researchtrends

ISSUE 13 – SPECIAL ISSUE | OCTOBER 2009

Research into environmental challenges

Welcome to the 13th edition of Research Trends. This is a special issue dedicated to research into environmental challenges.

In July, the Smith School of Enterprise and the Environment, University of Oxford, brought together government policy-makers, industry and the academic community to discuss the effects of the economic climate on global efforts to control CO_2 emissions. See "Where government, industry and academia meet".

Taking inspiration from the Smith School's founding principle that our environmental challenges can only successfully be met through concerted effort by government, industry and science, we also report on how public opinion, political policy and research interact to raise awareness and seek solutions. See "Tackling climate change on three fronts: politics, public opinion and science".

Meanwhile, positive steps are being made. The rate of increase in published research into both climate change-led sea-level rises and CO_2 emissions recently outstripped the rate of increase in sea levels and emissions themselves. In fact, research into CO_2 emissions is closely related to economic growth, which is itself driven by the very energy that is producing the emissions in the first place. See "Climate research outstrips CO_2 emissions".

And, more good news: recent research into the potential of oilgae is showing great promise and attracting the interest of governments, including the G8. See "Biomass and biofuels – the promising potential of oilgae".

If you would like to comment on any of the topics covered, please use our **feedback** facility.

Kind regards,
The Research Trends Editorial Board

DID YOU KNOW?

Top-cited energy papers focus on alternative sources

Ranking all research articles published in the field of energy since 2007 reveals that the most highly-cited papers to date are focused on just two key topics: biofuels and solar cells. The top four articles in each year 2007, 2008 and 2009 (to date) have been collectively cited 646 times. Eight of these 12 articles relate to developments in polymer solar cell technology, while the remaining four discuss bioethanol, biodiesel and biohydrogen as alternative energy sources. **See table.**

ISSUE 13 OCT 2009

Tackling climate change on three fronts: politics, public opinion and science

GERT-JAN GERAEDS

US President Barack Obama's priority to battle global warming and the success of Al Gore's movie *An Inconvenient Truth* are only two examples of the growing political and public interest in climate change. In 2001, Gerald Stanhill published a bibliometric study into the growth of climate change science *(1)*. He found that over a 25-year period between 1970 and 1995 the annual number of publications on climate change in the abstracting journal of the *American Meteorological Society* increased from 14 to 372.

Stanhill published his analysis in the journal *Climatic Change*, one of the first journals dedicated to the problem of climate variability and change. Showing significant growth rates, *Climatic Change's* publication data from 1996 onward indicate a continuation of the trend that Stanhill describes: the number of articles and reviews published in the journal increased from 83 in 1996 to 162 in 2007 while simultaneously maintaining a positive citation trend, as indicated by the average citations per paper (see Figure 1). A modest rise in the number of unique authors and unique author affiliations in the journal over the same period suggests that this growth in output is at least partly the result of attracting new minds to the problem.

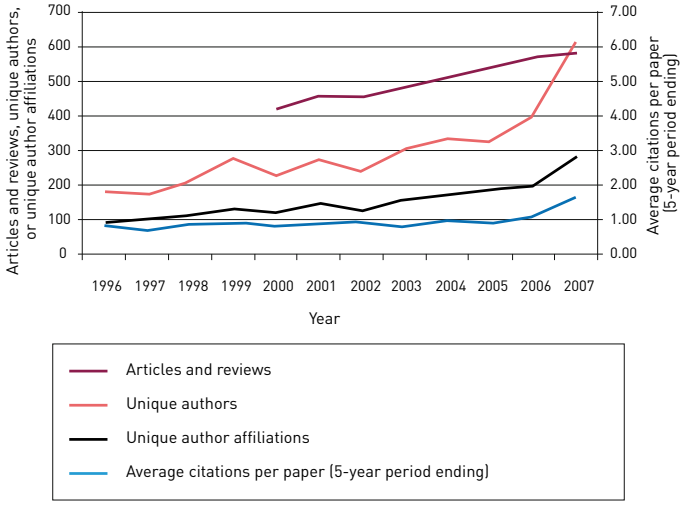


Figure 1 – Publications and citation trends in the journal *Climatic Change* have risen steadily during the last decade. Source: Scopus

The power of public opinion

In his article, Stanhill emphasizes the impact of extra-scientific factors, such as public interest and government support, on the growth of climate change studies: "The continued public interest and political support needed for this to occur is at least partially dependent on the emergence within the near future of unambiguous and palpable evidence of widespread and economically damaging climate change, preferably in accordance with current scientific predictions."

