and China. The U.S. and the U.K once again exhibit an overall lack of specialization accompanied by levels of impact above the world level. Canada, Japan, France, Australia, Germany, Italy and the Republic of Korea all fall below the world average in both specialization and impact.

Clean Energy Vehicles: Canada is uniquely positioned in this subfield, as it is the only country to have levels of both specialization and impact above the world average. The Republic of Korea, China, Japan and India are all highly specialized, but their papers, on average, are not highly cited. Meanwhile, the U.S., the U.K., Germany, Australia, Turkey and the Netherlands all demonstrate an overall lack of specialization but high levels of scientific impact in this subfield

Green Buildings: The degree to which the countries are distinguishable within this subfield lies primarily in their relative specialization scores, as nearly all of the countries are positioned at or near the world average for impact. Turkey is a notable exception, as both its SI and ARC scores are well above those of remaining countries. The U.K., India and Sweden are also specialized. However, Canada's position falls below the world average in terms of both specialization and impact.

International collaboration patterns in clean energy R&D: For the 2005–2009 period, the five leading countries in terms of propensity to collaborate in clean energy R&D were France, Germany, the U.K., Australia and the Netherlands (Canada ranked 9th). Only three countries – Netherlands, India and Turkey – have increased their overall collaboration rates during this period. Based on the PAI, in over 60% of cases, the leading countries are collaborating less than expected by chance with their leading counterparts. In clean energy R&D, the country pairings with the strongest affinity are Canada/Turkey and the Republic of Korea/India. Canada also has strong affinities with the U.S. and China. Note that collaboration affinities tend to be regionally focused (i.e., between Asian countries or European countries), whereas the U.S. and the U.K. most often have relatively high affinities with large numbers of their counterparts; these trends holds true for all three subfields.

Future Generation Biofuels: Based on their propensity to collaborate, the five leading countries are all E.U. members: France, the Netherlands, the U.K., Sweden and Germany (Canada ranked 8th). Sweden, China and Spain generally showed the most consistent increases in the proportion of papers published with international co-authors from 2005 to 2009. In terms of the PAI, the country pairings with the strongest affinity are India/Republic of Korea, Australia/Japan and Germany/Turkey. Canada's strongest affinities lie with the U.S., Turkey and China, but it also collaborates more than expected with India and France.

Clean Energy Vehicles: Over the 2005–2009 period, the five countries with the highest propensity to collaborate were Australia, Sweden, France, Germany and the U.K. (Canada ranked 7th). Only four countries – the U.S., Sweden, Japan and France – exhibited a general increase in collaboration rates from 2006 to 2009. In terms of the PAI, the country pairings with the strongest affinity index are the Republic of Korea/India and the U.S./Turkey. Again, Canada's strongest affinities lie with Turkey, China and the U.S.

Green Buildings: In terms of collaboration rates, the six leading countries are all European: the Netherlands, France, Germany, Spain, Sweden and the U.K. (Canada ranked 11th); note that the propensity to collaborate could not be reliably computed for this subfield. The relatively small number of collaborative papers for each country makes the determination of statistically significant trends difficult, and contributes to the volatility of the results. Based on the PAI, the country pairings with the strongest affinity index are the Republic of Korea/India, China/India, Canada/Republic of Korea, and Canada/Turkey.

Effect of international collaboration on scientific impact and quality: Overall, with a few exceptions, papers published collaboratively with other countries are, on average, more highly cited than non-collaborative papers. Countries whose papers without international co-authors had impact (ARC) and quality (ARIF) scores below the world level generally scored above the world level with international co-authors. An analysis of the impact of international collaboration on ARIF scores shows a less dramatic effect overall, with the majority of countries exhibiting little to no change in their scores when comparing collaborative versus non-collaborative papers.

Leading U.S. & Canadian institutions: The overall production trends for the top 20 U.S. producers of papers in clean energy R&D almost all show an increase in output over the 2005–2009 period.

