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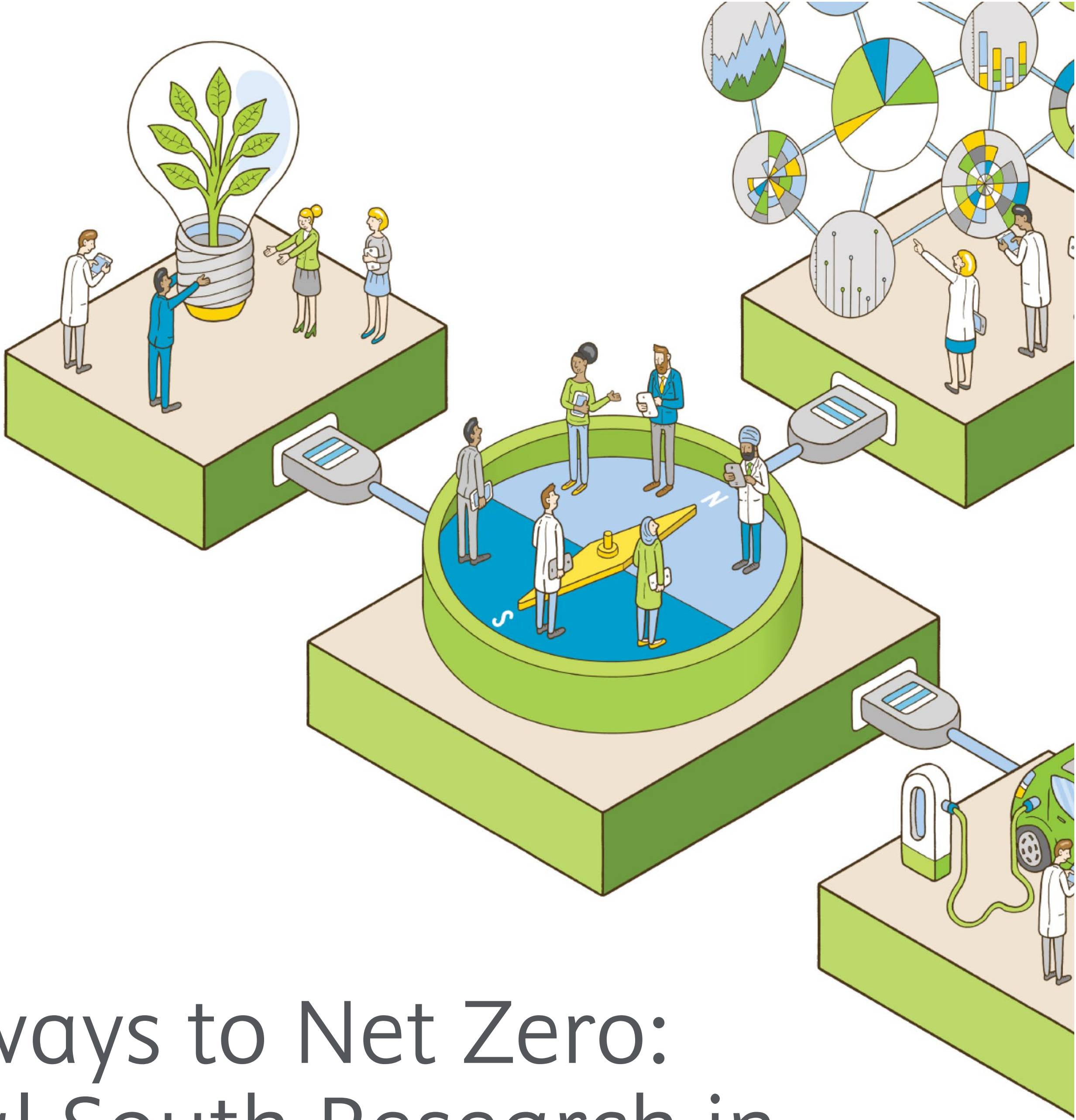


Pathways to Net Zero: Global South Research in the Transition to Clean Energy

Analytical Services

Executive summary

The ambition of achieving net zero greenhouse gas emissions by 2050 to tackle climate change requires a global effort. The Global South is likely to be disproportionally affected and has an important role to play in realizing this target. This report examines how net zero research in the Global South is contributing to a clean energy future.

Greenhouse gas (GHG) emissions from burning fossil fuels and deforestation are rising, producing global heating that is altering the climate and putting populations and ecosystems at risk.[1] The 2015 Paris Agreement pledged to limit global temperature rise to less than 2°C above pre-industrial levels and achieve net zero emissions—where unavoidable GHG emissions are balanced by removal strategies such as reforestation and carbon capture and storage—by 2050.[2]

Many countries are committed to achieving net zero by this date and are investing in net zero research and innovation. In this follow-up to Elsevier's report *Pathways to Net Zero: The Impact of Clean Energy Research*[3], which presented a broad perspective on the impact of clean energy research on achieving net zero, we focus specifically on the Global South. This classification encompasses Upper-Middle-Income Countries (UMICs), Lower-Middle Income Countries (LMICs), and Low-Income Countries (LICs), as defined by the World Bank.[4] Arguably, these countries will bear the brunt of the socio-environmental impacts of climate change, while simultaneously seeking ways to increase their level of economic development and the well-being of their citizens. Global South-led research and innovation must, therefore, be positioned to tackle the local environmental, as well as economic, challenges that these communities will face in the future.

This evidence-based report builds on the findings of *Pathways to Net Zero: The Impact of Clean Energy Research* through a bibliometric analysis of over 1.7 million research publications from 2002 to 2021, identified from the Scopus database[5], a publication set we refer to as *NØEnergy research*. The analysis focuses on understanding how the Global South's NØEnergy research effort is contributing to the transition to net zero by characterizing the overall performance and that of individual countries—as well as the

[1] IPCC. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Masson-Delmotte, V., et al. (eds.). Cambridge University Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[2] United Nations. (2015). *Paris Agreement.* Article 2, p. 3. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[3] Elsevier. (2021). *Pathways to Net Zero: The Impact of Clean Energy Research*. https://www.elsevier.com/connect/net-zero-report

[4] The World Bank. https://www.worldbank.org

[5] Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 84 million documents published by some 7,000 publishers. For further details, see https://www.elsevier.com/solutions/scopus

effectiveness of collaboration within Global South countries and beyond with the Global North. The report illuminates the crucial contributions that the Global South is making to NØEnergy research in the push towards a clean energy future, and offers an insight into the NØEnergy research profiles of three Global South countries—Brazil, Egypt, and Indonesia—to provide national context for understanding how high-level developments in research are being effectively deployed on the ground.

Key Findings

Net zero research can be subject to unique challenges in the Global South, including financial barriers and access to equipment or other resources. At the same time, our analysis indicates that many Global South countries are seeing some of the highest rates of growth in NØEnergy research output, outstripping their Global North counterparts. This finding indicates that NØEnergy research has been acting as a pathway for research and capacity development in these countries over recent years. Our characterization of Global South NØEnergy research provides a preliminary indication that these countries are likely to benefit from greater involvement in research focused on net zero objectives. Many Global South countries showing growth in NØEnergy research output, such as Egypt, are making significant shifts in the composition of their overall research portfolios towards addressing net zero challenges.

Encouragingly, our findings demonstrate that equity in the attribution of researchers' contributions to collaborative publications, as indicated by lead author positions, has greatly improved over the last decade within South–North collaborations. By 2021, Global South researchers took approximately half of lead authorship positions on South–North collaborative publications on average, up from as little as 15% a decade ago.

These figures signal growing parity in relations between Global South and Global North researchers in the NØEnergy field, with the former now achieving greater levels of visibility, seniority, and prestige in collaborative publications. Moreover, progress towards parity between Global South and Global North researchers suggests the potential for more effective knowledge transfer between countries with different levels of scientific capacity. Improved parity in South–North co-publications is necessary for an equitable research ecosystem and to support South-driven solutions to local challenges.

Although South–South collaborations currently amount to less than 10% of the total number of international collaborations in NØEnergy research, in terms of publications, the proportion has increased steadily over the last decade. Crucially, South–South collaborations offer distinct benefits for the researchers involved, notably in terms of fostering multidisciplinarity. To maximize its effectiveness, net zero research needs to cut across traditional disciplines, embracing ideas, expertise, approaches, and solutions from many different areas: the multidisciplinarity of South–South collaborations puts the region's research enterprise in an exceptionally strong position to tackle the complex societal and environmental challenges ahead.

At the level of individual countries, Brazil's BIOEN funding program provides an example of how targeted support can help expand NØEnergy research capacity in Global South countries.

The Egypt-Japan University of Science and Technology's solar energy research portfolio, meanwhile, demonstrates how Global South universities and research organizations can foster small-scale but highly influential research.

Finally, Indonesia illustrates how an all-rounder Global South country can target its research efforts in multiple clean energy directions (e.g., bioenergy, solar, geothermal, and hydro) and benefit from high growth in NØEnergy research overall.

The key findings of this report provide encouragement that NØEnergy research is growing in the Global South and that the research enterprise in these countries will benefit from increased support for South–South collaboration, as well as South–North collaboration with improved levels of parity between researchers.

Contents

Introduction

This report presents a bibliometric analysis of the Global South's contributions to the net zero research landscape and a clean energy future.

This report is released to coincide with COP27, the United Nations' Climate Change Conference taking place in Sharm el-Sheikh, Egypt, in November 2022.[6] It is highly significant that the meeting is taking place in the Global South, which is likely to be disproportionally affected by climate change.

In this second report from Elsevier on the global net zero research landscape as it moves toward a clean energy future, we focus **wholly on the Global South.** Although the previous report, *Pathways to Net Zero: The Impact of Clean Energy Research*[7], explicitly sought to capture contributions from Global South researchers and countries to net zero research, the analysis likely reflects the under-representation of this region in academia, as recently exposed in climate[8] and biomedical sciences.[9] This report concentrates on the Global South in its own right.

Throughout these pages, we intentionally refer to *South–North collaborations* or *co-publications*, where at least one researcher from the Global South and one from the Global North are involved, in order to address, to some extent, any inherent inequalities within these relationships. For instance, the recent analysis of the publishing gap between the South and North, involving a set of highly cited climate science publications, revealed that nearly 90% of authors were concentrated in countries associated with the North. Despite its population size, African authors represented less than 1% of the total in the analysis and of those 10 authors, eight were from South Africa, with most African countries unrepresented.

Against this background, the current report aims to address the following key questions:

- Is net zero energy research growing at the same pace in the Global South as the Global North? Is it focused on the same research areas and topics? In collaborative publications, are the most visible author positions shared equitably between South and North researchers?
- Do South–South collaborations, involving researchers from at least two different Global South countries, provide equally rich opportunities for these researchers as those with the Global North? Are South–South collaborations better adapted to the specific needs of researchers in these countries?
- What do Global North researchers gain from increasing their level of collaboration with the Global South?
- What kind of support mechanisms can help Global South researchers in net zero build capacity in their countries?

The report begins with a broad look, in Chapter 1, at the publication output, pace of growth, and collaboration trends in net zero research across the Global South. We examine international collaboration and co-publications within the

[6] https://cop27.eg
[7] Elsevier. (2021). *Pathways to Net Zero: The Impact of Clean Energy Research*. https://www.elsevier.com/connect/net-zero-report
[8] Tandon, A. (2021). *Analysis: The lack of diversity in climate-science research*. CarbonBrief. https://www.carbonbrief.org/analysis-the-lack-of-diversity-in-climate-science-research/
[9] Hedt-Gauthier, B. L. *et al.* (2019). Stuck in the middle: A systematic review of authorship in collaborative health research in Africa, 2014-2016. *BMJ Global Health*, **4**(5), pp. 2014–2016. https://doi.org/10.1136/bmjgh-2019-001853

Global South and with countries of the Global North. International collaboration with well-funded scientists in the Global North is a potential solution for Global South researchers who face barriers to publication such as insufficient resources, equipment, or funding. However, the studies mentioned above suggest that collaborations like these, if carried out on an unequal footing, may unduly benefit researchers from the Global North. Here we investigate and compare the performance of international co-publications arising from South–North, South–South, and North–North collaborations.

It is noteworthy that Egypt, a Global South country, is hosting the COP27 at a time when the country is making substantial investments in solar energy in the form of the Benban Solar Park, in order to meet its renewable energy goals. In Chapter 2, we discuss Egypt's commitment to renewable energy generation and analyze its contributions to solar energy research. We then turn our focus to Brazil, a leader in renewable energy use, particularly biofuels. We then examine the country's contributions to research in these fields and identify some of the major funders of research. Finally, we outline and analyze Indonesia's diverse portfolio of net zero research.

The report concludes with some recommendations for achieving a more equitable global research strategy, and associated policies, in net zero research, as well as further questions that have arisen from our findings.

Methodology

We briefly describe here the terminology and methodology used throughout this analysis. More comprehensive descriptions are available in Appendix B.

Global South definition

This report uses the definition of the Global South introduced in the first report, in line with World Bank definitions[10]. The Global South refers to three groups of countries:

- Upper-Middle-Income Countries (UMICs)
- Lower-Middle-Income Countries (LMICs)
- Low-Income Countries (LICs)

IPCC definition of net zero

The IPCC Glossary distinguishes between the terms *carbon neutrality*, *net zero* and *climate neutrality*.

In brief, carbon neutrality entails balancing emissions of anthropogenic CO_2 with their intentional removal from the atmosphere. This is also referred to as *net zero CO_2 emissions*.

Net zero represents the same concept but applied to all GHG emissions, not just CO_2.

Climate neutrality is the state whereby anthropogenic activities have no net effect on the climate system as a whole. The IPCC Glossary notes, "Achieving such a state would require balancing of residual emissions with emission (carbon dioxide) removal as well as accounting for regional or local biogeophysical effects of human activities that, for example, affect surface albedo or local climate."

For the full definitions and others, see the IPCC Glossary: https://www.ipcc.ch/sr15/chapter/glossary

In these pages, the Global South excludes China, which is usually considered a UMIC. However, although China is a recipient of some development aid, it is a scientific powerhouse and collaborates routinely because of its high academic status rather than as a result of development-oriented scientific efforts.

Global North countries are sub-divided into four categories:

- China
- EU-27 countries (including Bulgaria, a UMIC, but included in the Global North here)
- The United States

[10] The World Bank, https://www.worldbank.org

- Other High-Income Countries (HICs), including Australia, Canada, Israel, Japan, Saudi Arabia, South Korea, Switzerland, United Arab Emirates, and the United Kingdom

Note that some analyses in this report present India separately from other LMICs and the United Kingdom separately from other HICs. India is always considered a Global South country, however.

Publication set

This report focuses on journal articles, conference proceedings, books, and book chapters. Unlike the prior report, it does not provide an analysis of patents. The sole sources of publications are the Scopus and SciVal databases, often using a specific implementation of those databases developed under the Science-Metrix brand. Throughout the report, we refer to the publication set as *NØEnergy*.

The thematic classification of NØEnergy research closely follows that of the prior report, but the publication set has been updated to include 2021, shifting the coverage period from 2001–2020 to 2002–2021 (or a subset of this period).

SciVal Topic clusters

Since the NØEnergy publication set based on our specific search queries generates a single but very large data set, we sometimes use SciVal **topic clusters** to analyze the broader NØEnergy area in a more granular way.[11] Publications in Scopus are categorized into more than 97,000 **topics** using an algorithm that considers the citation links between publications. Since topics are based on citation patterns and not journal categories, they are multidisciplinary. Topics are grouped into over 1,500 topic clusters using the same algorithm. Both topics and topic clusters are mutually exclusive: a publication belongs to only one topic and only one topic cluster. Using topic clusters allows us to view the NØEnergy research landscape from the bottom up. Topic clusters are named by the three most relevant key phrases within the cluster—for example, *Wind Power | Electric Power Transmission Networks | Electric Power Distribution*. Distinct key phrases are extracted using the Elsevier Fingerprint Engine, a text-mining software system.[12]

Most of the report focuses on the largest topic clusters within the NØEnergy publication set in terms of scholarly output; however, given the importance of some areas, such as carbon capture and storage to achieving net zero, we also include such relevant and related topic clusters, which might not appear among the most published.

Collaboration and co-publications

Collaboration between researchers is measured by counting the number of publications resulting from the efforts of two or more authors from distinct organizations or institutions. Such publications are referred to as **co-publications** throughout the report. Collaboration can be categorized into various types, but here we focus on international collaboration where the affiliations of authors on a publication include institutions from two or more countries or regions.

Since international co-publications are important engines of scientific capacity building and, given this report's focus on the Global South, we distinguish here between Global South countries' collaborations with other Global South countries (**South–South collaborations**) and those with Global North countries (**South–North collaborations**). Publications with authors from two distinct LICs, LMICs, or UMICs are considered **South–South co-publications**. The reader is reminded to abandon any ideas of countries' geographical location when considering South–South, South–North, or North–North collaborations. For example, a co-publication with authors from Chile, China, and Oman is considered a North–North collaboration, while a Brazilian–Serbian co-publication would be considered South–South. In some characterizations of collaboration patterns, we also measure the propensity towards South–South and South–North collaboration versus North–North collaboration.