According to Hans-Martin Füssel, senior research fellow and head of the working group on adaptation in the research domain Sustainable Solutions at the Potsdam Institute for Climate Impact Research (PIK) in Potsdam, Germany: "The growth in scientific publications on climate change identified in the review study by Stanhill is remarkable in itself, but it covers only part of the literature. The last decade saw a remarkable growth in climate change-related studies in the social sciences, economics and engineering that are unlikely to be covered in the *Meteorological and Geoastrophysical Abstracts*. This growth is also reflected in the recent launch of several specialized journals, such as *Mitigation and Adaptation Strategies for Global Change, Climate and Development*, and *Carbon and Climate Law Review*. It would certainly be worthwhile to conduct an updated review study that includes literature from all three working groups of the Intergovernmental Panel on Climate Change."

Stephen Schneider, Founder and Editor of *Climatic Change*, adds: "I don't know if the scientific output on climate change will continue to increase as it has over the years. I do know, however, that despite the launch of several new journals, *Climatic Change* has grown and shows growth again this year."

Schneider agrees that the development of climate change research depends, at least partially, on public interest: "It is a matter of policy and in the end it comes down to the question of how much the public is willing to spend. It is true that people want evidence of global warming; people want certainties. On the other hand, people also understand that uncertainties can never be ruled out completely. Financial investments in climate change research are like any other insurance that people buy to protect against future uncertainties. Unfortunately, extreme weather events like hurricane Katrina or the heatwave in 2003 in Europe that killed more than 50,000 people are more likely to get the media's and other people's attention."

Continued on page 3

Continued from page 2

Harnessing political will

According to Schneider, the US, as a major contributor of CO_2 emissions and an industrial and political power, plays a critical role in the course climate change policy will take: "President Obama's approach is a dramatic improvement from that of the previous administration. His biggest challenge will be to get support from Congress, which tends to think local and short term, while a global approach and long-term vision are needed."

Schneider writes in the introduction of his new book scheduled for publication later this year, *Science as a Contact Sport; Inside the Battle to Save Earth's Climate (2)*: "Today, climate change is acknowledged by most climatological experts around the world. Some have replaced the term global warming with global heating or the global heat trap or simply climate disruption, to indicate our human agency in what has occurred. The more jargon-bound scientists, in their endless striving to prove dispassionate objectivity, call this anthropogenic climate change, an accurate phrase, but not a favorite of newspaper headline writers and TV anchors.

"This acknowledgement of global concern has been achieved through surmounting numerous obstacles along the way. Policymakers, lobbyists, financial interests and extreme skeptics have struggled mightily to steer public opinion – and the funds associated with it – in their preferred directions. Most mainstream scientists have fought back with the weapons at their disposal: methods of truth seeking, such as peer review, responsible reporting of research data, best practice theory, international cooperation and cautious calls for policy consideration. The battle is by no means won. The world needs all our combined strengths to cope with the dangerous climate impacts already in the pipeline, much less prevent far more damaging climate change 20 or more years from now.

"If only President Obama and former rival Senator John McCain – an early supporter of climate action – could unite in showing leadership from one end of Pennsylvania Avenue to the other, we might at last achieve meaningful climate policy."

Useful links:

Intergovernmental Panel on Climate Change
An Inconvenient Truth
World Meteorological Organization
American Meteorological Society
Stephen H. Schneider
Environmental science and ecology, Elsevier

References:
(1) Stanhill, G. (2001) "The growth of climate change science: a scientometric study", *Climatic Change*, Vol. 48, pp. 515–524.
(2) Schneider, S. (2009) "Science as a contact sport; inside the battle to save earth's climate", to be published by *National Geographic Society Press.*

Stephen Schneider with the bust of Svante Arrhenius, who performed the first CO_2 climate change calculations over 110 years ago.

Stephen H. Schneider is the Founder and Editor of the journal *Climatic Change*. He has published more than 215 articles that have been cited more than 3,800 times since 1996 (source: Scopus). He is co-author of the article "Fingerprints of Global Warming on Animal and Plants" (2003), *Nature*, 421, pp. 57–60, which has received 730 citations to date. His new book *Science as a Contact Sport; Inside the Battle to Save Earth's Climate* will be published by National Geographic Society Press later this year.