Nearly all these institutions also have ARC and ARIF scores above the world average. The top 20 Canadian institutions generally demonstrate a similar pattern in growth trends (i.e., overall positive) but when considered in light of the 20 top U.S. institutions, only 4 Canadian institutions would rank among the U.S. list based on number of clean energy papers produced. The small size of datasets prevents the calculation of an ARC value for half of the Canadian organizations in this field but, based on available data, most have scientific impact levels above the world average.

In terms of Canada/U.S. collaboration patterns, Canadian institutions tend to collaborate more with U.S. institutions than U.S. institutions do with Canadian organizations; however, this is not surprising given the relative size of organizations in these countries. In terms of leading collaborators in clean energy R&D and in the three subfields, the U.S. institutions appearing most frequently in the tables are Michigan State University and various DOE national laboratories. On the Canadian front, the three institutions that tend to collaborate most frequently with U.S. counterparts are the University of British Columbia, the University of Toronto and the National Research Council of Canada.

Appendix – Methods

Bibliometrics can be broadly defined as a set of methods and procedures used in the quantification of bibliographic records. Bibliometric methods can be used to measure scientific outputs (scientometrics, where basic units of measurement are peer-reviewed publications) and technological outputs (technometrics, where basic units of measurement are patents). Bibliometric indicators, because they rest on a set of internationally recognised standards, are among the most objective and reliable measures of academic research outputs available. They are also extremely cost-effective compared to using surveys or building researchers' publication lists to obtain the same extent of data.[9]

Scientometrics

Selection of database

Access to a database containing the most complete bibliographic information on scientific serials published worldwide is essential for the gathering of bibliometric data. In this study, Thomson Reuters' Web of Science (WOS), which includes three databases (the Science Citation Index Expanded™ [SCI Expanded], the Social Sciences Citation Index™, and the Arts & Humanities Citation Index™) covering various fields of science (e.g., natural sciences and engineering [NSE], social sciences and humanities) was used to produce statistics on the scientific production in the area of clean energy R&D in Canada and the U.S., with particular focus on three subfields: future generation biofuels, clean energy vehicles (transportation), and energy efficiency (green homes and buildings).

The WOS was chosen because it indexes some 9,000 of the world's most cited refereed journals (with approximately 1,500,000 peer-reviewed scientific documents added each year), which are generally regarded by the scientific community as the most renowned and reliable journals available in their respective fields. Furthermore, unlike Medline, the WOS lists the cited references of each document it includes (e.g., articles, chapters published in journals or book series). This permits the analysis of the scientific impact of publications based on citation counts and the impact factor. Also, compared to databases that only provide the address of the first author of a publication (e.g., Medline), the WOS includes all authors and their institutional affiliations, which allows collaboration rates between various entities (e.g., countries, institutions, and researchers) to be analysed.

Although the WOS lists several types of documents, only articles, research notes, and review articles were retained in producing the bibliometric indicators, as these are considered to be the main types of documents through which new knowledge is disseminated in the NSE. In addition, all of these documents have been subject to peer review prior to being accepted for publication, ensuring that the research is of good quality and constitutes an original and robust contribution to scientific

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[9] Archambault, É. & Côté, G. (2008). Better bibliometrics needed for greater accountability of research expenditures. *Research Money*, 12: 8.

knowledge. In this report, articles, notes and reviews are collectively referred to as papers. A five-year period (2005–2009) was analysed in this project.

Constitution of datasets

The identification of publication datasets, using a bibliometric approach, requires a systematic examination of the nature and type of research being conducted. The first step in this process is to identify a set of search terms that together, encompass the majority of active research topics encompassed by the field. A preliminary list of relevant keywords is identified based on a thorough analysis of self-identified clean energy publications and rigorous web-based research. This list of terms is then used to extract a preliminary set of articles from the WOS database. These articles are carefully and systematically examined for their relevance to the subject. Suitable articles are retained as the core, preliminary dataset.

The titles, keywords and abstracts (as they occur in the original database) of these papers are then extracted into a searchable text file. Once compiled, the file is parsed using a natural language algorithm that returns the most frequently occurring words along with how often they appear. This breakdown permits the assemblage of a more expansive set of keywords that are further tested for their relevance and applicability to the task at hand. Each keyword is individually queried within the general database to determine its suitability based on (i) the number of articles it returns and (ii) the overall selectivity of the word for topic of interest. Keywords are also combined into compound search terms to increase the specificity of the query.