The co-authorship of researchers on individual publications represents a **co-publication link** between not only those individual researchers but also the institutions or organizations with which they are affiliated and the countries in which they are located. For example, a co-publication authored by researchers located in Nigeria, France, and Italy would give rise to three bilateral links between Nigeria–France, Nigeria–Italy, and France–Italy (i.e., two South–North links and one North–North link, regardless of the

[11] See https://www.elsevier.com/solutions/scival/features/topic-prominence-in-science

[12] See https://www.elsevier.com/solutions/elsevier-fingerprint-engine

number of researchers from each country). The sum of these bilateral co-publication links between author countries can be calculated to provide an indication of the intensity of collaborative relationships, specifically between Global South and Global North countries.

Within the context of such collaborative relationships, **homophily** is the tendency of researchers or countries (or other entities) to be associated with others of a similar type. For example, researchers (or countries, or institutions) collaborating more with those from their own country than elsewhere would be regarded as **homophilic**. The reverse, where researchers collaborate more with those from different countries than similar ones are termed **heterophilic**. Determining the homophily or heterophily of collaborative relationships is one tool available as part of social network analysis. **Social network analysis** refers to a group of statistical tools that are used to characterize relationships or interactions between different socio-economic categories or entities, such as individuals, organizations or companies, at scale.

From the perspective of research collaborations between the Global South and the Global North, South–South and North–North international co-publications can be considered homophilic links, while South–North international co-publications can be defined as heterophilic links.

Classifying collaboration modalities can also identify the potential differential benefits for Global North researchers engaging in South–North or North–North collaboration versus non-collaborative research, as well as for Global South researchers engaging in South–North or South–South collaboration versus non-collaborative research.

Assessment indicators

Most findings in this report are derived from a few core assessments and their associated indicators, as follows:

Publication volume output for a given country, group of countries, year, or other category provides a very rough estimate of the intensity of an activity. This information can be relativized by presenting it as a share of the overall sum of publications in the field to which a country's publications have contributed. Multiple countries can contribute to a single research publication, so collaborative publications are counted in the contributions of multiple countries.

The **compound annual growth rate** (CAGR) is defined as the year-over-year constant growth rate in a specified period of time. Starting with the first value in any series and applying this rate to each successive time interval yields the final value of the series. **Differential CAGR** is determined as the difference between the CAGR in NØEnergy research and in research overall. A positive ratio denotes an increasing degree of specialization in a research field within a country or group of countries' overall research portfolio.

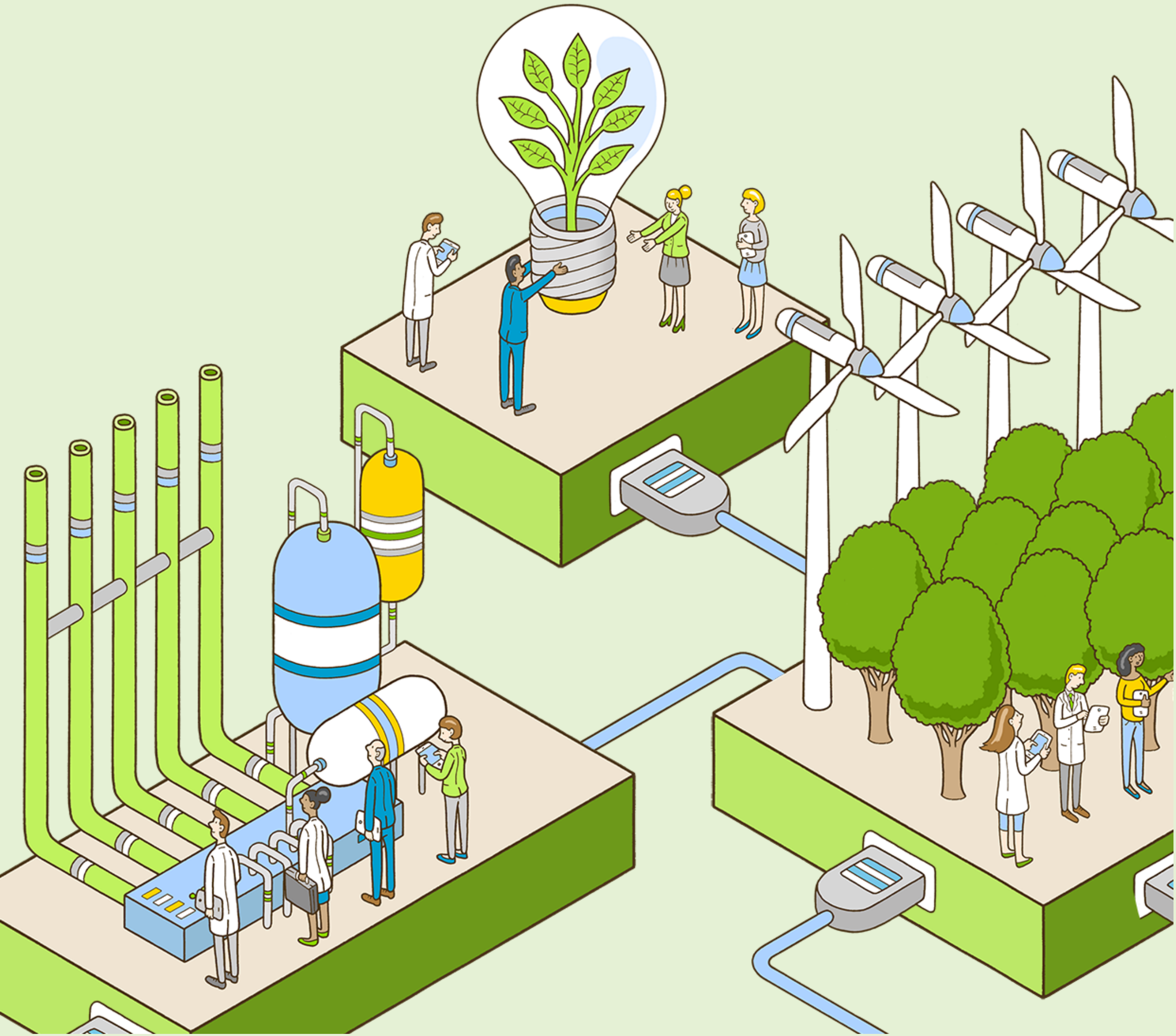
Output can be further relativized by comparing the share of publications in a given topic or subfield to which a country (or group of countries or other entity) has contributed to the expected global share. This is the **relative activity index** (RAI), which is also considered a measure of specialization within a field of research.

Given that cross-disciplinary approaches in science are more conducive to tackling wide-ranging societal and environmental problems, our analysis employs two related indicators. These are **multidisciplinarity**, which denotes the diversity in disciplinary background of authors on a given publication, and **interdisciplinarity**, which shows the diversity in the disciplines from which prior knowledge integrated into a publication has been drawn.

Finally, our analysis also uses a **citation impact indicator**, the share of publications from a given country (or group of countries or other entity) that is among the most highly cited in the subfield and year. Scientific citations are commonly perceived as a measure of the quality of research within a given publication set, but citation impact can also be viewed as a measure of the capacity of research to prompt or facilitate follow-up investigations or further innovation.

Chapter 1

Trends in Global South NØEnergy research and collaboration



1.1 Trends in Global South NØEnergy research output

Global South countries saw high growth in NØEnergy research output volume between 2012 and 2021, outstripping the Global North.

This section analyzes the contributions of Global South LICs, LMICs, and UMICs, as well as selected individual countries, to NØEnergy research, updating the previous report[13] to include data from 2021. The findings characterize both the volume of research output and, more importantly, the growth in NØEnergy research by income group and for selected countries over the period 2012 to 2021. Given the small annual output volumes of most Global South countries, along with the increasing priority of NØEnergy research, the relative growth in publication volume is, arguably, as or more important as absolute publication volumes in understanding country-level efforts in NØEnergy research.

The analysis of the share of NØEnergy research contributed by Global South income groups reveals that LICs contributed to less than 1% of publications, LMICs to 18% (including India's contribution, which is discussed in more detail below), and UMICs to 16% by 2021. However, it is important to note that because multiple countries may contribute to a single research publication, the sum of country-level shares to NØEnergy research output exceeds 100%.

Although India is usually classified as a LMIC, it is considered as an individual country here, presented separately in FIGURE 1-1, because it is a scientific powerhouse that produces more NØEnergy research than all other LMICs combined. India contributed to 11% of all global NØEnergy research publications in 2021. Similarly, China, while classified as an UMIC, is considered in this report as a Global North country because of its well-developed research system. China accounted for the largest contribution to global NØEnergy research in 2021 by far, with 35% of publications in the field having at least one Chinese author.

To characterize the growth in NØEnergy research output across the Global South between 2021 and 2012, we calculated the compound annual growth rate (CAGR). According to our analysis, LICs lead the way with a CAGR of 24%. However, since LICs contribute to less than 1% of NØEnergy research overall, this high growth is associated with a small subset of the field. LICs also show the highest growth in research across the board (CAGR of 15%), resulting in a differential CAGR—the difference between the CAGR for NØEnergy research and that for research overall, across all subjects and disciplines—of +9 percentage points (or p.p.), where a positive ratio denotes an increasing degree of specialization in NØEnergy within a country or group of countries' overall research portfolio. By this measure, LICs rank third in terms of differential CAGR.

LMICs (excluding India) rank second with a CAGR of 22% in NØEnergy research (versus 13% in research overall) in the selection of country groups and major countries presented here. The differential CAGR for LMICs is marginally above that of LICs. India follows just behind the group of LMICs in terms of NØEnergy research growth (with a CAGR of 20%) but has the highest differential CAGR (+11 p.p.) in this selection,

[13] Elsevier. (2021). *Pathways to Net Zero: The Impact of Clean Energy Research.* https://www.elsevier.com/connect/net-zero-report

indicating a rapid pace of specialization in the field. (Note that India leads in differential NØEnergy CAGR within the analysis of major countries and country groups by income, but not within the country-level analysis reported in FIGURE 1-2).

UMICs (excluding China) show lower growth in NØEnergy research than LICs and LMICs, with a CAGR of 14% and +6 p.p. differential CAGR. China closely follows the rest of the UMICs in terms of both CAGR and differential CAGR in NØEnergy research, although it is worth noting that the country contributes to a much larger share of global research output.

All HICs demonstrate NØEnergy research CAGRs and differential CAGRs below the average global level. The EU-27, United Kingdom, and other HIC groups and individual countries have seen growth in NØEnergy research slightly above that for research overall except for the United States, where growth in NØEnergy research was on par with the country's overall research portfolio.

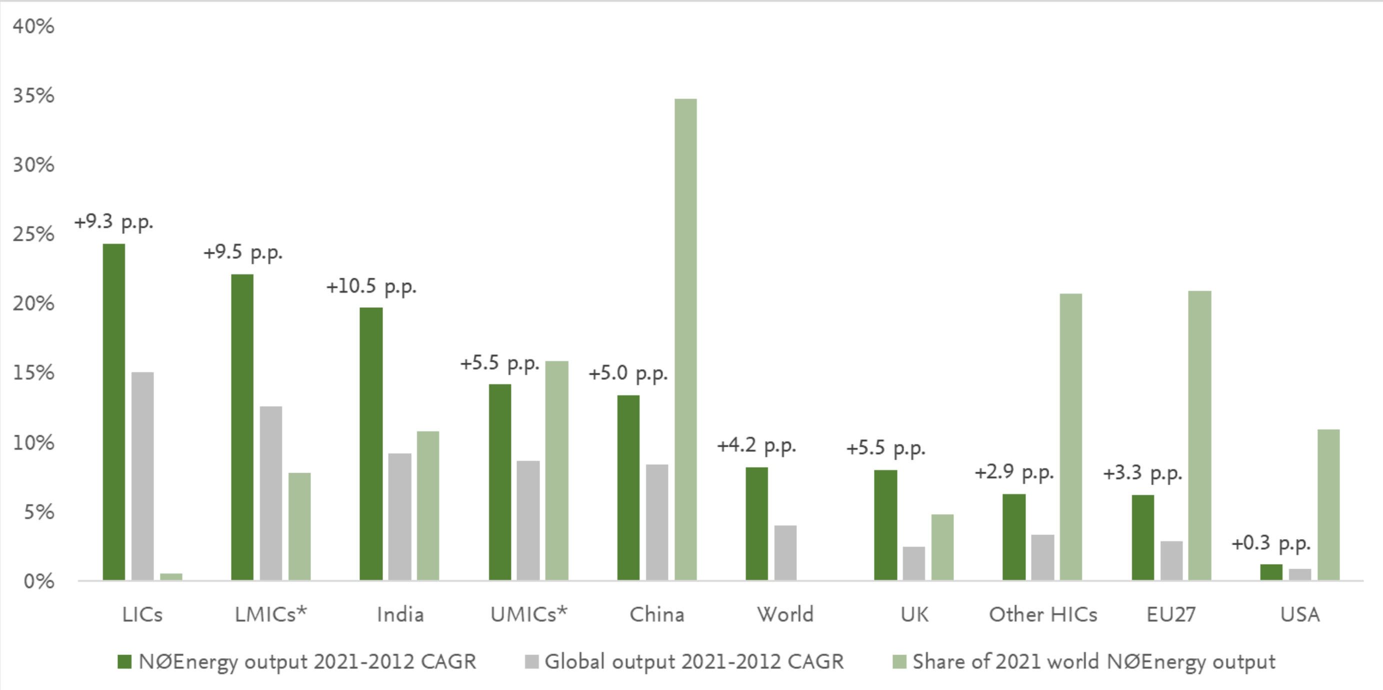


FIGURE 1-1
Comparative compound annual growth rates (CAGRs) in NØEnergy research, by country income groups or major research-producing countries, 2012–2021.
Note: LMIC and UMIC categories in this analysis do not include India and China, respectively, as they are presented separately.
Source: Scopus

At the level of individual countries in this analysis, Global South countries account for seven of the top 10 countries reporting the largest differential growth in NØEnergy research between 2012 and 2021 (FIGURE 1-2). The ranking in FIGURE 1-2 captures countries with increasing levels of relative activity or specialization in NØEnergy research over time (in descending order of differential growth).

Of these countries, Pakistan, a LMIC, records the highest differential growth in NØEnergy research (+18 p.p.) with a CAGR of 34%, compared with a CAGR of 15% in research overall. In 2021, Pakistan contributed to 1.6% of global NØEnergy research publications in total.

Morocco, another LMIC, has the next highest differential CAGR (just below +18 p.p.) in NØEnergy research with a CAGR of 31%, compared with a CAGR of 13% in research overall. The country contributed to 1% of NØEnergy research in 2021.

In third position, quite some way behind, is the Global North HIC Saudi Arabia, with a differential CAGR of +11 p.p., a CAGR of 27% for NØEnergy research, and a CAGR of 16% for research overall.

The other Global South countries in the top 10 with positive differential CAGRs for NØEnergy research are Viet Nam, India, Nigeria, Egypt, and Tunisia. These nations are joined by the Global North countries Oman and Bulgaria (although the latter is considered a HIC in this report because it is one of the EU-27 countries, although the World Bank considers it a UMIC).

Brazil and Indonesia, as other Global South countries of interest to this report, are also included in the analysis. The former ranks in 44th position worldwide in terms of its differential CAGR (with a CAGR of 9% in NØEnergy research compared with a CAGR of 5% in research overall), while the latter comes in 74th, with a null NØEnergy differential CAGR because of very high base CAGRs for both NØEnergy research and overall research of 31%.