Biomass and biofuels – the promising potential of oilgae

SARAH HUGGETT

Biomass, commonly defined as a renewable energy source using energy from living or recently living organisms, is not a new initiative. As early as the beginning of the last century, pioneers such as Henry Ford and Rudolph Diesel designed cars and engines to run on biofuels and before World War II, the UK and Germany sold biofuels mixed with petrol or diesel.

However, as the case for climate change becomes more widely accepted, interest in renewable energies in general and biomass in particular is increasing. One outcome of the G8 summit in Italy in July was a document entitled *Responsible Leadership for a Sustainable Future (1)*, which introduced the idea of a "green recovery" through investment in ecological R&D, industry and infrastructure.

The G8 leaders also expressed a specific interest in biofuels: "We welcome the work of the Global Bioenergy Partnership (GBEP) in developing a common methodological framework to measure greenhouse gas emissions from biofuels and invite GBEP to accelerate its work in developing science-based benchmarks and indicators for sustainable biofuel production and to boost technological cooperation and innovation in bioenergy." *(1)* Interestingly, the list of most recently prolific institutes in the field (see Table 1) reflects this international awareness.

Food for thought

However, there is also an ethical issue associated with biofuels, as the agricultural land required to produce them takes scarce farmland away from food crops. "Biofuels could help mitigate emissions from the transportation sector," says Oliver Inderwildi, research fellow at the Smith School of Enterprise and the Environment, University of Oxford, "but not all biofuels are low-carbon fuels. Some emit even more carbon than conventional fossil fuels. Moreover, feedstock farming has serious effects on water resources, food prices and ecosystems. A considerable amount of research is focused on those environmentally unfriendly, high-carbon biofuels. This is because energy security concerns were the key drivers for the recent hype in biofuel research, rather than environmental concerns."

This is where algal fuel (also known as oilgae) comes in: not only is its productivity higher than that of other biofuel crops, but algae do not need arable land or potable water to thrive *(2)*, therefore reducing competition with food crops. Furthermore, algae sequester CO_2 as they grow, making them a carbon neutral energy source and the by-products of oilgae production

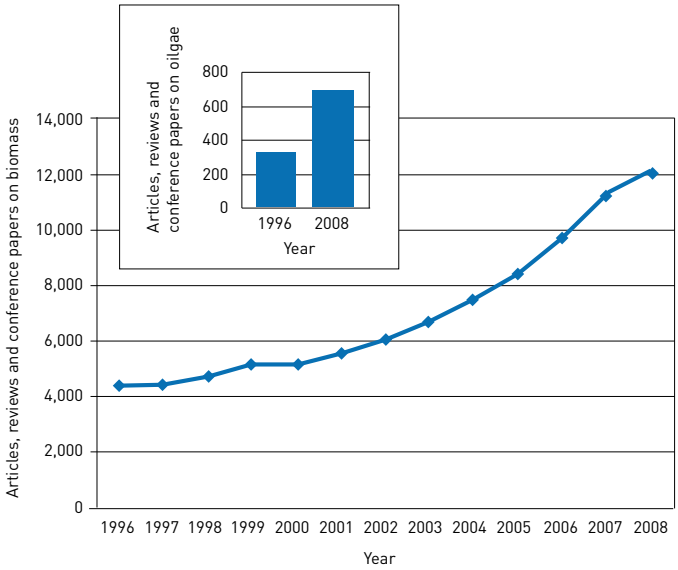


Figure 1 – Scientific literature on biomass has grown steadily over the past 12 years.
Source: Scopus

can have other applications, such as in animal feed or as a replacement for common petroleum products, such as plastics or cosmetics. There are even claims that genetic engineering has allowed scientists to modify algae to produce crude oil *(3)*, which can be used to generate different types of fuels and thus eliminates the need to retro-engineer existing engines.

Yusuf Chisti, Professor of Biochemical Engineering at Massey University in New Zealand, believes that using microalgae to produce renewable, carbon-neutral transport fuels is the only way forward. "The technology for transforming crude algal oils into diesel, gasoline and jet fuels exists already," he comments. "Only microalgae have the potential to provide crude oil in sufficient quantities to meaningfully displace petroleum-derived fuels. Microalgae can do this without affecting our food supply, animal feed or freshwater; producing fuels from algae will not cause deforestation. Algal fuels are currently expensive, however. But due to concerns about climate change, it's likely that we'll eventually have to switch to these environmentally friendly fuels."