The combination of the identified keywords into one set of search terms is called the search envelope. The search envelope combines the individual terms using SQL syntax and commands in a way that maximizes recall and precision. The list of papers generated by querying the search envelope in WOS is then used to identify the final dataset (or compilation of publications) that will be used in subsequent analyses.

Disciplinary Classification

The categories and methods used to delineate the various domains of activity are, by and large, those used by the U.S. National Science Foundation (NSF) in the Science and Engineering Indicators series (see: http://www.nsf.gov/statistics/seind06/); the taxonomy is a journal-based classification and has been in use since the 1970s.

The resulting taxonomy has one important advantage over other classifications; it is mutually exclusive, which means that each paper is attributed to a single field or subfield based on the journal in which it is published. One limitation of this classification is that papers published on a subject, such as, for example, the environment, but in a journal specialized in chemical engineering, would be classified as belonging to the field of chemistry and the subfield of chemical engineering, even though its subject is the environment. The anomalies have little effect when large numbers are considered; however, their impact is greater when the number of papers considered is small (e.g., below 30). Some of the subfields are categorized as general (e.g., general biomedical research), and this reflects the fact that, in many fields, some journals that address a broader readership.

Bibliometric indicators

Number of papers: Whole counting of scientific papers written by authors associated with geographic areas (e.g., Canada and the world) or institutions.

Specialization index (SI): This is an indicator of the intensity of research of a given geographic area (e.g., Canada) or organizational entity (e.g., Environment Canada) in a given research area (e.g., field or subfield) relative to the intensity of a reference entity (the world) in the same research area. The SI can be formulated as follows:

$$\mathbf{SI} = \frac{(\mathbf{X_S}/\mathbf{X_T})}{(\mathbf{N_S}/\mathbf{N_T})}$$

Where,

X_S = Papers from entity X in a given research area (e.g., Canada in physics)

X_T = Papers from entity X in a reference set of papers (e.g., Canada in all fields)

N_S = Papers from the reference entity N in a given research area (e.g., the world in physics)

N_T = Papers from the reference entity N in a reference set of papers (e.g., the world in all fields)

In this example, a value above 1 means that Canada is specialized in physics relative to the world, while a value below 1 means that Canada is not specialized relative to the world.

Average of relative citations (ARC): This is an indicator of the scientific impact that the papers produced by a given entity (e.g., a country, an institution) have on the scientific community. In general, papers reach their citation peak (year in which they have receive the most citations) two to three years after publication. Thus, the number of citations received for each paper was counted for the year in which it was published and for the two subsequent years. For example, for papers published in 1996, citations received in 1996, 1997, and 1998 were counted. The exceptions are 2008, which comprises a citation window of two years (2008 and 2009), and 2009, which contains a citation window of one year, since there were no published citation data for subsequent years. Because incomplete citation windows can lead to biases in the results, the year 2008 and 2009 were excluded in computing the ARC indicator.

To account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), each paper's citation count was divided by the average count of all papers in its subfield (based on the NSF classification of journals by fields and subfields of science) to obtain a relative citation count (RC). The ARC of a given entity (e.g., a country or an institution) is the average of the RC of papers belonging to it.

When the ARC is above 1, an entity (e.g., country, institution, or researcher) scores better than the world average; when it is below 1, an entity publishes papers that are cited less often than the world average.