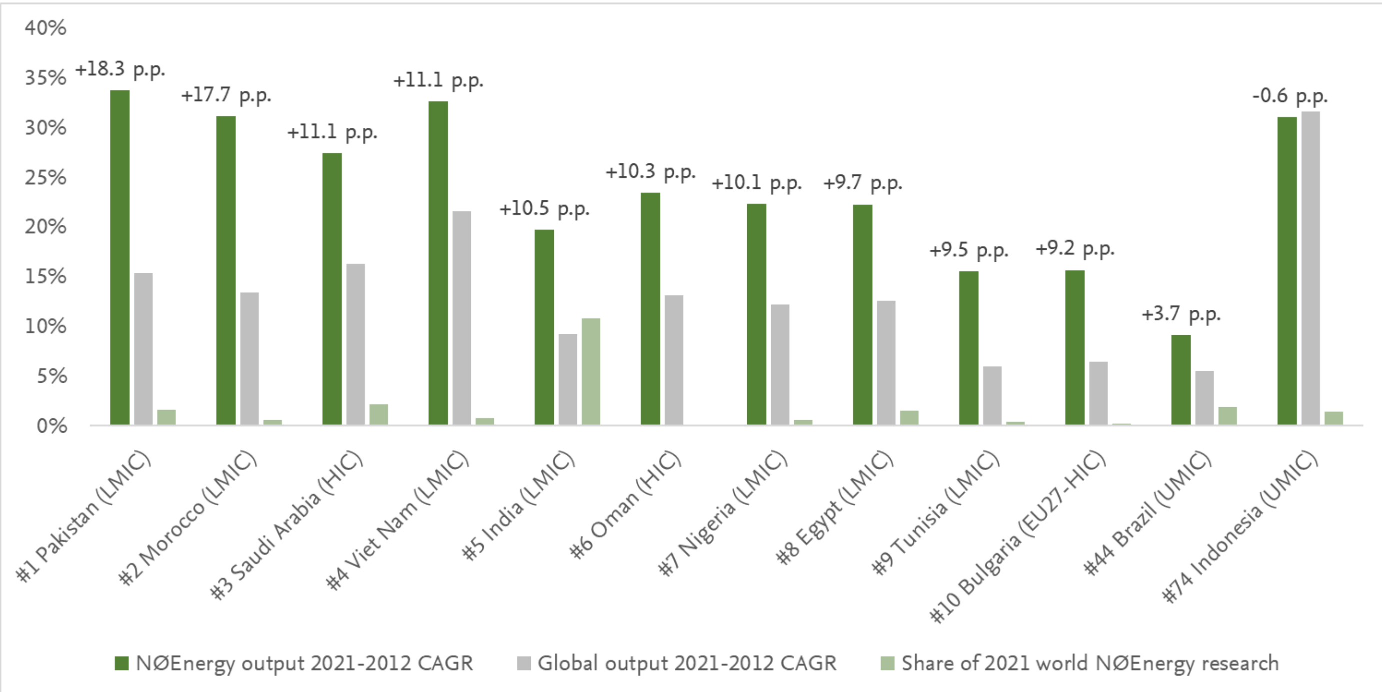


FIGURE 1-2

Comparative compound annual growth rates (CAGRs) for NØEnergy research, by selected country, 2012–2021.

Source: Scopus

1.2 Understanding Global South NØEnergy research by topic

The largest topic clusters in Global South NØEnergy research relate to wind and solar power, lithium batteries, and bioenergy.

In this section, we characterize NØEnergy research in the Global South in terms of topic clusters (see Introduction for more details) to provide a high-level assessment of the distribution of research efforts across different fields. The growth in these topic clusters between 2012 and 2021 is computed using CAGRs, with the corresponding CAGR for Global North countries provided for reference.

The topic cluster with the most publications—representing 9% of all Global South NØEnergy research publications in 2021—is *Wind Power | Electric Power Transmission Networks | Electric Power Distribution*. The Global South reports a CAGR of 20% in this topic cluster. The second largest topic cluster is *Electric Inverters I Electric Potential | DC-DC Converters*, associated with 8% of Global South NØEnergy publications. A number of topic clusters including: *Photocatalysts | Solar Cells | Photocatalysis*; *Lithium Alloys | Secondary Batteries | Electric Batteries*; *Solar Energy | Solar Radiation | Photovoltaic Cells*; and *Wireless Sensor Networks | Routing Protocols | Sensor Nodes* account for 4–5% shares of NØEnergy research across the Global South with CAGRs of between 20% and 30%.

While most of the topic clusters mentioned above clearly relate to NØEnergy research, the inclusion of *Wireless Sensor Networks | Routing Protocols | Sensor Nodes* may appear less obvious. This topic cluster, however, is concerned with the use of clean energy sources to power smart grids and smart homes, smart technologies and those related to the internet of things to increase energy efficiency in a variety of applications, and intersects with various aspects of NØEnergy research.

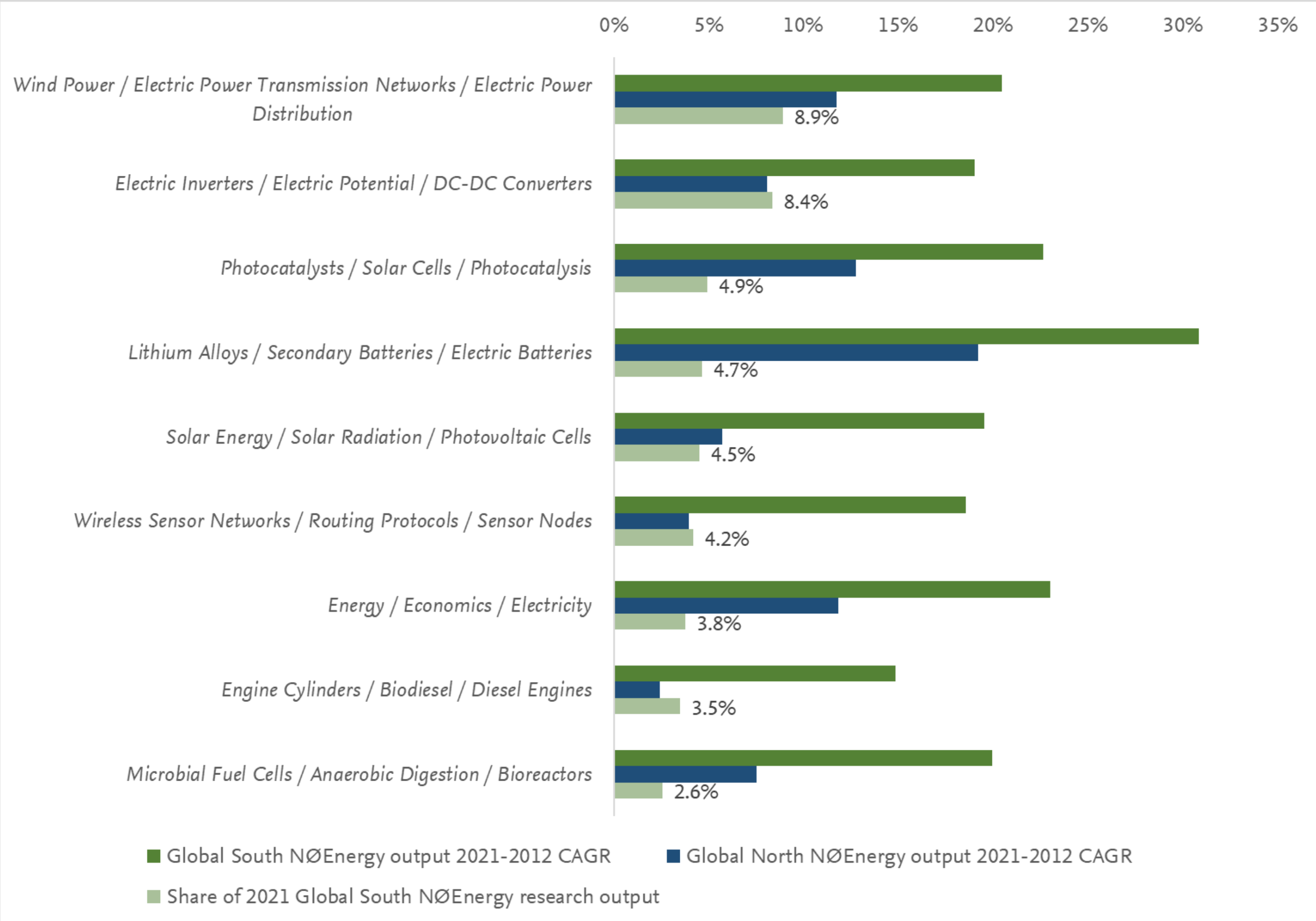


FIGURE 1-3
The top nine topic clusters in NØEnergy research in terms of the compound annual growth rate (CAGR) of output from Global South and Global North countries, with the share each cluster represents of 2021 overall global NØEnergy research, 2012–2021.
Source: Scopus

1.3 Collaboration in NØEnergy research in the Global South

Within the last decade, South–South and South–North collaborations have risen. There is still opportunity for more frequent collaboration, especially between the Global South and Global North.

Since South–North and South–South collaborations are likely to foster knowledge transfer and capacity building across Global South countries, it is useful to track their frequency and the specific development and/or funding instruments that support them. In this section, therefore, we examine the co-publication links between Global South and Global North countries, using the concepts of homophily and heterophily from social network analysis (see Introduction and Appendix B for more details).

The findings, shown in FIGURE 1-4, indicate that homophilic international co-publication links in the Global South (South–South homophilic co-publication links) are slightly higher than expected, making up 9% of international co-publication links versus an expected level of 7% in 2021 (which is estimated assuming a random assortment of countries in a co-publication network).

"South-South collaboration is needed. [These] countries face similar challenges and [share] similar historical backgrounds and cultural roots. They can learn one from another on how to overcome barriers and face similar situations."

Kathlen Schneider, Director, Ideal (Institute for the Development of Renewable Energies in Latin America) and Co-Founder and Coordinator, Brazilian Network of Women in Solar Energy (Rede MESol)

Interestingly, the shares of South–South and North–South links between bilateral co-publications in NØEnergy research are increasing at the expense of North–North bilateral co-publication links, which are decreasing. This observation is in line with expectations because the NØEnergy research outputs of Global South countries are increasing at a faster pace than those of their Global North counterparts, providing a relatively larger volume of opportunities for South–South and South–North collaboration. It could be concluded, therefore, that the NØEnergy collaboration network is increasingly heterophilic with regard to South–North collaboration, with the share of all bilateral co-publications reaching 34% in 2021 up from 18% in 2004.

However, comparing the observed alues for each type of co-publication (i.e., homophilic links between North–North and South–South co-publications and heterophilic links between South–North co-publications) with their expected values offers a contrasting perspective. In these relative terms, the share of South–North co-publication links has decreased relative to expectations while links between both types of homophilic co-publications have increased beyond expectations. In other words, because there were fewer Global South publications in 2004 there were fewer opportunities for South–North co-publications. The larger share of South–North co-publications in 2021 equates, therefore, to a smaller proportion of all Global South publications overall than the smaller share of South–North co-publications in 2004, which represented a larger proportion of all Global South publications. In this interpretation, NØEnergy research appears more homophilic in 2021 than it was in 2004.

“[South–North energy collaborations are] not equally beneficial… [but are] equally important and needed if we want to build a more diverse and just energy transition for all nations.”

Kathlen Schneider, Director, Ideal and Co-Founder and Coordinator, Rede MESol

Overall, homophilic South–South co-publication links have increased over the last twenty years, along with heterophilic links between South–North co-publications. South–South co-publication links, moreover, have increased at a slightly greater pace than expected, while those between South–North co-publications at a slower pace. The findings indicate that there is potential in fostering greater links between the Global North and Global South that, as will be shown below in section 1.5, are beneficial to researchers in the Global South and, with some trade-offs, to their Global North counterparts.

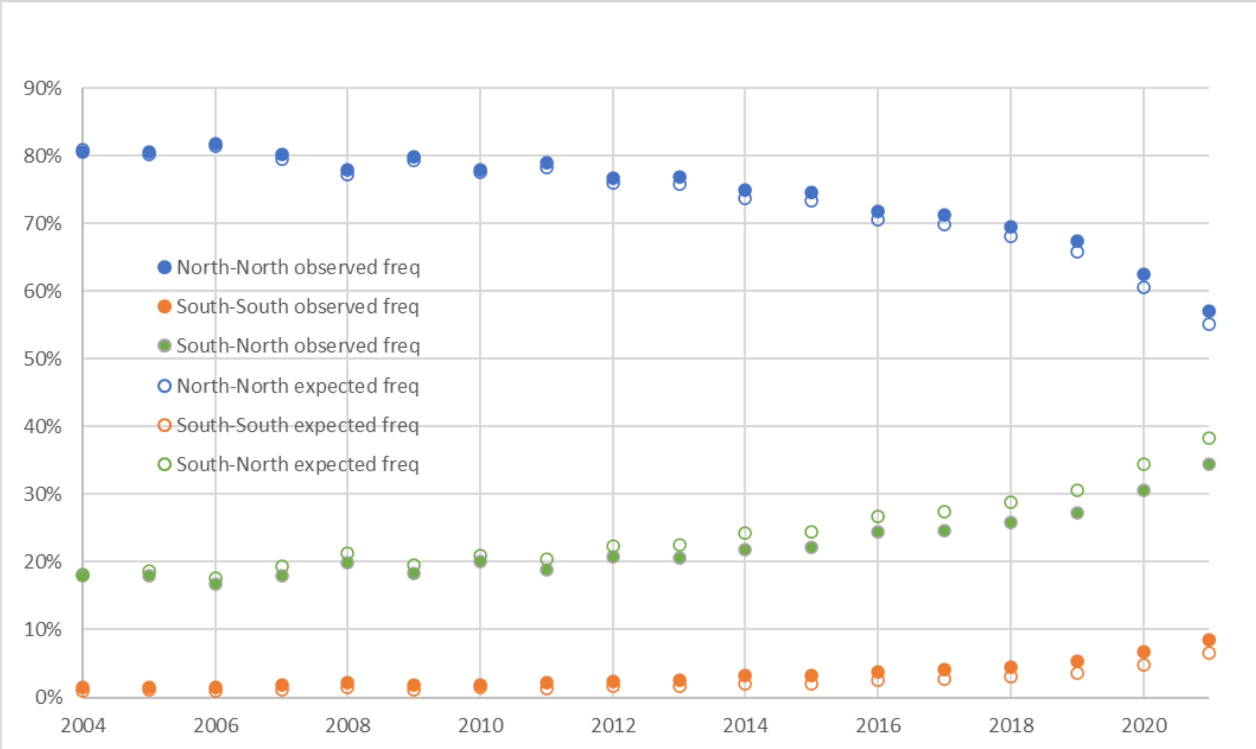


FIGURE 1-4
Expected (unfilled markers) and observed (solid markers) annual frequencies of South–South, South–North, and North–North bilateral links in NØEnergy research, 2004–2021.
Source: Scopus

1.4 Fostering South–South collaboration in NØEnergy

Despite low levels of South–South collaboration overall, a few Global South countries produce as many, or more, co-publications of this type as with Global North partners.

The smaller volume of research contributions from Global South countries means that South–South co-publications are relatively scarce, in general. Some Global South countries do appear, however, to have been more successful in fostering these collaborations as part of their overall research portfolio.

Nigeria, for example, stands out as a country where more than half (53%) of its NØEnergy research output was an international co-publication. Between 2012 and 2021, South–South co-publications accounted for 36% of the country's publications, with South–North co-publications making up 27%. Note that South–South co-publications in this analysis can include one or more partners from the Global North, so the two categories are not mutually exclusive.

In Belarus, South–South co-publications also outstripped South–North co-publications over the same period. Of the country's publications, 48% were South–South co-publications and 36% South–North co-publications. Overall, Belarus recorded a very high share of international co-publications at 69%.

The other Global South countries with the highest ratios of South–South to South–North co-publications— with ratios close to one, meaning that the rates are similar—are Iraq (with roughly 32% of each type of co-publication; Bosnia and Herzegovina (around 30%); and Malaysia (with 27% and 29%, respectively) (FIGURE 1-5).

These findings indicate that, from a national research and innovation policy perspective, wherever theory and/or evidence suggest it would be desirable,[14] it should be possible to actively foster South–South collaboration pathways beyond expected levels (assuming a random assortment of bilateral co-publication links in the research collaboration network). Further research is required, however, to provide more robust and comprehensive recommendations on the contexts in which this would be desirable, as well as how to achieve this outcome most effectively.

One limitation of this analysis is that it uses broad definitions of South–South and South–North co-publications. However, half of South–South co-publications in NØEnergy research are, simultaneously, South–North co-publications because they include authors from three or more countries. Nevertheless, fostering the inclusion of multiple Global South countries in South–North collaborations may be as desirable as fostering co-publications among multiple Global South countries.

[14] Jacob, M. (2013). *Research funding instruments and modalities: Implication for developing countries*. Research Policy Institute, Lund University. Prepared for the OECD Programme on Innovation, Higher Education and Research for Development (IHERD).