However, genetic engineering comes with its own concerns: while the organisms created still require an artificial environment in which to live and multiply, there are concerns that they could escape and adapt to survive in a natural environment *(4)* where their potential impact is unknown.

Continued on page 6

Continued from page 5

Challenges and champions

Despite the controversies, scientific literature on biomass has increased by 9% per annum over the past decade, representing a three-fold increase in articles, reviews, and conference papers between 1996 and 2008. At the same time, research into the subfield of oilgae grew 6% per annum, with the number of articles, reviews, and conference papers published each year on the subject more than doubling between 1996 and 2008 (see Figure 1). This is a strong indicator of the potential of this field.

While the high-yield capacity of algae has been experimentally proven, the production of algal biofuels in vast quantities remains a challenge. However, the G8 leaders expressed a multinational commitment to develop biofuels and invest in renewable energies as part of the "green recovery" plan. Significant R&D investment could help the industrial production of oilgae take off. Further developments on the subject are expected to be unveiled at the United Nations Climate Change conference in Copenhagen in December.

Useful links:

United Nations Climate Change Conference 2009
G8 Summit 2009

References:
(1) Documents of the G8 Summit 2009
(2) Jha, A (2008) "Oil from algae' promises climate friendly fuel", *The Guardian*
(3) Jha, A (2008) "Gene scientist to create algae biofuel with Exxon Mobil", *The Guardian*
(4) Rosenberg, J.N., Oyler, G.A., Wilkinson, L. and Betenbaugh, M.J. (2008) "A green light for engineered algae: redirecting metabolism to fuel a biotechnology revolution", Current Opinion in Biotechnology, 19 (5), pp. 430–436

Rank	Institute	Country	Articles, reviews, conference papers	Average citations by publication
1	Chinese Academy of Sciences	China	1135	1.79
2	USDA Agricultural Research Service	USA	462	3.24
3	University of Florida	USA	312	2.83
4	Universidade de Sao Paulo	Brazil	302	3.33
5	Zhejiang University	China	296	1.81
6	Wageningen University	Netherlands	286	3.81
7	UC Davis	USA	280	3.87
8	Russian Academy of Sciences	Russia	264	1.29
9	Sveriges lantbruksuniversitet	Sweden	261	4.26
10	Oregon State University	USA	248	6.38
11	University of British Columbia	Canada	229	4.73
12	Lunds Universitet	Sweden	223	5.04
13	Michigan State University	USA	221	5.44
14	Cornell University	USA	209	5.31
15	Tsinghua University	China	206	2.70
16	USDA Forest Service	USA	204	4.19
17	Iowa State University	USA	204	2.75
18	University of Tokyo	Japan	200	3.45
19	Universiteit Gent	Belgium	197	4.48
20	Consiglio Nazionale delle Ricerche	Italy	194	3.63

Table 1 – Most prolific institutes in biomass and biofuel research; publication and citation years: 2005–2008.
Source: Scopus

Profile

Where government, industry and academia meet

ANDREW PLUME

The 2009 Times/Smith School World Forum on Enterprise and the Environment, held at the University of Oxford in early July, brought together leaders in the policy-making, business and academic communities to address the issue of carbon emissions in a radically changed economic climate. Eminent speakers, including former US Vice President Al Gore, discussed the challenges ahead during the three-day forum hosted by the Smith School of Enterprise and the Environment.

Presidential commitment

Mohamed Nasheed, President of the Maldives, was one of two heads of state in attendance at the World Forum (the other was Paul Kagame, President of Rwanda). Nasheed explained that the people of his island nation would be among the first to suffer if decisive action is not taken on the climate crisis. With an average ground level of just 1.5 meters above sea level, the Maldives is the lowest country in the world. While Global Mean Sea Level (GMSL) has recently been rising at a rate of about 3mm per year, from 105mm in 1996 to 142mm in 2006 *(1)*, this rise is not evenly distributed across the globe. Indeed, data suggest that the rate may be closer to 4mm per year in the Maldives over recent years *(2)*.

John Church at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) says it is clear that sea levels are continuing to rise: "The Greenland Ice Sheet seems to be making an increasing contribution and there are indications of an increasing contribution from parts of the Antarctica Ice Sheet." He adds that a major challenge is "whether we can avoid crossing thresholds leading to a larger and more rapid contribution from the ice sheets – meeting this challenge requires urgent mitigation".