Average relative impact factor (ARIF): This is an indicator of the quality of papers produced by a given entity (e.g., a country, a specific set of papers, a researcher) based on the journals in which they were published. Thomson Reuters calculates an annual impact factor (IF) for each journal based on the number of citations it received in the previous two years, relative to the number of papers it published in the previous two years. Thus, each journal's IF will vary from year to year. The IF of a journal in 2007 is equal to the number of citations to articles published in 2006 (8) and 2005 (15) divided by the number of articles published in 2006 (15) and 2005 (23) (i.e., IF = numerator [23] / denominator [38] = 0.605). However, as pointed out by Moed and colleagues (1999), Thomson Reuters' IF is flawed in that its numerator and denominator are not symmetric:

> ISI classifies documents into types. In calculating the nominator of the IF, ISI counts citations to all types of documents, while as citable documents in the denominator ISI includes as a standard only normal articles, notes and reviews. However, editorials, letters, and several other types are cited rather frequently in a number of journals. When they are cited, these types do contribute to the citation counts in the IF's numerator, but are not included in the denominator. In a sense, the citations to these documents are "for free".

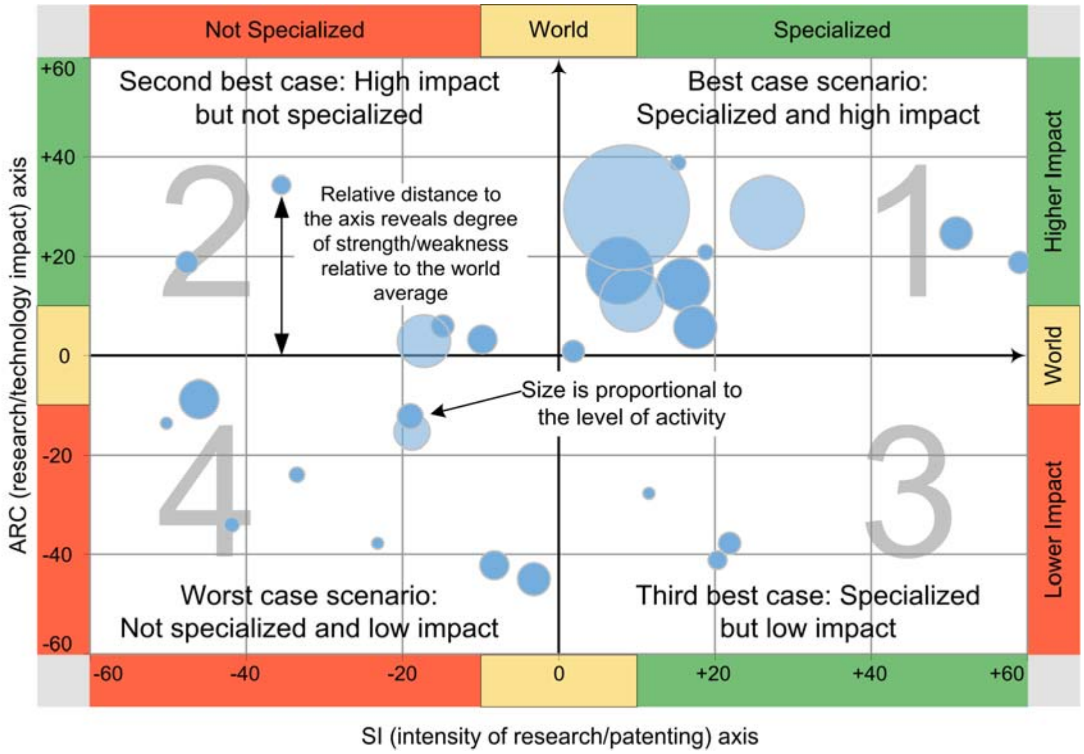
In this study, we therefore used a symmetric IF based on peer-reviewed scientific articles using the WOS database.

The IF of papers is calculated by ascribing to them the IF of the journal in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), each paper's IF was divided by the average IF of the papers published the same year in its subfield to obtain the Relative Impact Factor (RIF). The ARIF of a given entity is the average of its RIFs (i.e., if an institution has 20 papers, the ARIF is the average of 20 RIFs, one per paper).

When the ARIF is above 1, an entity (e.g., country, institution, or researcher) scores better than the world average; when it is below 1, an entity scores lower than the world average.

Positional analysis: To more easily interpret the strengths and weaknesses of an entity (e.g., a country or an institution) through the use of several separate indicators, Science-Metrix uses a graphical representation called positional analysis (see example below). This graphical representation logically combines three of the previously mentioned indicators (number of papers, SI and ARC).