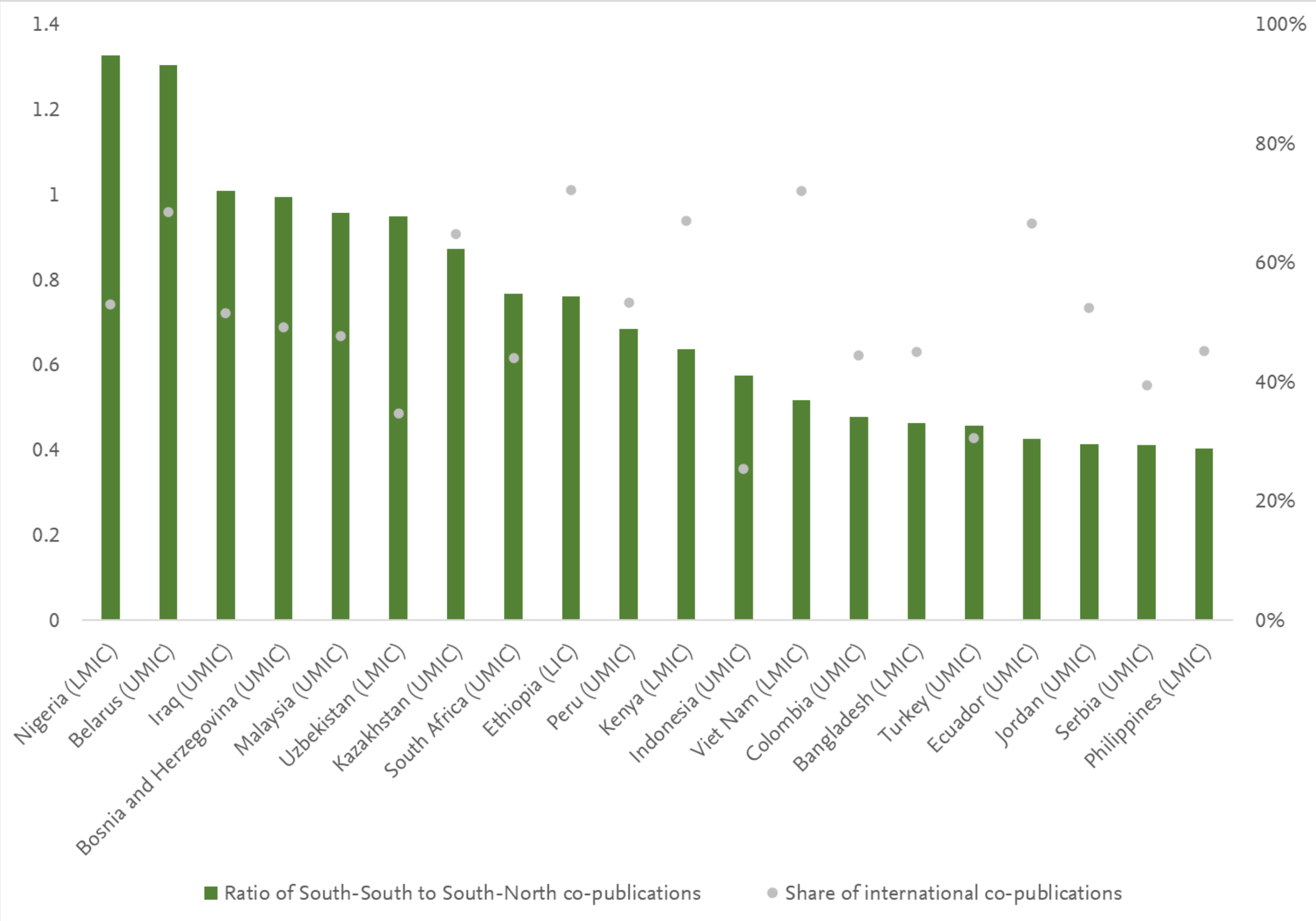


FIGURE 1-5
Ratio of South–South to South–North co-publications, for the top 20 Global South countries, 2012–2021.
Note: In this figure, individual publications with authors from three or more countries could be included in both indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publication are not fully mutually exclusive. Reference level for international co-publications is based on weighted country-level average.
Source: Scopus

1.5 Benefits of South–South and South–North collaboration

South–South co-publications offer benefits to Global South researchers over nationally collaborative or non-collaborative publications, on a par with South–North co-publications.

International collaborations and the associated co-publications can be correlated with higher citation impact and, potentially, fostering knowledge transfer.[15] But should Global South countries prioritize collaboration with similar nations or the Global North, or a mixture? From the perspective of the Global North, what are the benefits of collaborating with the Global South?

In this section, to answer these questions, we measure citation impact and cross-disciplinarity indicators for South–South, South–North, and North–North co-publications with authors from two distinct countries. As a reference point, we also determine these indicators for Global South and North publications that are not international co-publications. In addition, we also analyze other types of co-publication with more complex author affiliations because, although most international co-publications are authored by researchers from only two countries, co-publications with contributors from more than two countries tend to perform better on citation impact and are likely to perform well on cross-disciplinarity. A further benefit of this approach is that, compared with the findings presented in Section 1.4, the categories of co-publications shown in FIGURE 1-6 are mutually exclusive, which enables the determination of differential values.

The comparison of two-country co-publications shown in FIGURE 1-6 reveals that the share of highly cited articles among South–South co-publications is 50% higher than for Global South single-country publications (15% versus 10%, respectively). South–South co-publications are also much more likely to be among the most multidisciplinary of their subfield and year (15% versus 11%, respectively).

South–North co-publications perform noticeably better than Global South single-country publications in terms of citation impact and cross-disciplinarity, but not South–South co-publications. On the basis of these observations, there are clear benefits for Global South researchers, institutions, and funding bodies to fostering and conducting South–South and South–North collaborations over single-country efforts.

The situation is different for Global North researchers, however. As expected, both North–North and South–North co-publications achieve higher citation impact than single-country publications. Nearly a quarter of North–North co-publications (22%) are among the most highly cited publications, along with 15% of South–North co-publications and 14% of single Global North country publications.

[15] Chen, K., Zhang, Y., and Fu, X. (2019). International research collaboration: An emerging domain of innovation studies? *Research Policy*, **48**(1), pp. 149–168. https://doi.org/10.1016/j.respol.2018.08.005.
Katz, J. S., and Martin, B. R. (1997). What is research collaboration? *Research Policy*, **26**(1), pp. 1–18. https://doi.org/10.1016/S0048-7333(96)00917-1

While South–North co-publications lag North–North co-publications on citation impact, they compensate with a greater propensity towards multidisciplinarity (14% of South–North publications versus 10% of North–North publications).

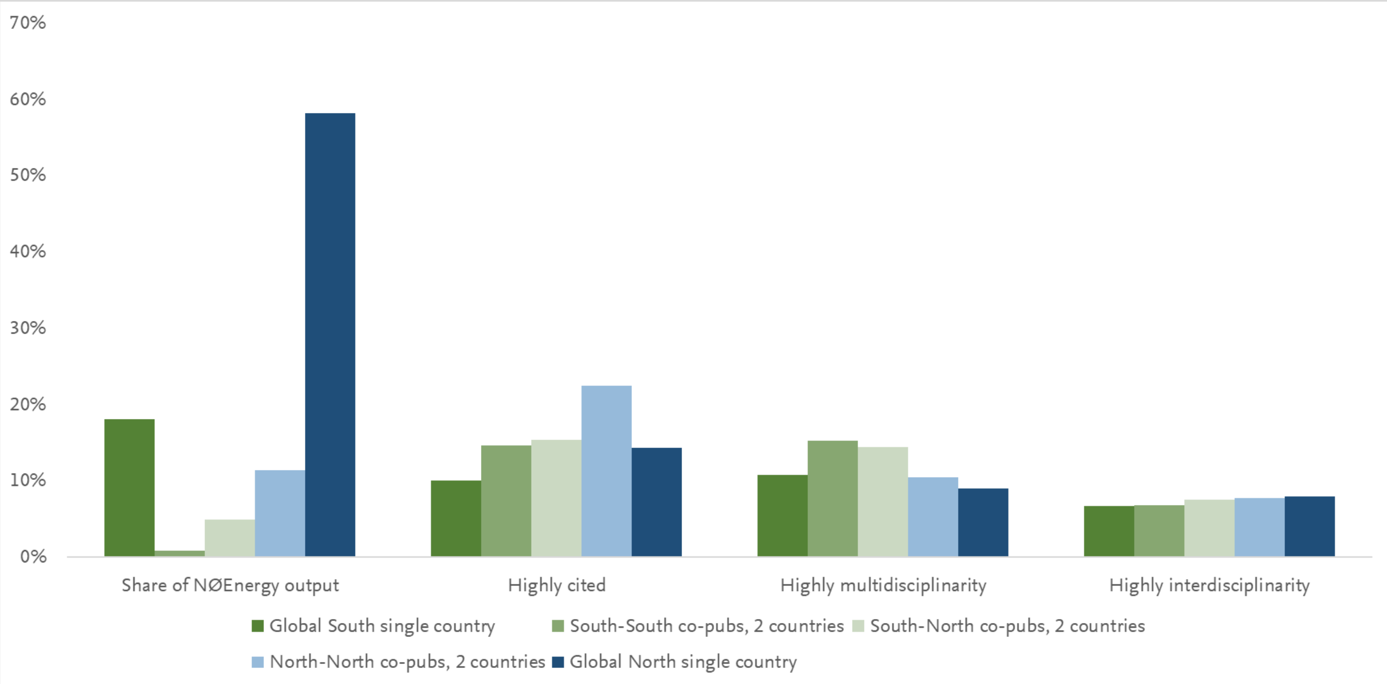


FIGURE 1-6
Citation impact, international co-publication, and cross-disciplinarity profiles by publication collaboration status for two-country co-publications or single country publications, 2012–2021.
Note: In this figure, co-publication categories are mutually exclusive.
Source: Scopus

When we move the focus to more complex co-publications involving three or more countries, multiple modalities of South–North co-publications can be identified: those dominated by Global South countries (multiple Global South countries with one North country); those dominated by Global North countries (two or more Global North countries with one South country) and those with two or more countries of each type. In practice, however, co-publications with more complex country distributions are quite rare in NØEnergy research, as shown in FIGURE 1-7. Here again, categories of co-publications are mutually exclusive.

As expected, international co-publications with more complex arrangements see increased citation impact profiles across the board, ranging from 20% of South–South co-publications (involving three or more countries) to 28% of North–North co-publications of the same type.

Even in this scenario, with authors from three or more countries, South–South and South–North co-publications continue to lead North–North co-publications in terms of multidisciplinarity (19% and 20% of co-publications with no or one North country contributor, respectively, versus 16% and 13% for those with only one or no South country contributor). Co-publications with the most complex arrangements (two or more South and North countries) have the largest multidisciplinary share (25%), in addition to a high citation impact profile (27%), which is close to that achieved by Global North co-publications with three or more countries (28%).

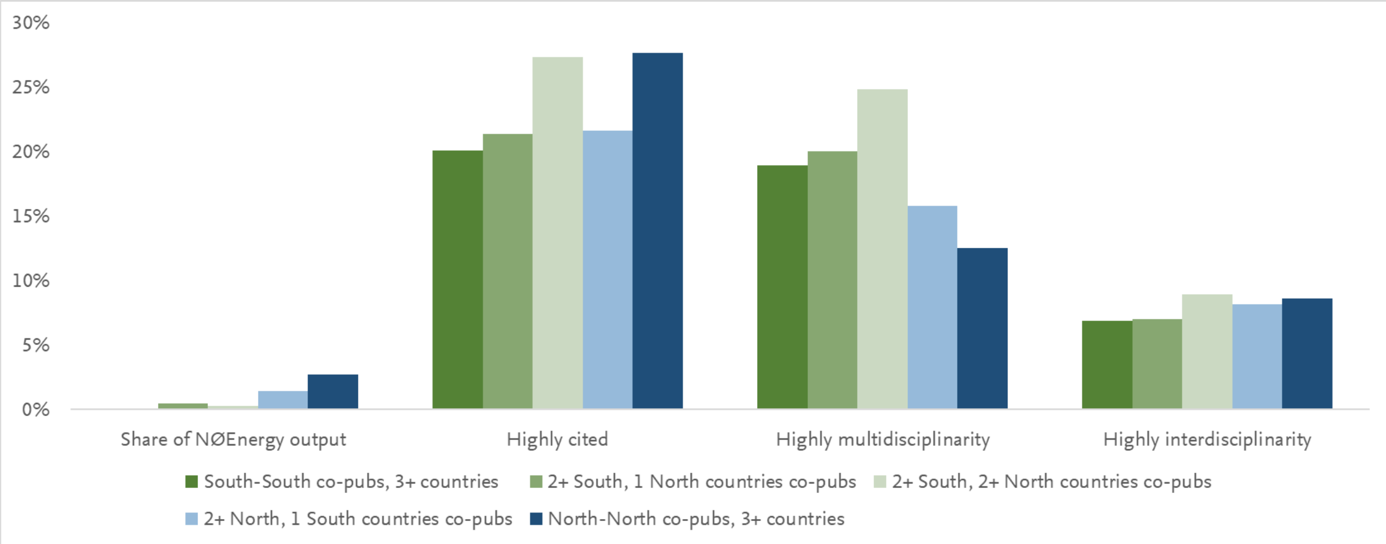


FIGURE 1-7
Citation impact, international co-publication, and cross-disciplinarity profiles by publication collaboration status for co-publications with co-authors from three or more countries, 2012–2021.
Note: In this figure, co-publication categories are mutually exclusive.
Source: Scopus

In most cases, Global South researchers gain from participating in any sort of international co-publication, whether South–South or South–North, as both offer similar citation impact and multidisciplinarity benefits. However, for two country co-publications, Global North researchers may lose out on citation impact when collaborating with the Global South. There are compensations for Global North researchers, nevertheless, in terms of higher multidisciplinarity. Collaboration, and the associated co-publications, between multiple Global South and one or more Global North countries offers benefits to all researchers, achieving high levels of both citation impact and multidisciplinarity.

1.6 Achieving equity in South–North collaboration

While Global North researchers tended to monopolize lead authorship positions on South–North co-publications a decade ago, equity for Global South researchers has greatly improved.

Recent reports highlight how South–North co-publications tend to benefit Global North researchers over their Global South counterparts. Researchers in the Global South may be impeded by financial barriers, unable to access necessary resources, including laboratory equipment and journals, or have their professional mobility limited by difficulties fulfilling complex or expensive visa requirements for work-related travel.[16] In particular, financial support is likely to be limited, as a recent analysis of global research funding shows.[17] Despite the vulnerability of African countries to climate change and their population size, global climate change funding does not flow commensurately to these nations and largely supports research in the Global North. In addition, South–North co-publications have historically tended to benefit researchers from the Global North. A recent study of authorship positions on African health publications, for example, found that the inclusion of Global North researchers from the United States, Canada, or Europe was associated with a decrease in the representation of African authors from the Global South.[18] Conversely, the highest levels of representation of African authors were associated with South–South collaborations (in this case, between different African countries). Cultural biases in distributing research credits may be particularly subtle to participants, while gender biases remain a challenge and may compound other biases.[19]

Against this background, we aim here to measure the extent to which South–North co-publications in NØEnergy research are authored by equal numbers of Global South and Global North researchers. We focus on the extent to which Global South authors on South–North co-publications take up the most critical authorship positions (first, last, or corresponding author), which maximize professional visibility. In this analysis, for the reasons highlighted above, the results are stratified according to the number of distinct countries affiliated to co-publication authors. Given the very low numbers of publications retrieved in some cases, the analysis focuses on the period from 2012 to 2021.

As shown in FIGURE 1-8, great progress in lead authorship parity between Global South and Global North researchers has been made in the last decade. The lowest shares of lead authorship positions taken up by

[16] Inayat Singh and Alice Hopton. (2021). *Global south suffering gap in climate change research as rich countries drive agenda, studies suggest*. CBC News. https://www.cbc.ca/news/science/global-south-climate-science-1.6212471

[17] Indra Overland, *et al.* (2022). Funding flows for climate change research on Africa: where do they come from and where do they go? *Climate and Development*, **14** (8), 705-724. https://www.tandfonline.com/doi/full/10.1080/17565529.2021.1976609

[18] Bethany L. Hedt-Gauthier, *et al.* (2019). Stuck in the middle: a systematic review of authorship in collaborative health research in Africa, 2014–2016. *BMJ Glob Health*, **4**(5): e001853. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6830050/

[19] Ayesha Tandon. (2021). Analysis: The lack of diversity in climate-science research. *CarbonBrief.* https://www.carbonbrief.org/analysis-the-lack-of-diversity-in-climate-science-research/

Global South researchers were recorded in 2013, ranging from 49% of two-country-co-publications (with at least three authors) to just 15% of co-publications with five or more countries. However, all categories of South–North co-publications have seen a marked increase in South–North lead authorship equity in the following eight years. By 2021, 53% of lead authorship positions are taken up by Global South authors in two-country co-publications with at least three authors. For co-publications involving researchers from five or more countries, this share reached 43% in 2021.

While it is not surprising that South–North co-publications with researchers from two countries (three or more authors) have shown parity, or close to it, in lead authorship for some years,[20], it is more interesting that progress is being made in other categories of co-publication and that parity is now close to being a reality across the board. Although lead authorship parity is a highly imperfect and partial proxy for determining more general equity in relationships between collaborating researchers, these findings show it is possible to foster equitable South–North NØEnergy research that is likely to contribute to capacity-building in the Global South.

It is also worth noting here that the average shares of authorship position taken up by Global South researchers, when all authors are considered in the analysis, closely track the lead authorship share (data not shown).