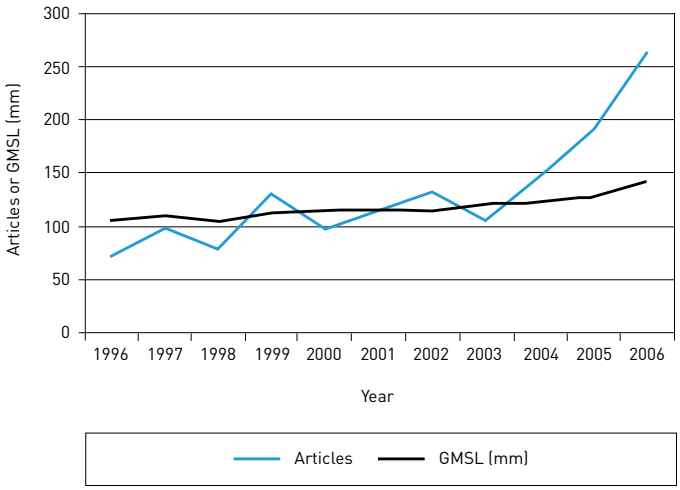


Figure 1 – Annual global output of articles on "sea level" and "climate change" and global mean sea level (mm) 1996–2006 Source: Scopus

Encouragingly, the global output of research articles focused on climate change-led sea level changes has recently outstripped the rise in the GMSL itself (see Figure 1). With so much at stake, the Maldives has recently committed to lead by example in the fight against climate change by pledging to be the world's first carbon-neutral country within a decade.

A unique position

The World Forum was hosted by the Smith School of Enterprise and the Environment, founded in 2008 as a unique interdisciplinary hub where leading academics work with the private sector and government to meet the environmental challenges of our times.

As Dr John Hood, Vice-Chancellor of the University of Oxford, said in his introductory remarks to the World Forum: "All this was thanks to benefactor Martin Smith who realized we had a large number of scholars researching climate change in many different fields, but no interaction with business. This was the gap that the Smith School could fill. The School had the capacity to bring together private companies, academic institutions, governments and non-governmental organizations to meet the climate challenge. The location of the Smith School at Oxford University meant its research could be fully interdisciplinary."

In this way, the Smith School embodies the concept of the Triple Helix of university-industry-government interactions. This model of innovation, developed by Henry Etzkowitz and Loet Leydesdorff in the 1990s, invokes a spiral of complex and dynamic interactions and knowledge flows between the three players but places the university as the leader in the creation of knowledge and economic development.

The school's research fellows, visiting research fellows and faculty associates provide expertise in fields as diverse as engineering, physics, geography, economics, law and philosophy. Founding Director Sir David King, who served as the UK Government's Chief Scientific Adviser and Head of the Government Office of Science from 2000 to 2007, told the World Forum that, "the Smith School is a global hub to facilitate governments, the private sector and academia to meet the climate challenge". Sir David is the author of more than 400 articles since the 1960s that have collectively attracted more than 750 citations in 2008 alone (source: Scopus). A surface chemist, his work on catalysis on solid surfaces has paved the way for improvements in the efficiency of industrial processes and reductions in the cost of catalytic converters for cars.

Continued on page 8

Continued from page 7

An inconvenient truth

Former US Vice President Al Gore, co-winner of the 2007 Nobel Peace Prize with the Intergovernmental Panel on Climate Change, gave the closing address to the World Forum. His remarks, while critical of the role that he felt government had so far neglected to play in the climate crisis, were also positive for our chances to avoid catastrophe: "I say we ought to approach this challenge with a sense of joy. What a privilege to have work so worthy of one's best efforts. A challenge so crucial to all future generations."

Gore, who brought climate change awareness to a mass audience with the 2006 documentary *An Inconvenient Truth,* noted that one way forward was continued advances in renewable energy science and technology. "I come away from that journey absolutely convinced that we have the tools available to us to solve three climate crises. We only have to solve one."

In his final remarks at the World Forum, Gore said of the future of climate change action: "It can happen. It will happen. We have everything we need, except political will – and political will is a renewable resource."

Sir David King added: "Uniquely, the first Smith School World Forum provided a venue for entrepreneurs, scientists and business leaders to seek and assess ways of defossilizing our economies. As the Copenhagen protocol develops, the World Forum will become the key annual event for leaders of governments, the private sector and academe to examine progress and the many innovative solutions to this unavoidable challenge."

References:

(1) Church, J.A. and N.J. White (2006) "A 20th century acceleration in global sea-level rise", Geophys. Res. Lett., 33, L01602. Updated **data**.