The horizontal axis of this positional graph corresponds to the SI, and the vertical axis to the ARC. These data are transformed to obtain a symmetrical distribution of possible values between -100 and +100, with zero representing the world level. The size of the bubbles is proportional to the number of papers produced by the country or institution.



The position of a country or institution in one of four quadrants can therefore be interpreted as follows:

- Quadrant 1: Located at the top right of the graph, this quadrant is synonymous with excellence. Institutions and countries in this quadrant specialize in the given domain and their activities have a high impact, meaning that their papers are more frequently cited than the world average in this field.
- Quadrant 2: Located at the top left of the graph, this quadrant indicates high-impact scientific production, but the countries or institutions are not specialized in the field.
- Quadrant 3: Located at the bottom right of the graph, this quadrant indicates specialization in the field, although the entity's scientific impact is below the world average.
- Quadrant 4: Located at the bottom left of the graph, this quadrant represents the worst case scenario, as both the specialization level and impact are below the world average in the field.

International collaboration rate: This is an indicator of the relative importance of international collaboration. For a given entity (e.g., a country or an institution), the rate is calculated by dividing the number of papers written in collaboration with an author from a country other than that of the entity by the entity's total number of papers. For example, if a paper is co-signed by McGill and Environment Canada, the paper will not be considered to be an international collaboration. If instead the paper is co-signed by McGill and the USDA, the paper will count as one international collaboration for Canada, one for the U.S., one for McGill, and one for the USDA.

Propensity to collaborate: This is a scale-independent indicator of international collaboration, which takes into account the country's size and the specific collaboration dynamics in a system. It is calculated based on a power-law relationship in which the number of publications and number of international collaborations at the country level are log-transformed, allowing for analysis using linear regression models. More specifically, the model is used to estimate the constants (*a* and *k*) of the power-law relationship:

$$\mathbf{Exp_C(P) = \mathit{a} * (P \wedge \mathit{k})}$$

Where,

$\mathbf{Exp_C}$ is the expected number of international collaborations of a country based on the regression model.

P is the observed number of publications of the country being measured.

Based on this model, the expected number of international collaborations is computed for each country being measured. The propensity to collaborate is equal to the ratio of observed to expected international collaborations.

Probabilistic Affinity Index (PAI)**:** The PAI is an indicator of the *intensity of scientific collaboration* between two countries. It is based on the number of bilateral collaborations of countries and not on the absolute number of papers written in international collaborations by countries. The distinction here is important. One paper written in international collaboration is counted as a single bilateral collaboration only when the paper is co-authored by researchers from two countries (e.g., a paper co-authored by authors from McGill and the USDA is equal to one bilateral collaboration for Canada and one for the U.S.). However, when a paper is co-authored by researchers from more than two countries, this counts as more than one bilateral collaboration. Indeed, a paper co-authored by a Canadian, an Italian, and a U.S. researcher is equal to three bilateral collaborations: one between Canada and Italy, one between Canada and the U.S., and one between Italy and the U.S. In this case, Canada would therefore have two bilateral collaborations, but only one paper in international collaboration.

The indicator compares the observed number of bilateral collaborations between two countries with the number expected, given their individual share of world bilateral collaborations. The index is computed as follows:

$$\mathbf{PAI} = \frac{\mathbf{N_O}}{\mathbf{N_E}}$$

Where,

$\mathbf{N_O}$ = Observed number of bilateral collaborations between country *x* and country *y*.

$\mathbf{N_E}$ = Expected number of bilateral collaborations between country *x* and country *y*. The expected number is calculated using the probability of having bilateral collaborations between the two countries given their individual number of bilateral collaborations relative to the total number of bilateral collaborations in the world. The calculation of the expected probability assumes that collaboration must involve two distinct countries and so corrects for the null diagonal (e.g., Canada with Canada) in the collaboration matrix.

An index value above 1 means that country *x* and country *y* collaborate more than expected, whereas an index value below 1 means the opposite.