A potential limitation of this analysis is that gaps in parity between North and South researchers are observed when the three lead author positions (first, last, and corresponding author/authors) are viewed separately. For example, preliminary findings (not shown) reveal that a moderate gap in parity remains between the distribution of North and South researchers in last author position, although this has improved over time. Moreover, the parity gap between North and South researchers remains larger for some types of Global South country, for example LIC, LMIC, or UMIC. Conversely, some Global South countries such as India are more likely to collaborate on an equal footing with Global North partners.

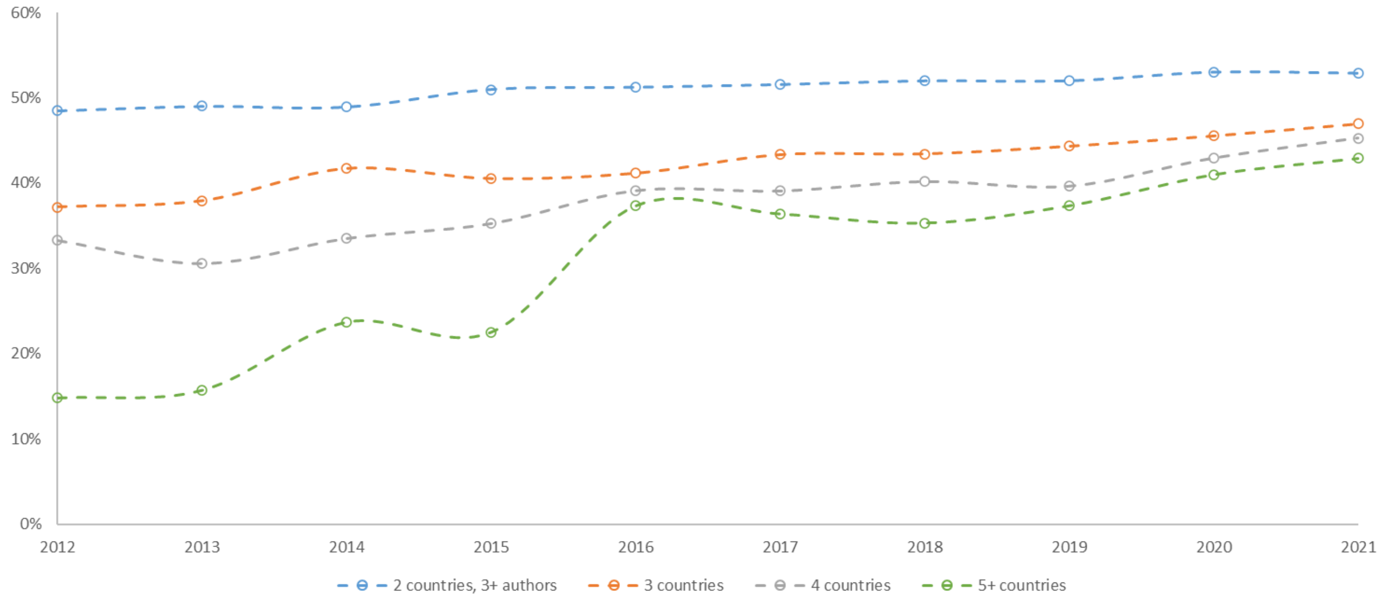


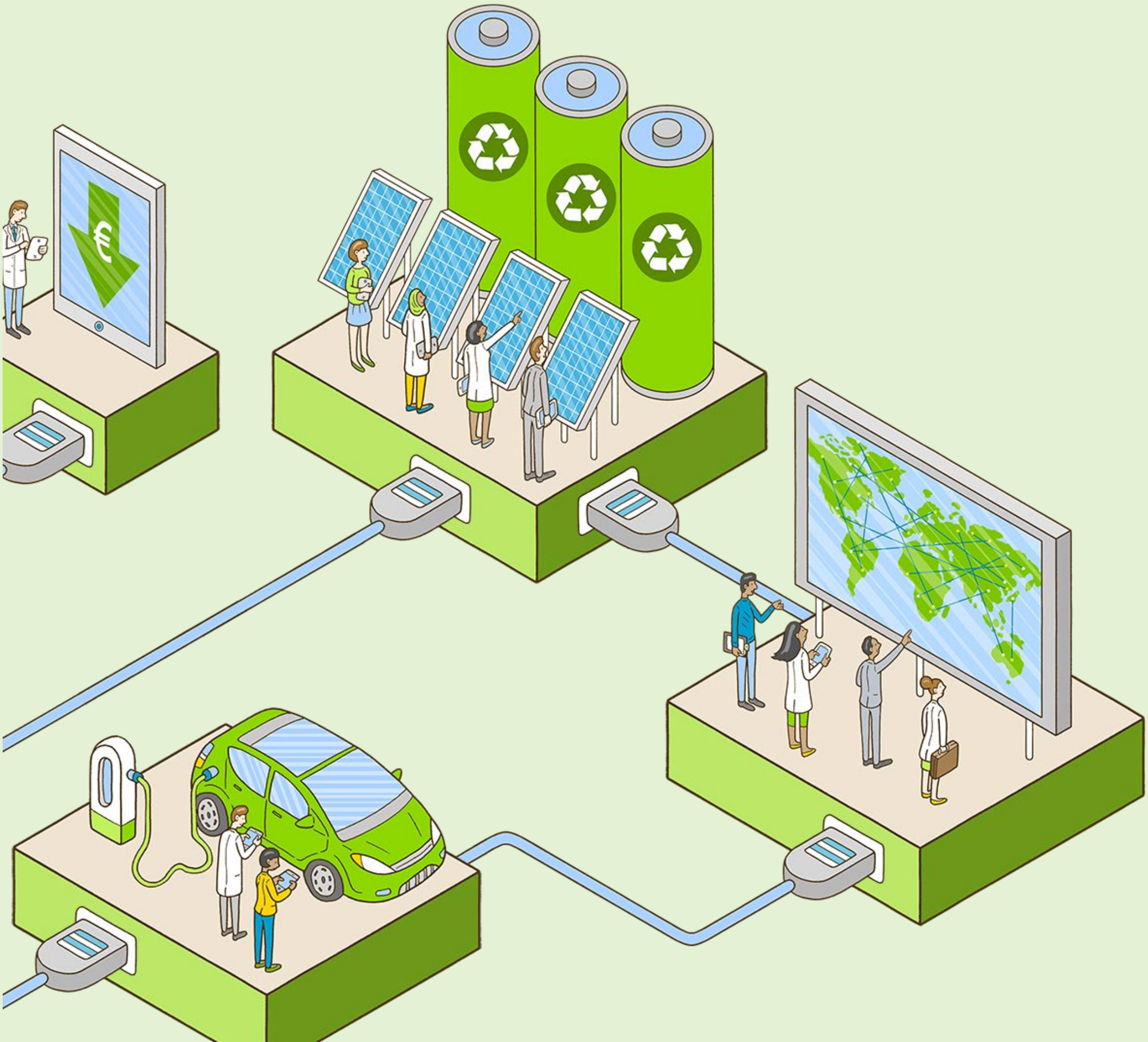
FIGURE 1-8

[20] With three authors and at least two lead author positions per publication (first and last author position, excluding corresponding author who may overlap with the first/last author), one would expect parity by chance alone if there are as many three-author publications with two Global North authors as there are with two Global South authors.

Share of lead authorship positions (first, last, or corresponding) taken by Global South researchers on South–North co-publications, 2012–2021.
Note: Only South–North co-publications involving at least three authors are retained in this analysis (because two-author South–North co-publications will, by definition, will record average shares of around 50% in lead authorship positions taken up by Global South authors).
Source: Scopus

Chapter 2

National NØEnergy research in Brazil, Egypt, and Indonesia



2.1 Brazil's bioenergy research landscape

Brazil has long fostered industrial and public adoption of bioenergy and biofuels but has only recently established itself as a major power in research. The BIOEN program is a model of how support initiatives can expand Global South countries' capacity in NØEnergy research.

Brazil is a world leader in the use of renewable energy—nearly half of the country's energy mix is derived from renewable sources[21]. While hydroelectric power is an important contributor to Brazil's energy mix, much of the country's renewable energy comes from biofuels and, in particular, biofuel derived from sugarcane. Sugarcane has been farmed in Brazil since the 16th century, and the country is the world's largest producer of the crop, dominating the world sugarcane market with a 38% share in 2019[22]. Sugarcane has distinct advantages over other biofuel crops in terms of its efficiency—sugarcane yields more liters of biofuel per hectare than competing crops such as maize, cassava, or soy[11].

"The Brazilian electricity matrix is more than 80% renewable. However, most isolated systems (in the Amazon region) are powered by diesel, [which] brings a huge challenge in decarbonizing the region while guaranteeing energy security to the local population."

Kathlen Schneider, Director, Ideal and Co-Founder and Coordinator, Rede MESol

Ethanol, produced from the sucrose in sugarcane, has been a mandatory addition to fuel in Brazil since the 1930s.[11] The introduction of flex-fuel cars in the early 2000s, which run on blended fuel or pure ethanol, has now accelerated the use of biofuel to the point where 90% of all new cars sold in Brazil are flex-fuel.[23]

[21] Carlos H. de Brito Cruz. (2012). Bioenergy in Brazil. Presented at: Brazilian ChemComm Symposium–Chemistry and Sustainable Energy, São Paulo. https://fapesp.br/eventos/2012/11/ChemComm/Brito.pdf

[22] Yi Zheng, Ana C. dos Santos Luciano, Jie Dong, Wenping Yuan. (2021). High-resolution map of sugarcane cultivation in Brazil using a phenology-based method. *Earth System Science Data Discussions*. https://essd.copernicus.org/preprints/essd-2021-88/essd-2021-88.pdf

[23] Luiz A. H. Nogueira, Rafael S. Capaz. (2013). Biofuels in Brazil: Evolution, achievements and perspectives on food security, *Global Food Security*, **2**(2), 117-125. https://doi.org/10.1016/j.gfs.2013.04.001

Renewable energy R&D in Brazil has focused mainly on new developments in cultivating sugarcane, such as increasing the varieties of sugarcane available or improving the efficiency of ethanol production processes, as well as examining the environmental, agricultural, social, and economic impacts of growing sugarcane and producing sugarcane-derived ethanol. How this economic and technological focus has influenced NØEnergy research in Brazil will be shown in this section.

In the last few decades, Brazil has established itself as a top global producer of bioenergy and biofuels research, with more than 36% of its research publications in NØEnergy devoted to this field. Our analysis of Brazil's development broadly tracks some of the outcomes of mission-oriented funding programs aimed at expanding capacity in the area, in particular the BIOEN program of Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

FAPESP is a public foundation, supported through 1% of São Paulo's state taxes, with a mandate to increase scientific and technological development in the region.[24] The stability of its funding has allowed it to play a disproportionally influential role supporting research and innovation in São Paulo in areas such as biodiversity, bioenergy, and climate. While a large proportion of its funding fosters the advancement of knowledge, the foundation also increasingly provides support to applied research via special theme-oriented programs, such as the BIOEN program. The BIOEN program initially started with a focus on advancing knowledge related to sugarcane and ethanol production for clean energy but more recently expanded to include all biomass resources.[25] BIOEN supports exploratory research and fosters partnerships between academia and industry, as well as supporting trans-disciplinary actions to aid policy-making, particularly related to the sustainability and decarbonization of transportation.

"We need local data and we need open access to it. We have a lot of difficulty in accessing data and success in the deployment of bioenergy is very context specific... To inform policy in developing countries, we need real world data from local experts that are in touch with the industry."

Professor Glaucia Souza, President of BIOEN and Full Professor, Institute of Chemistry, University of São Paulo

While this report focuses on BIOEN's research achievements (in terms of publications), there are multiple other outcomes that are not captured by the bibliometric indicators discussed below. For example, BIOEN's administration has been leading a task force on *Biofuels to decarbonize transport* at the International Energy Agency, which aims to foster policy-related outcomes for research in a host of partner countries from the Global South.[26] BIOEN also participates in the Biofuture Platform, which helps to improve the coordination of governmental, industrial, and academic partners in the deployment of bioeconomy initiatives. Finally, BIOEN's administration is working to expand open data sharing practices, which are

[24] https://fapesp.br/en/about
[25] https://fapesp.br/en/bioen
[26] https://task39.ieabioenergy.com/about/

crucial to the implementation of bioenergy innovation. In this regard, BIOEN has provided seed funding for more than 200 start-ups. One success story has been FAPESP's and BIOEN's support of the Hytron company, which is moving towards the commercialization of ethanol-derived hydrogen fuel in partnership with the University of São Paulo, Shell, and Raízen.

How is Brazil positioned globally in bioenergy and biofuels research?

Brazil is now one of the top producers of bioenergy and biofuels research globally

Brazil is a significant source of bioenergy and biofuels research internationally, accounting for the fourth largest share of NØEnergy research in this area between 2002 and 2021 (FIGURE 2-1). The country contributed slightly more than 5% of all publications in bioenergy and biofuels globally.

The country's overperformance in bioenergy and biofuels research is demonstrated by our finding that Brazil contributed, on average over the same period, just 2% of publications across all disciplines and thematic research areas. In fact, Brazil produced more than twice (2.3 times) as many publications in biofuel and bioenergy research as expected (if its output were distributed evenly across all research areas). In terms of specialization, which is measured in terms of relative activity index (RAI), Brazil ranks fourth among the top 20 producers of research in the bioenergy field. By these two indicators, Brazil is demonstrably specialized in bioenergy and biofuels research relative to the rest of the world.

The other major contributors to bioenergy research do not appear to be highly specialized in this field (i.e., RAI values below the global reference value of 1). This is certainly the case for the United States, which although ranking as the second largest producer of bioenergy publications with 18% of the global total, is relatively unspecialized in the area. Similarly, Germany and the United Kingdom account for 5% of bioenergy publications each but achieve RAIs of only 0.7. China, by contrast, although producing the largest output in this area (18% of all publications, on par with the United States), is slightly more specialized than these Global North countries, with a RAI of 1.1. Nevertheless, China's degree of specialization in bioenergy research is still less than Brazil's.

Brazil, along with India (ranked third by share of overall research output in this area) and Malaysia (ranked 10^{th}), stand out as the only top 10 producers of bioenergy research that are not HICs. Overall, in terms of the share of global research output, only India (with 10% of global publications) surpasses Brazil in the Global South. India's RAI of 2.2 in bioenergy research places the country in fifth position in the top 20 producers, just behind Brazil. Four other Global South countries rank among the top 20 producers of bioenergy research: Malaysia (with 3% of global publications), Indonesia (2%), Thailand (2%), and Turkey (2%). Malaysia, Thailand, and Indonesia are also notable for their high RAIs in this area (4.1, 3.7, and 3.5, respectively), indicating a high level of specialization.

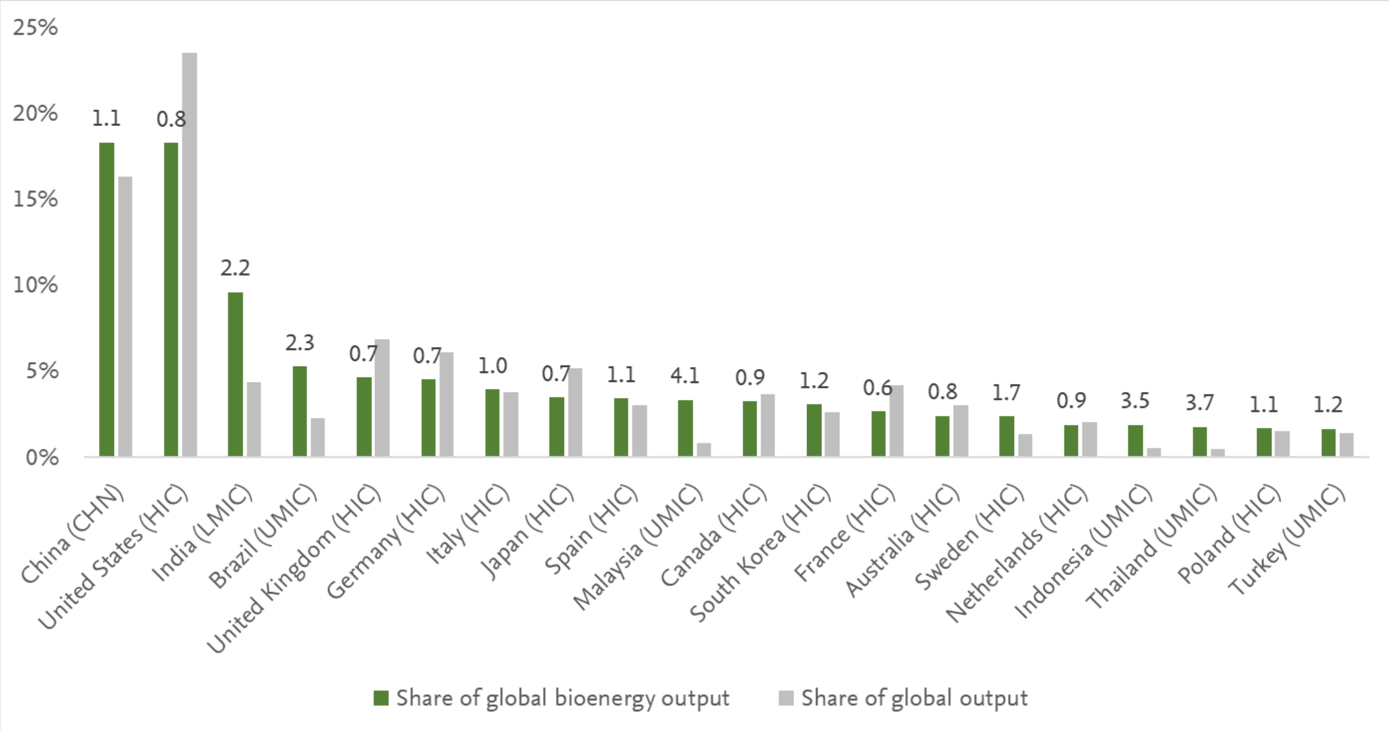


FIGURE 2-1
Share of biofuel publications and all publications, and resulting relative activity index (RAI), by top producing country, 2012–2021.
Source: Scopus

How is Brazil's bioenergy research output developing?