(2) Khan, T.M.A., Quadir, D.A., Murty, T.S., Kabir, A., Aktar, F. and Sarkar, M.A. (2002) "Relative sea level changes in Maldives and vulnerability of land due to abnormal coastal inundation", *Marine Geodesy,* 25, 133–143.

Four challenges

In his keynote speech, Lord Browne of Madingley set forth four challenges to be met if we are to tackle climate change. President of the Royal Academy of Engineering and former group chief executive of BP, Lord Browne noted direct effects on the pockets of consumers, with fuel bills expected to rise by 2–3% each year for the next two decades as emissions are reduced. Meanwhile, investment in ambitious sustainable energy projects must be stimulated and emissions trading schemes ("cap and trade") implemented to motivate investors. Opportunities and incentives must be made for business to pursue low carbon technology in their core activities. Finally, global governance must involve all stakeholders, since two thirds of potential emissions reductions could be achieved at half the cost in the developing world.

Policy

Climate research outstrips CO_2 emissions

ASCHWIN WIJNSMA

In the 1820s, the French scientist Joseph Fourier formulated the idea that some gases in the atmosphere freely let through visible and ultraviolet sunlight that heats the earth's surface but absorb and scatter the infrared radiation that is reflected back to space. As a result, heat is trapped in the atmosphere, which causes the temperature on earth to rise. This is known as the greenhouse effect.

In the late 19th century, the Swedish scientist Svante Arrhenius was the first to speculate that rising carbon dioxide (CO_2) levels in the atmosphere could change the earth's surface temperature through this greenhouse effect. He calculated that cutting CO_2 levels by half would lower the earth's temperature by 4–5°C.

His ideas were generally dismissed or simply ignored by contemporary scientists, but in 1938, Guy S. Callendar revisited his ideas and brought up more arguments in favor of Arrhenius's hypothesis. More and more scientists became convinced that atmospheric CO_2 strongly influenced the temperature on earth and that anthropogenic carbon emissions contributed significantly to atmospheric CO_2 levels. In 1960, Charles D. Keeling was the first to start measuring the carbon dioxide level in the atmosphere very precisely, and on the basis of these data was able to conclude that it was rising rapidly *(1)*.

With climate research in its infancy, Helmut E. Landsberg stressed in his 1970 *Science* paper *(2)* that very little was known about how human activity might change the climate. His article marked the establishment of modern climate change research, which continues to thrive today.

Article output and the economy

Bibliographic analysis of research articles on climate change with reference to CO_2 in peer-reviewed journals reveals that those specifically mentioning anthropogenic CO_2 form a major subset (up to half) of all articles mentioning CO_2 over the period 1996–2006 (see Figure 1). Also visible are the stagnations of growth around 1998–1999 and 2001–2002, and a plateau around 2004–2006. These periods coincide with global economic recessions.

To investigate whether there might be a relationship with the economy, the **article-output data was compared with the global gross domestic product** (GDP). And, since economic growth is driven by energy, which is predominantly generated by burning fossil fuels, another relevant **data set is the growth of anthropogenic carbon emissions** *(3)*. Putting these data together reveals a cycle whereby rising CO_2 levels drive research on CO_2-led climate change, but where funding for such research is ultimately dependent on the CO_2 emissions that drive economic growth (See Figure 2).

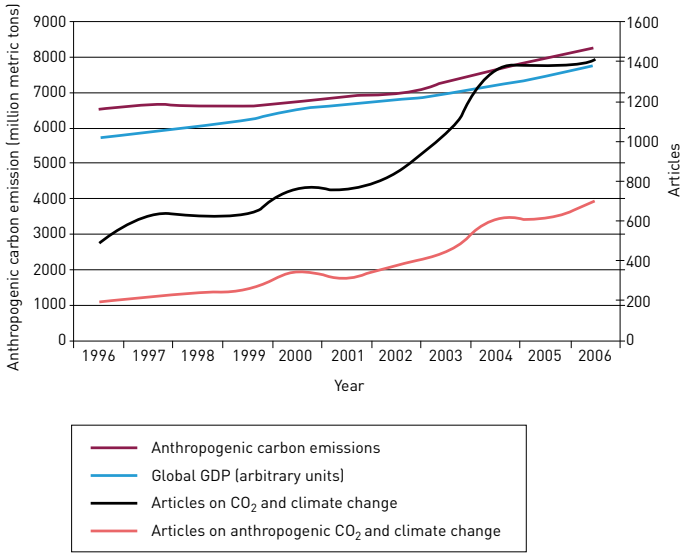


Figure 1 – Article output (articles), carbon emissions (metric tons) and GDP (arbitrary units) have all risen between 1996 and 2006, with small plateaus around major recessions. Source: Scopus