Brazil's output in bioenergy research has grown over the last two decades, in contrast with many Global North countries.

Over the 2002-2021 period, Brazil's share of global research output in bioenergy and biofuels has shown a steady upward trend. In recent years, Brazil has consistently ranked fourth in overall annual output of bioenergy publications.

In comparison with selected countries analyzed here (the United States, China, Germany, India, Italy, and the United Kingdom), Brazil's share of global output in bioenergy and biofuels has increased from only 1–2% in 2002/2003 to over 5% in 2021 (FIGURE 2-2). While the country ranked 19th globally in 2002 in terms of its bioenergy research publication volume, Brazil climbed to fourth position in 2021. Along with this growth, Brazil's RAI in bioenergy and biofuels sharply increased from 1.5 or less to 1.9 or more after 2008/2009 (data not shown).

Meanwhile, India's and, to a lesser degree, China's contributions to global output in bioenergy-related research have increased in line with their gradually increasing specialization in the field (data not shown). By contrast, the United States' output as a share of the global total has decreased over the same period, coinciding with a falling level of relative activity (data not shown).

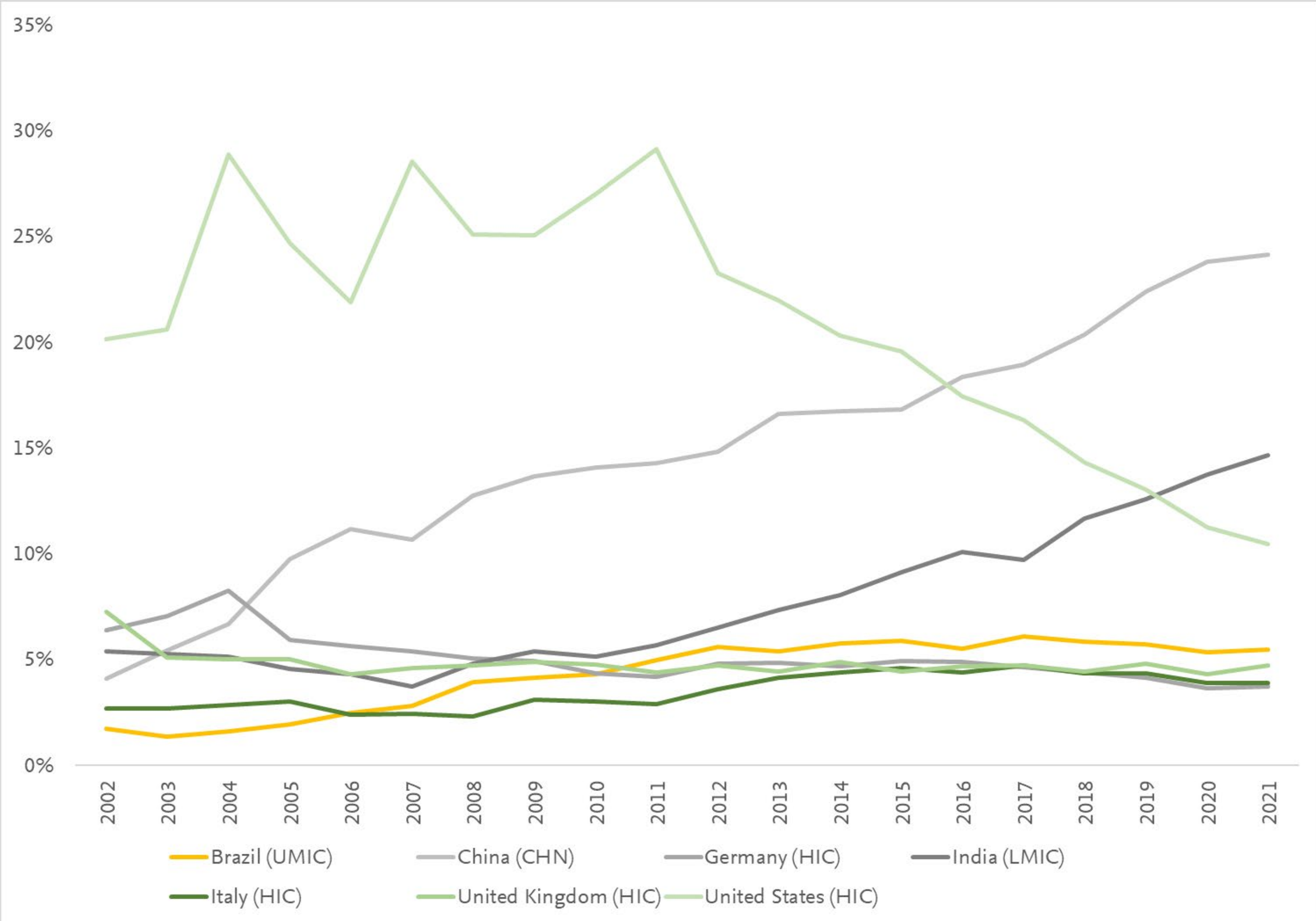


FIGURE 2-2
Share of world output for bioenergy and biofuel research for Brazil and comparator countries, by year, for the period 2002–2021.
Source: Scopus

What are the strengths of Brazil's bioenergy research?

Among the top producers of bioenergy and biofuels publications in the Global South, Brazil's output is some of the most cross-disciplinary.

As our analysis shows, Brazil has become one of the major global players in bioenergy and biofuels research. In comparison with other major producers of bioenergy research in the Global South, Brazil ranks first for its share of publications that are rated as highly interdisciplinary (13%) and fourth in terms of its share of highly multidisciplinary publications (17%).

Brazil's share of multidisciplinary publications is very similar to those of Malaysia, the Russian Federation, and Iran (all between 15% and 17%), and to Mexico, the Russian Federation, and Indonesia in terms of interdisciplinary publications (13%, 12%, and 11%, respectively).

Overall, a 9% share of Brazil's bioenergy publications are highly cited, putting the country in ninth position out of the countries analyzed here. By this metric, Brazil is well ahead of the Russian Federation (with only a

5% share of highly cited publications) and on a par with a large group of countries including Thailand, Indonesia, and Mexico (which record shares of between 9% and 10%). In terms of absolute numbers of highly cited publications, Brazil ranks third among Global South countries (with 533 highly cited publications between 2012 and 2021). Only India and Malaysia, by a very small margin, surpass Brazil by this measure (with 1,302 and 578 highly cited publications, respectively). Globally, Brazil ranks 12th in terms of the absolute number of highly cited publications in the field.

However, in our analysis of South–South co-publications in bioenergy research, Brazil ranked last with only a 6% share, followed by India with a 7% share and Thailand with a 10% share. Brazil performed better in terms of Global North co-publications, which account for a 23% share of its output, putting the country in eighth position in between Indonesia (with a 21% share) and Turkey (with a 24% share).

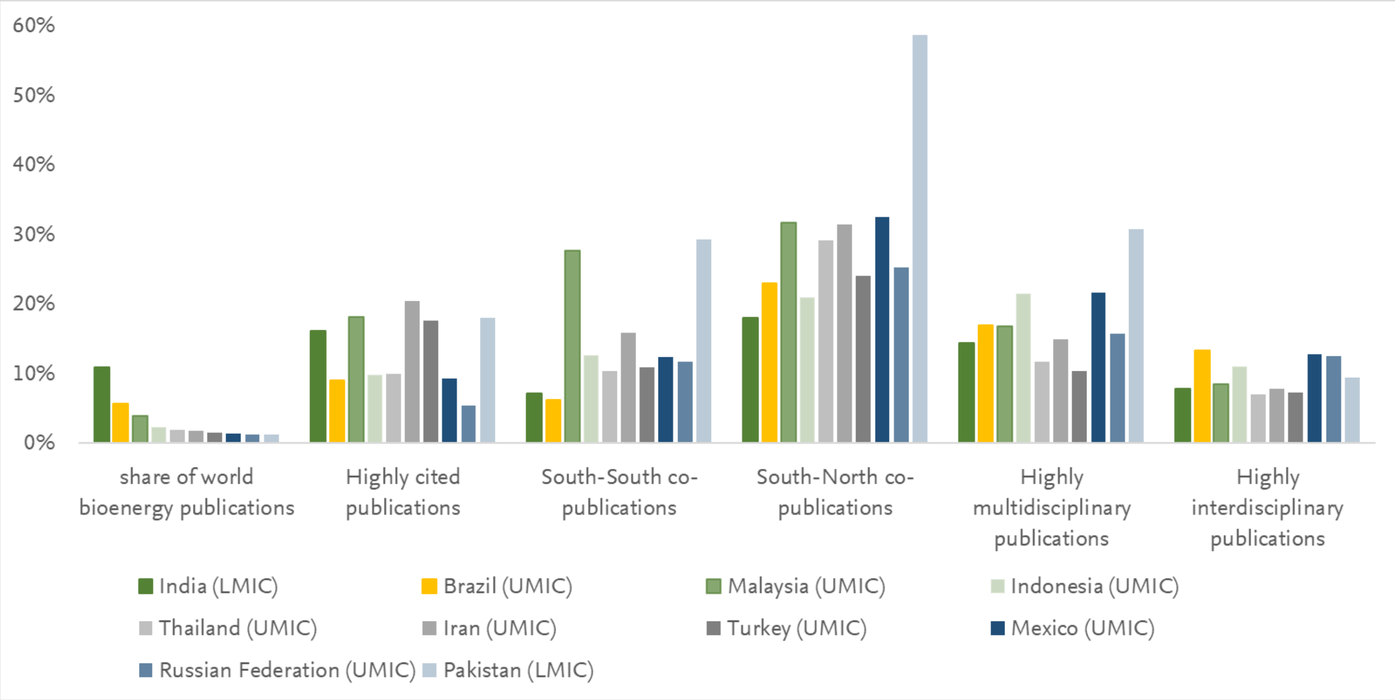


FIGURE 2-3
Top 10 largest producers of bioenergy research among Global South countries, with their citation impact, international co-publications, and cross-disciplinarity profiles, 2012–2021.
Note: In this figure, individual publications with authors from three or more countries could be included in both indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publications are not fully mutually exclusive.
Source: Scopus

On which topics does Brazil's bioenergy research focus?

Bioenergy research accounts for just over 36% of Brazil's NØEnergy research and the greatest volume of topic clusters between.

Bioenergy and biofuels research, like NØEnergy research in general, encompasses many different topics. For Brazil, five of the top 10 topic clusters with the greatest output in NØEnergy research are directly relevant to bioenergy and biofuels: namely, *Engine Cylinders / Biodiesel / Diesel Engines*; *Cellulases / Lignin / Cellulose*; *Pyrolysis / Coal / Gasification*; *Microbial Fuel Cells / Anaerobic Digestion / Bioreactors*, and *Bioenergy / Biomass / Biofuels*. Discussion of economic and policy issues related to bioenergy and biofuels also made up almost a quarter of the topic cluster *Energy / Economics / Electricity*.

The prolificacy of research in these bioenergy and biofuels related topic clusters strongly demonstrates the centrality of this area of research to Brazil's overall NØEnergy portfolio.

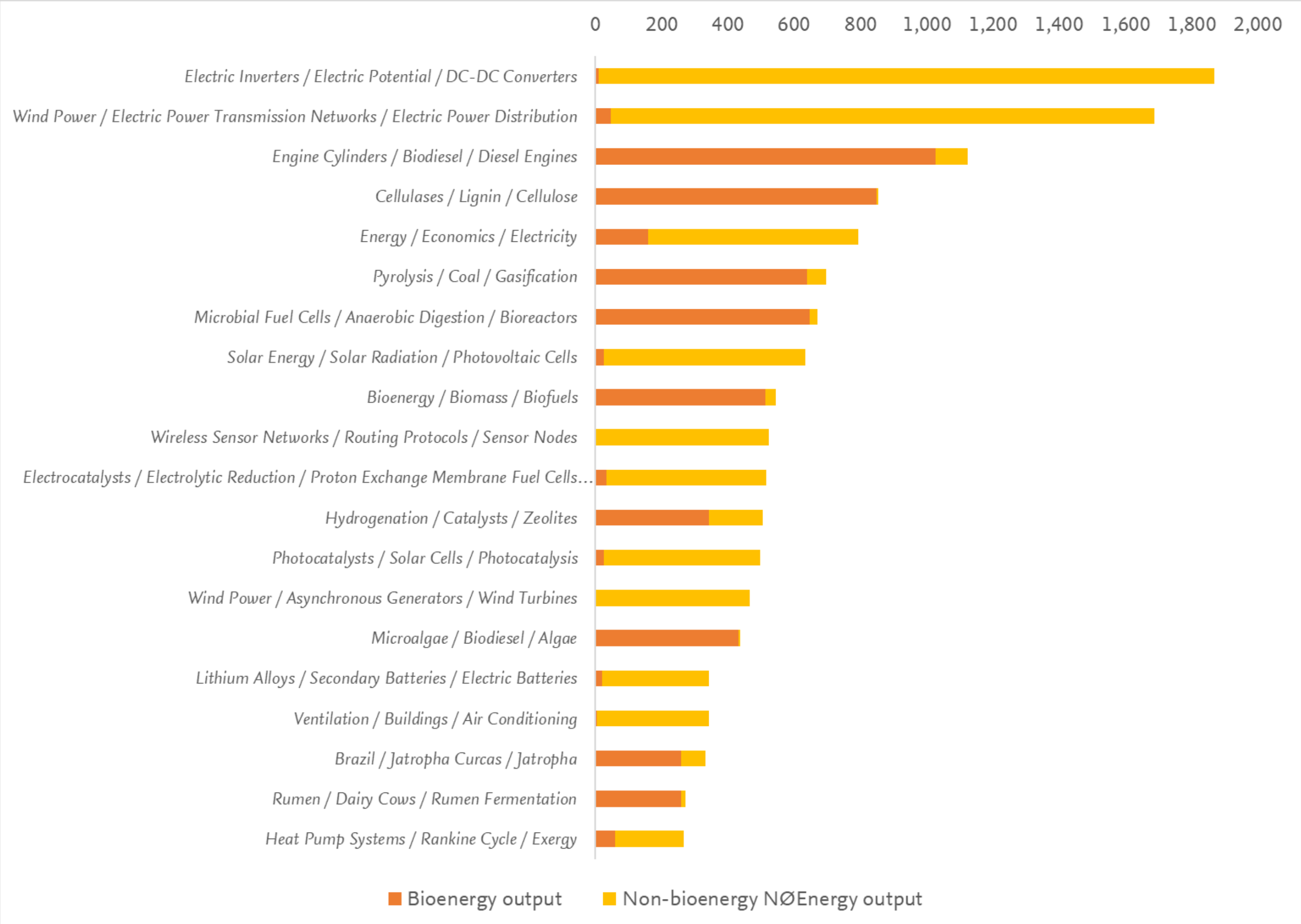


FIGURE 2-4
Brazil's scholarly output in NØEnergy research by 20 largest topic clusters, showing bioenergy-related (in orange) and non-bioenergy-related (in yellow) research, 2012–2021.
Source: Scopus

"In Latin America, Brazil stands out in distributed generation. We [have seen] the PV market grow from zero to 20 GW, with 70% of this capacity from small and distributed solar systems. This puts Brazil in a very favorable position to become a leader in a democratic energy transition [across the region]."

Kathlen Schneider, Director, Ideal and Co-Founder and Coordinator, Rede MESol

How is Brazil's bioenergy and NØEnergy research supported?

The strength of BIOEN/FAPESP-supported publications has reinforced Brazil's bioenergy research's citation impact and collaborative activities.

FAPESP, the São Paulo research foundation, funds research activities in bioenergy through its BIOEN program. Between 2012 and 2021, 17% of Brazil's bioenergy and biofuels publications were supported by BIOEN, along with other FAPESP bioenergy grants.