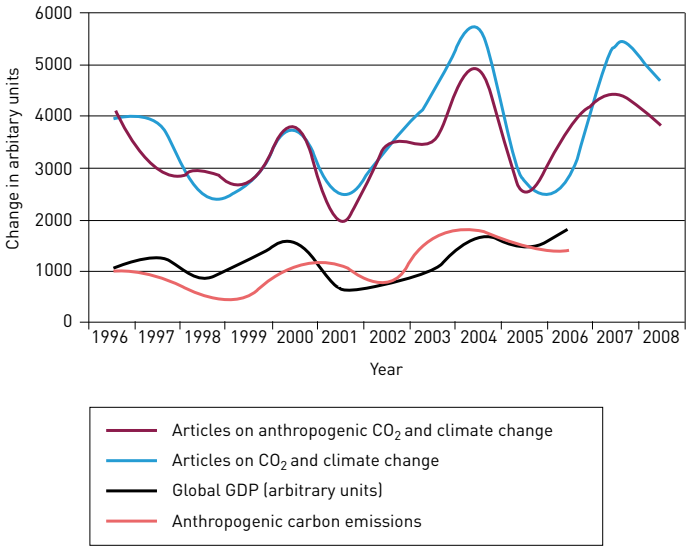


Figure 2 – Rescaling the annual variations in article output, carbon emissions and GDP in arbitrary units between 1996 and 2006 allows for direct comparison, indicating a cyclical relationship. Source: Scopus

Continued on page 10

Continued from page 8

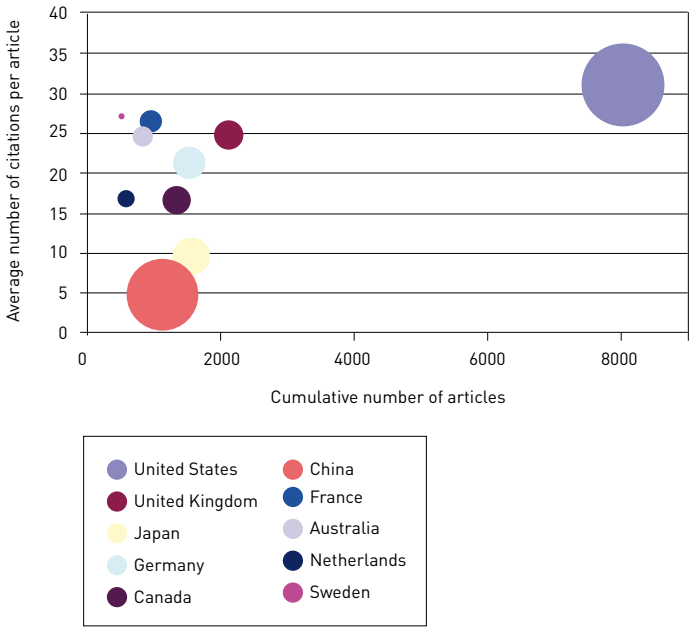
There is a clear relationship between both article output curves and the GDP curve. In addition, the carbon emission profile seems to either lag a year behind or jump a year ahead of the GDP curve between 1997 and 2002, but also follows the same general trend. The relationship between article output and the GDP may be explained by governmental and corporate research budgets that depend on tax revenues, and thus economically productive (CO_2-generating) activity.

Do national research outputs correlate with carbon emissions? Looking at cumulative carbon emissions and article output on CO_2 and climate change per country (see Figure 3) suggests that six of the top 10 countries publishing on this topic and also in the top 10 of carbon emitters: the US, UK, Japan, Germany, China and Canada. China appears to be a notable outlier, with research output failing to keep pace with carbon emissions, and these articles are also cited less than those of other high-emission nations.

With increasing carbon emissions and corresponding atmospheric CO_2 levels, climate change research is becoming more urgent as the potential for drastic impacts on humanity become more certain. Governments around the world are responding with a focus on research, and this is often on a par with the magnitude of each nation's carbon emissions. While it appears that the economic activity that drives CO_2 growth may also drive research on the effects of anthropogenic CO_2 on climate change, it is clear that the rate of production of scientific knowledge on anthropogenic CO_2 is outstripping growth of those emissions.

Interesting article:

Tucker, M. (1995) "Carbon dioxide emissions and global GDP", Ecological Economics, Vol. 15, Issue 3, pp. 215–223



Bubble size is proportional to cumulative carbon emissions

Figure 3 – Comparing the relationship between article output, average citation per article and carbon emissions (metric tons) between 1996 and 2006 indicates that countries with high CO_2 output are also among the most prolific in terms of article output.
Source: Scopus

References:
(1) Weart, S. (2009) "The Discovery of Global Warming – The Carbon Dioxide Greenhouse Effect"
(2) Landsberg, H.E. (1970) "Man-Made Climatic Changes: Man's activities have altered the climate of urbanized areas and may affect global climate in the future", *Science*, Vol. 170 (3964), p. 1265. DOI: 10.1126/science.170.3964.1265
(3) "International Carbon Dioxide Emissions and Carbon Intensity", Energy Information Administration, Official Energy Statistics from the U.S. Government

DID YOU KNOW?

Year	Topic	Article title	Author(s)	Journal	Cites to September 2009
2009	Solar cells	A complete process for production of flexible large area polymer solar cells entirely using screen printing – First public demonstration	Krebs F.C., Jorgensen M., Norrman K., Hagemann O., Alstrup J., Nielsen T.D., Fyenbo J., Larsen K., Kristensen J.	*Solar Energy Materials and Solar Cells*	21
2009	Solar cells	Polymer solar cell modules prepared using roll-to-roll methods: Knife-over-edge coating, slot-die coating and screen printing	Krebs F.C.	*Solar Energy Materials and Solar Cells*	17
2009	Biofuel	Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rape seed?	Thamsiriroj T., Murphy J.D.	*Applied Energy*	15
2009	Biofuel	Good or bad bioethanol from a greenhouse gas perspective - What determines this?	Borjesson P.	*Applied Energy*	15
2008	Solar cells	19.9%-efficient ZnO/CdS/ CuInGaSe2 solar cell with 81.2% fill factor	Repins I., Contreras M.A., Egaas B., DeHart C., Scharf J., Perkins C.L., To B., Noufi R.	*Progress in Photovoltaics: Research and Applications*	72
2008	Solar cells	Air stable polymer photovoltaics based on a process free from vacuum steps and fullerenes	Krebs F.C.	*Solar Energy Materials and Solar Cells*	48
2008	Solar cells	Flexible organic P3HT:PCBM bulk-heterojunction modules with more than 1 year outdoor lifetime	Hauch J.A., Schilinsky P., Choulis S.A., Childers R., Biele M., Brabec C.J.	*Solar Energy Materials and Solar Cells*	35
2008	Biofuel	Biohydrogen as a renewable energy resource – Prospects and potentials	Meher Kotay S., Das D.	*International Journal of Hydrogen Energy*	33
2007	Solar cells	Meeting the clean energy demand: Nanostructure architectures for solar energy conversion	Kamat P.V.	*Journal of Physical Chemistry C*	185
2007	Solar cells	Flexible, long-lived, large-area, organic solar cells	Lungenschmied C., Dennler G., Neugebauer H., Sariciftci S.N., Glatthaar M., Meyer T., Meyer A.	*Solar Energy Materials and Solar Cells*	71
2007	Solar cells	Continuous dark fermentative hydrogen production by mesophilic microflora: Principles and progress	Hawkes F.R., Hussy I., Kyazze G., Dinsdale R., Hawkes D.L.	*International Journal of Hydrogen Energy*	68
2007	Solar cells	Nanocrystalline dye-sensitized solar cells having maximum performance	Kroon J.M., Hore S., Wurfe U., Sastrawan R., Durrant J.R., Palomares E., Pettersson H., Gruszecki T., Walter J., Skupien K., Tulloch G.E., Bakker N.J., Smit H.J.P., Liska P., Thampi K.R., Wang P., Zakeeruddin S.M., Gratzel M., Hinsch A.	*Progress in Photovoltaics: Research and Applications*	66

Top-cited energy papers focus on alternative sources. The top four articles in 2007, 2008 and 2009 (to date) in the Scopus category Energy are listed with citation counts to date.
Source: Scopus

researchtrends

You can find more information on **www.researchtrends.com**
or contact us at **researchtrends@elsevier.com**