Other Brazilian funders supported 36% of Brazil's publications on bioenergy over the same period, although 40% of the country's bioenergy publications do not identify a funding source. Publications with at least one Brazilian author but which were supported solely by foreign sources account for 13% of the total in this field. However, publications may be supported by multiple funders, so it is important to note that some categories described here are not mutually exclusive and the total adds up to more than 100%.

BIOEN/FAPESP-supported publications outperform publications supported by other Brazilian funders in terms of highly cited status (14% compared with 10%, respectively). Only 6% of publications without stated or indexed funding information were highly cited.

In terms of collaboration, 30% of BIOEN/FAPESP-supported publications include at least one Global North co-investigator, similar to the share of publications supported by other Brazilian funders (29%). Only 17% of publications with no funding information represent South–North collaboration. However, BIOEN/FAPESP support does not appear to be linked with an increased level of South–South collaboration, which at a share of 5% of publications is comparable to that supported by other Brazilian funders or with no funding information.

However, while BIOEN/FAPESP funding may have fostered increased research excellence, in terms of citations and international collaboration, it may have done so at the expense of cross-disciplinarity. The share of BIOEN/FAPESP-supported publications classed as highly multidisciplinary (12%) is lower than that of publications supported by other Brazilian funders (19%). The same appears to be the case for interdisciplinarity, with 10% of BIOEN/FAPESP-supported publications rated as highly interdisciplinary, on par with expectations, slightly below the proportion of similarly-rated publications supported by other Brazilian funders (12%). Among publications with no identified funding source, 16% are classed as highly interdisciplinary.

In all metrics apart from interdisciplinarity, BIOEN/FAPESP-supported publications are surpassed by those supported by foreign funders. It is worth noting, however, that Brazilian publications with foreign funders will be biased towards those with international partners, which tend to drive up citation impact profiles.

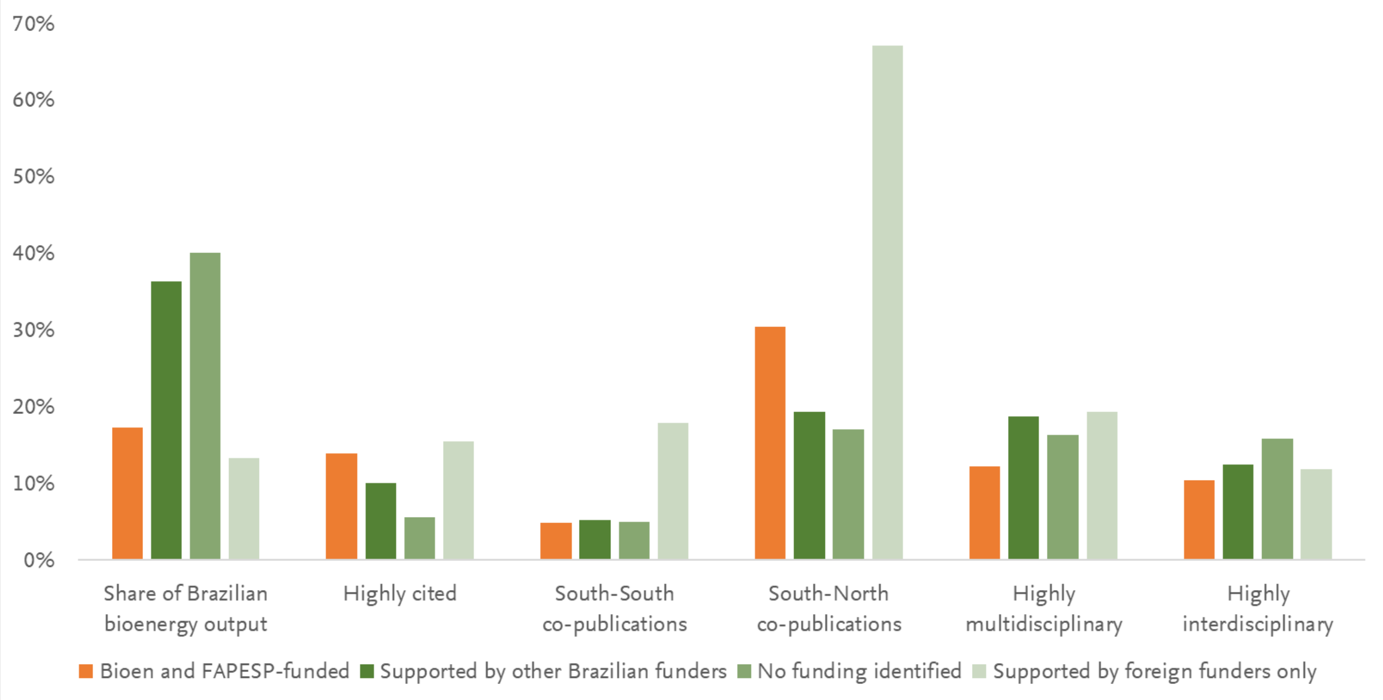


FIGURE 2-5
Comparative analysis of the citation impact, co-publication profile, and cross-disciplinarity of Brazil's bioenergy publications supported by BIOEN/FAPESP, other Brazilian funders, foreign funders, or without funding source identified, 2012–2021.
Note: In this figure, individual publications with authors from three or more countries could be included in both indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publications are not fully mutually exclusive.
Source: Scopus

2.2 Egypt's achievements and aspirations in solar energy

Egypt is poised to become a world leader in the use and distribution of solar energy with the construction of a massive new complex at the Benban Solar Park. The Egypt-Japan University of Science and Technology drives excellence in NØEnergy research.

Egypt, the third most populous country in Africa, has long been an important part of the international energy market, controlling strategic energy routes between Europe, the Middle East, Asia, and Africa via the Suez Canal and Suez-Mediterranean Pipeline (SUMED).

Benban Solar Park, located in the desert of Upper Egypt 50 km northwest of Aswan, is among the largest solar photovoltaic parks in the world and, when up and running at full capacity, is predicted to produce 4 TWh of power.[27] The complex will enable Egypt to exploit its sunny climate and topographic suitability for solar energy—Egypt has the highest typical daily irradiance values in Northern Africa[28]—and increase the share of renewable sources in its energy mix. This major investment in solar energy is key to establishing a consistent energy supply for Egypt and achieving its Integrated Sustainable Energy Strategy (ISES 2035) to convert 42% of its energy mix to renewable by 2035.[29]

In this section, we assess the strengths of Egypt's solar research activities, its areas of focus within this field and NØEnergy research more generally, its position within the global solar energy research landscape, and its main collaborative partners. According to Professor Hamdy Hassan of the Egypt-Japan University of Science and Technology (E-JUST), the country's solar energy research interfaces with and enables many NØEnergy research directions, cutting across disciplines and subject areas.

"In Egypt, renewable energy research takes different aspects. There is active research on PV thermal hybrid solar collectors, their cooling systems, and use in energy applications—not only power generation. There is research on concentrated solar power

[27] https://www.nsenergybusiness.com/projects/benban-solar-park/

[28] Salma I. Salah, Mahmoud Eltaweel, C. Abeykoon. (2022). Towards a sustainable energy future for Egypt: A systematic review of renewable energy sources, technologies, challenges, and recommendations. *Cleaner Engineering and Technology*, 8. https://doi.org/10.1016/j.clet.2022.100497

[29] IRENA. (2018). *Renewable Energy Outlook: Egypt*. https://www.irena.org/publications/2018/Oct/Renewable-Energy-Outlook-Egypt

systems and hydrogen production from renewable energy."

Professor Hamdy Hassan, E-JUST

How is Egypt positioned globally in solar energy research?

Egypt is one of the largest producers of solar energy research in the Global South, its output is twice as likely to be highly cited as the global average, and more than half is performed in collaboration with the Global North.

Our analysis of Egypt's NØEnergy research output between 2012 and 2021 reveals that 28% of its publications are dedicated to solar energy and that, overall, the country contributed 1.4% of the global total in solar research publications. In the Global South, Egypt's publication output volume in solar energy lags somewhat behind that of India, which accounts for the largest single contribution to the sector at 11%, as well as Iran (contributing 2.3%), Malaysia (2.2%), and Turkey (1.5%). Nevertheless, Egypt is the fifth largest contributor of solar energy research in the Global South and ranks 19th in the world.

Despite this, Egypt ranks second, in terms of the citation impact of its research, among the top 10 Global South countries making the largest contributions to solar energy research (FIGURE 2-6). With a 19% share of its solar energy publications achieving a high citation impact performance, Egypt is second only to Iran (21% of publications). Malaysia follows with 17% of its solar energy publications achieving highly cited status. Egypt's share of highly cited publications in solar energy research puts the country in 23rd position globally (data not shown). On average, the share of highly cited publications in solar energy research stands at 15%.

On the basis of its contribution to the global research portfolio and its citation impact profile, Egypt can be considered a key player in the global solar energy research field, especially among Global South countries.

In terms of collaboration with other Global South countries, Egypt's 17% share of South–South co-publications in solar energy research ranks behind that of Malaysia and Pakistan, with 31% and 21% shares, respectively. Other Global South countries, including the Russian Federation (16%), Turkey (15%), and Algeria (13%), all produced roughly similar levels of South–South co-publications.

Egypt, however, has a clearer lead over most other Global South countries considered here in its share of South–North co-publications, which stands at 57%. On this measure, Egypt is surpassed only by Pakistan, with a 60% share of this type of co-publication. By comparison, the Russian Federation trails both Egypt and Pakistan with a 34% share of South–North co-publications.

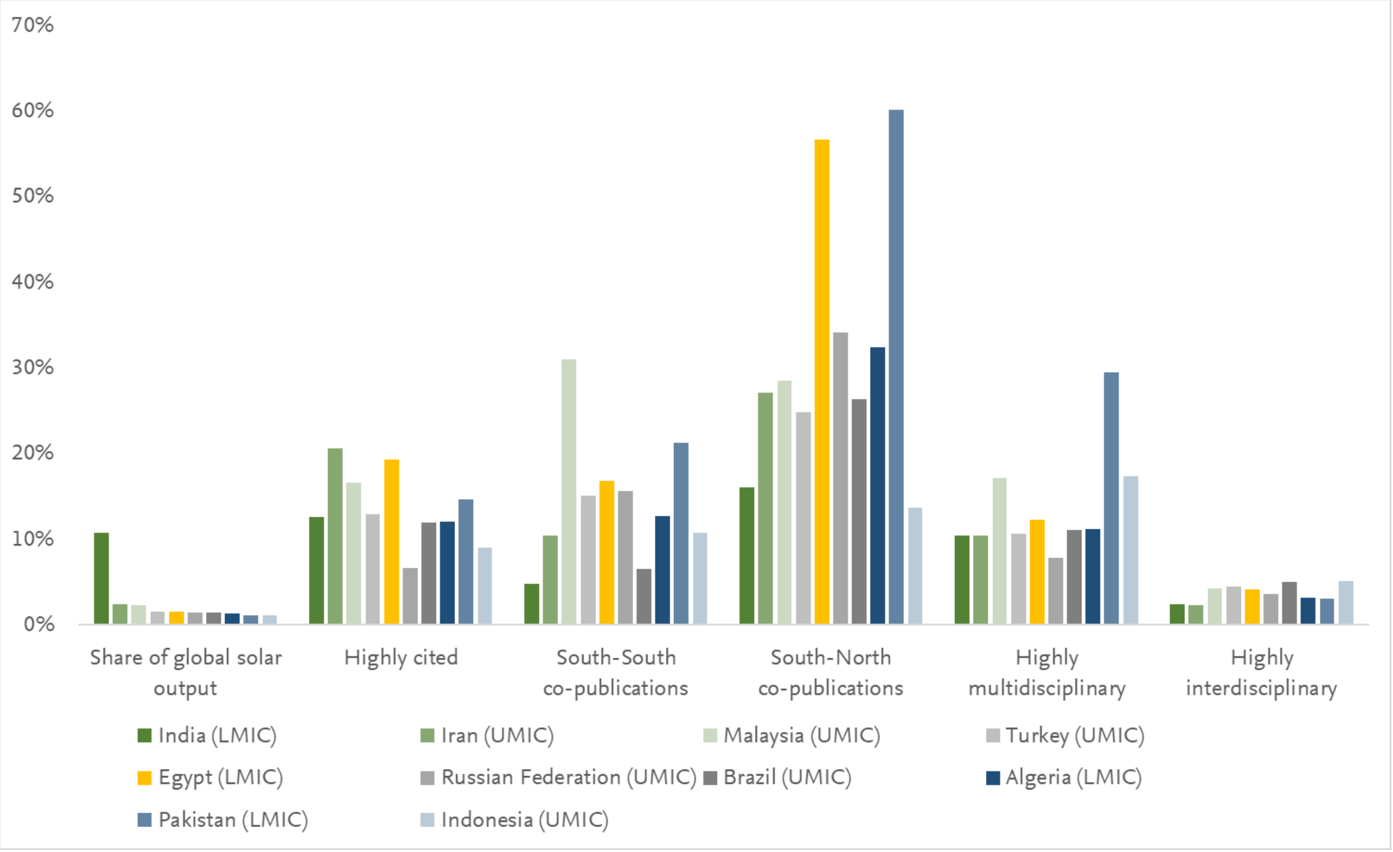


FIGURE 2-6
Top 10 largest contributors of solar energy research among Global South countries, their citation impact, international co-publication, and cross-disciplinarity profiles, 2012–2021.
Note: In this figure, individual publications with authors from three or more countries could be included both in indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publications are not fully mutually exclusive.
Source: Scopus

Looking at the multidisciplinarity of solar energy publications, Egypt ranks fourth, with 12% of its publications classified as the most multidisciplinary within their subfield and year, behind Pakistan with 30%, Indonesia, and Malaysia (both with 17%).

However, in terms of the interdisciplinary of solar energy publications, all Global South countries in the analysis performed at a similarly low level. Typically, only between 2% and 5% of publications fell within the top 10% most interdisciplinary in their subfield and year.

Considering these observations together, our analysis indicates that within the solar energy field, while Global South researchers may be adept at building project teams from a diversity of backgrounds, this disciplinary diversity does not necessarily lead to the integration of diverse prior knowledge.

On which topics does Egypt's solar energy research focus?

Egyptian solar energy research is linked to other NØEnergy topics such as desalination, wind power, and power distribution networks.

Solar energy research is related to a number of different topics in both NØEnergy and development-related research. Our previous report revealed that the focus of Global South countries' research is associated with different topic clusters than Global North countries.[30] However, it is important to understand that individual publications can simultaneously connect multiple research fields.

Our analysis, shown in FIGURE 2-7, illustrates how solar energy research in Egypt cuts across a number of different topics, beyond the obvious clusters of photocatalysis and solar cell materials. One of the country's major research topic clusters relating to the desalination of water, for example, deals with improving solar power generation specifically for desalination through the use of solar stills. At least 30% of Egypt's NØEnergy publications in the topic cluster of *Ultrafiltration | Desalination | Membranes* are linked with solar energy research (data not shown).

Egypt is also exploring hybrid wind- and solar-power systems. The topic cluster of *Wind Power | Electric Power Transmission Networks | Electric Power Distribution* includes a 30% share of publications relevant to solar energy research. The topic cluster of *Electric Inverters | Electric Potential | DC-DC Converters*, meanwhile, contains more than 50% of publications relevant to solar energy research, capturing efforts on the mutual adaptation of generic battery charging and power generation machinery to solar energy production.

"We use concentrated solar energy to produce electricity for water desalination and to power electrolyzers for hydrogen production."

Professor Hamdy Hassan, E-JUST

[30] Elsevier. (2021). *Pathways to Net Zero: The Impact of Clean Energy Research*. https://www.elsevier.com/connect/net-zero-report

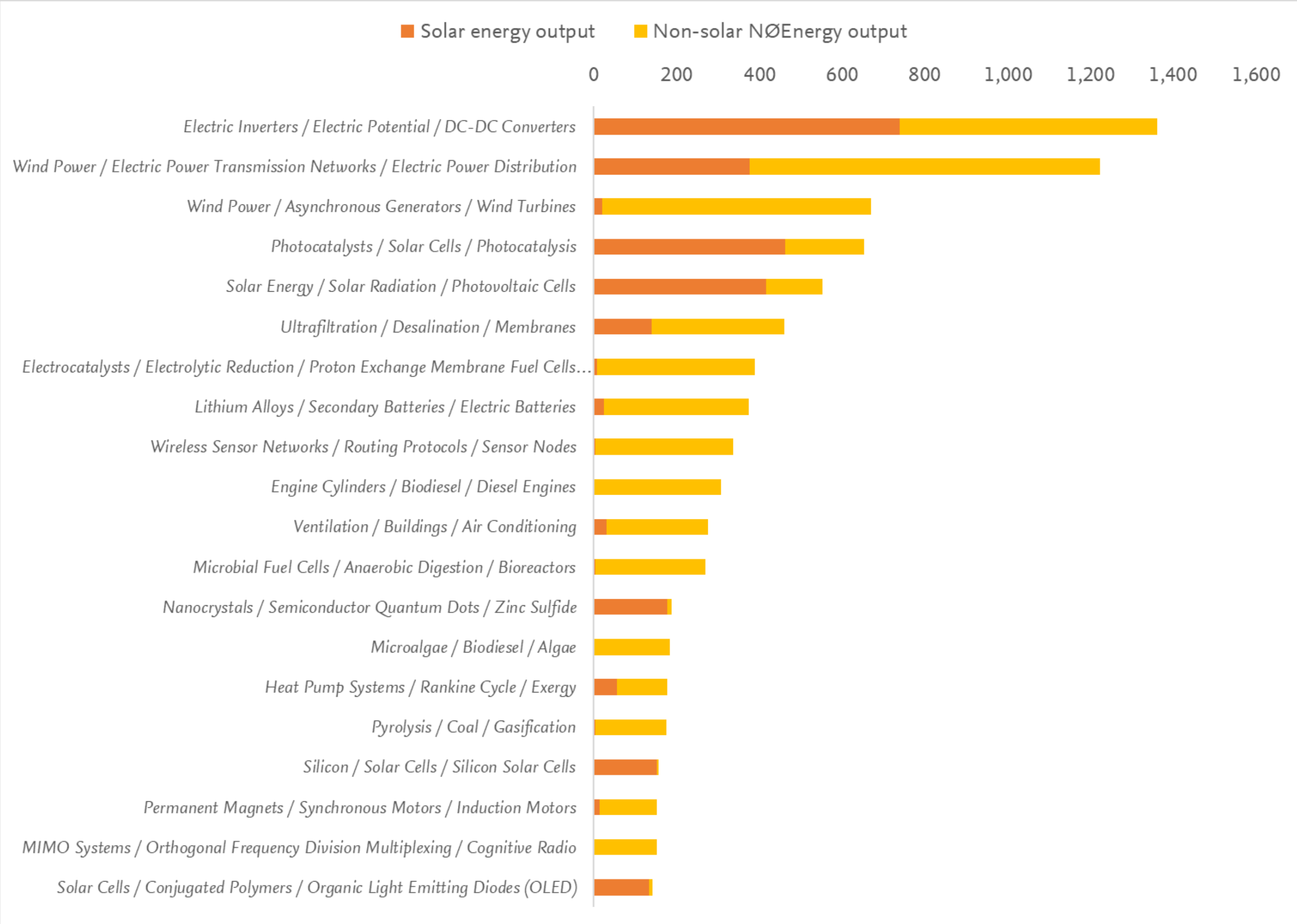


FIGURE 2-7
Largest topic clusters in Egypt's NØEnergy research output and the share of solar energy-relevant publications within each topic cluster, 2012–2021.
Source: Scopus

How does E-JUST contribute to Egypt's solar research landscape?

The Egypt-Japan University of Science and Technology (E-JUST) drives Egypt's strong national performance in some fields of NØEnergy research.

E-JUST, a relatively recently founded institution with a focus on technology and innovation, as well a mission to foster Egyptian–Japanese scientific collaboration, provides an illustration of how an individual organization can drive national performance in research and innovation.

While E-JUST publications in the field of solar energy have only numbered slightly more than 130 since 2012, a fraction of the more than 3,000 publications produced by Egypt's researchers over the same period, a disproportionally large share of these publications (63%) is classed as most highly cited within their subfield and year (FIGURE 2-8). This is a world-leading achievement by E-JUST in the field of solar energy research, by any measure. By comparison, 19% of Egypt's solar energy publications overall rank as highly cited, which is itself a strong result.

In terms of collaboration, a larger proportion of E-JUST publications (57%) are South–North co-publications than among Egypt's solar energy output in general (which comprise a share of 48%). E-JUST's systematic collaboration with Japanese colleagues shapes its achievements in solar energy research. A 41% share of E-JUST's South–North collaborations are co-publications with Japan (FIGURE 2-9). By contrast, at the national level, only 6% of solar energy research constitutes co-publications with Japan.

The institution's output is, however, less likely to represent South–South co-publications than the national average. Only 1% of E-JUST publications are classed as South–South co-publications. However, it is worth noting that the definitions of South–North and South–South co-publications used in this analysis are not mutually exclusive, so the former category does not have to be, in principle, a trade-off with the second.

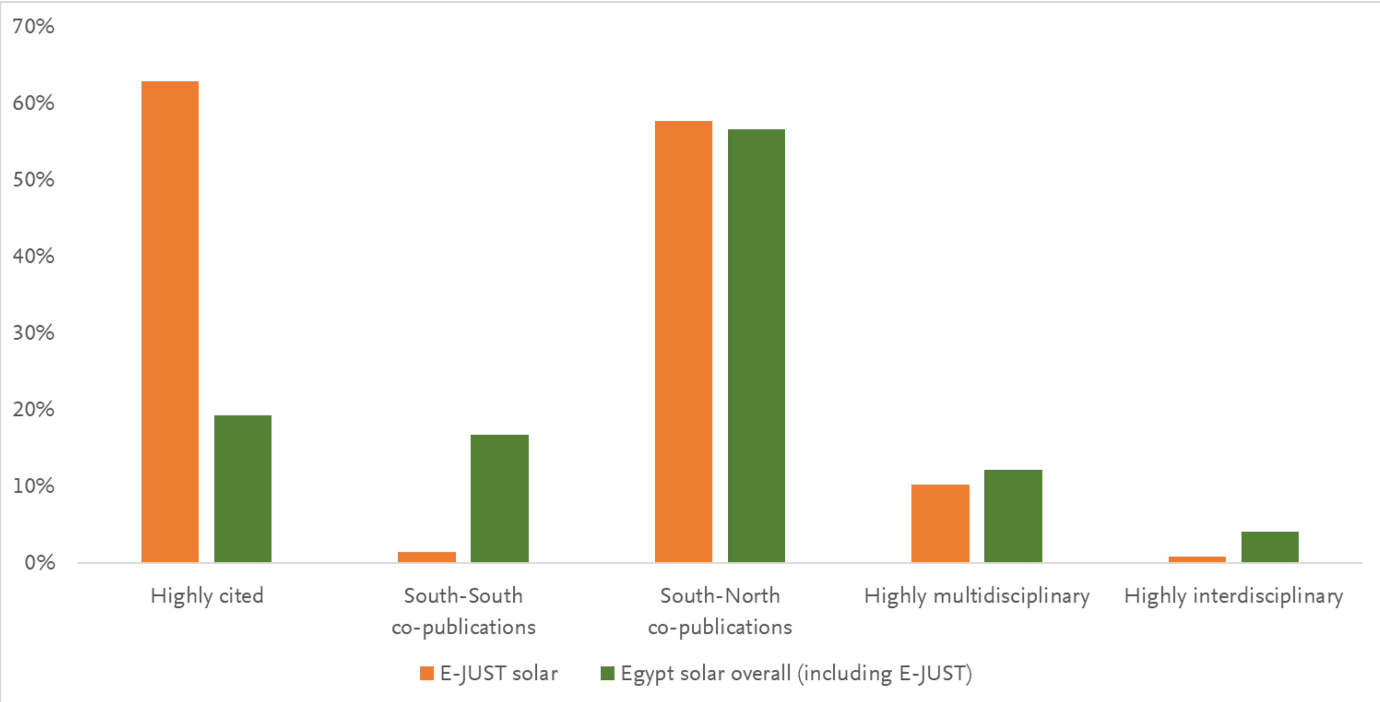


FIGURE 2-8
Contributions of E-JUST publications to Egypt's solar energy research output. 2012–2021.
Note: In this figure, individual publications with authors from three or more countries can be included in both indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publications are not fully mutually exclusive.
Source: Scopus

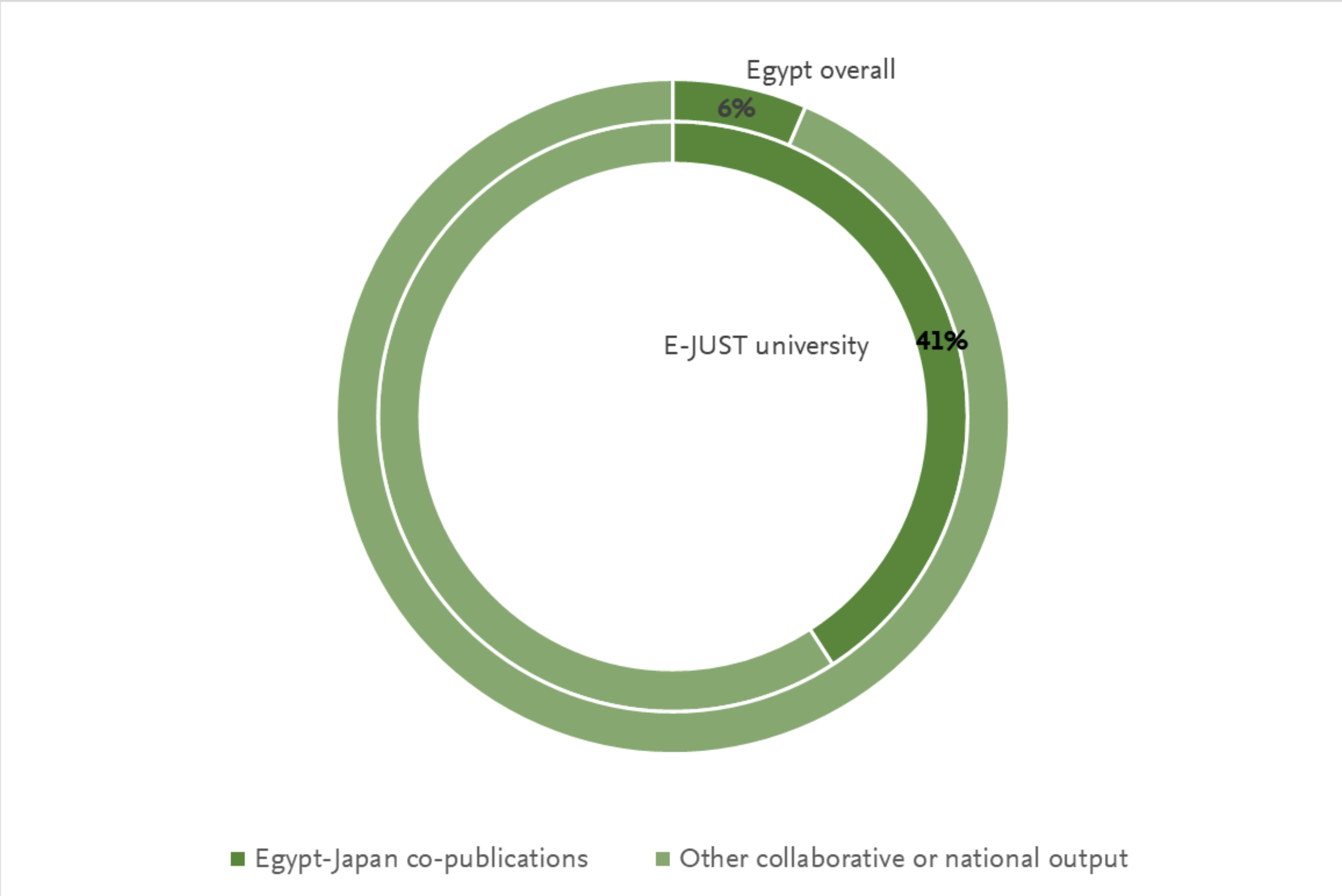


FIGURE 2-9
Share of Egypt–Japan co-publications within E-JUST and Egypt's solar energy research output in general, 2012–2021.
Source: Scopus

Which countries are Egypt's major international collaborators?

Egypt tends to collaborate more with Global North than Global South countries in solar energy and NØEnergy research.

As we can see in FIGURE 2-10, Saudi Arabia is, by far, Egypt's most preferred partner in solar energy and NØEnergy research international collaborations. Over a quarter (26%) of Egypt's solar energy output are co-publications with Saudi Arabia. In NØEnergy research overall, this share is 20%.

The United States is Egypt's next most common international partner, accounting for 7% of Egypt's solar energy co-publications. Over the same period, co-publications with Japanese and Chinese researchers follow closely behind, each making up 6% of Egypt's solar energy co-publications.

India is the only Global South country in Egypt's top ten most common partners for solar energy research international collaboration, ranking in fifth position. In this field, 4% of Egypt's publications include an Indian partner.

As shown in section 1.3, it is expected that countries with the most developed research systems and largest researcher populations will have the strongest pull as potential partners for international collaboration.

Egypt's orientation towards Global North partners in international collaboration is not, therefore, entirely surprising. However, collaboration preferences can be influenced by geographic proximity and shaped by national policies. The findings presented here prompt the question, therefore, as to whether Egypt in particular, or solar energy research more generally, might benefit from greater engagement with other Global South countries.

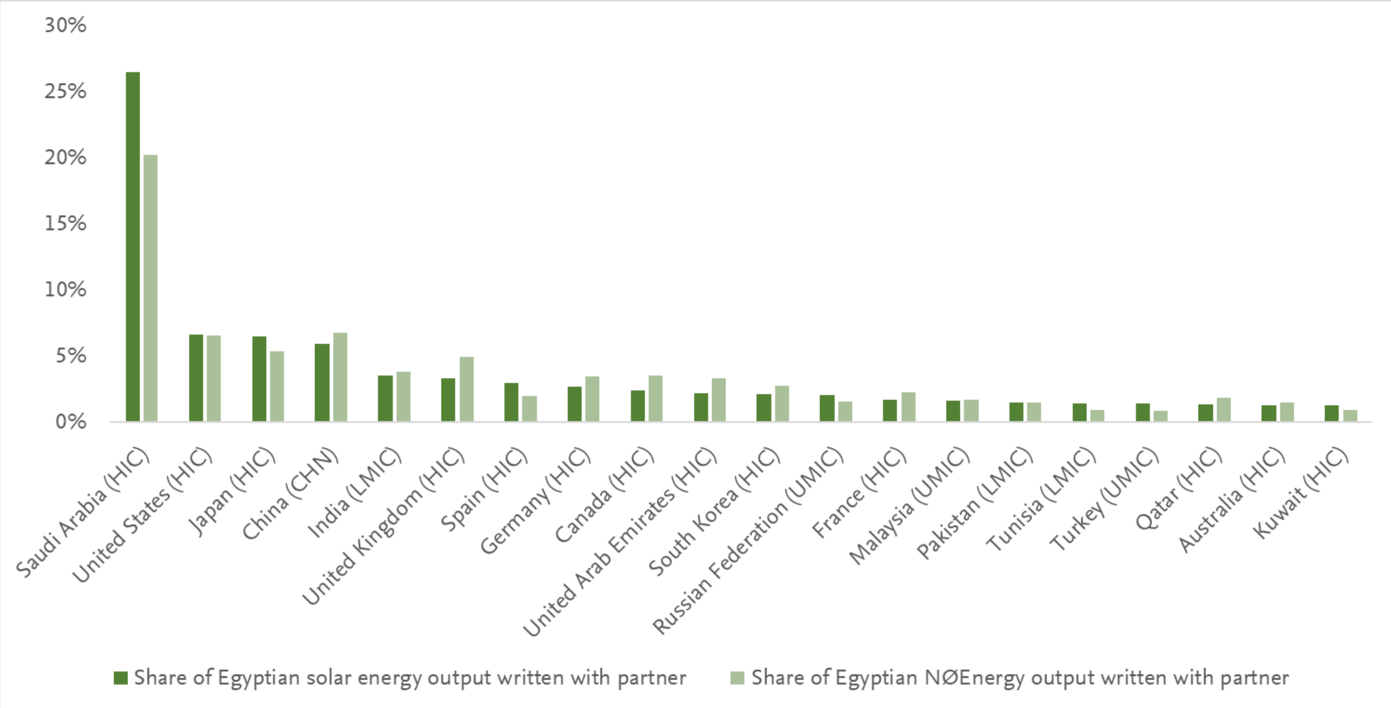


FIGURE 2-10
Egypt's most common international partners in solar energy and NØEnergy research publications, 2012–2021.
Source: Scopus

2.3 Indonesia's broad base in clean energy research

Indonesia's energy demand is increasing and, although the country abounds in clean energy options, renewables make up only a fraction of its energy mix. Investment is required to create a balanced portfolio.

Indonesia, first time holder of the G20 presidency[31] and meeting host in 2022, boasts a diverse clean energy profile, including biodiesel (from palm oil), geothermal, hydro, solar, wind, and marine energy generation.

Despite the wealth of choices, renewable energy made up just 14% of Indonesia's energy mix in 2020[32]. Moreover, Indonesia's demand for energy is increasing faster than almost any other country, making energy supply a critical issue. Rising demand is driven by a growing population, economic development, urbanization, and government efforts to extend electrification to the country's rural areas and remote islands. Indonesia's soaring energy requirements make a transition to renewables an important strategic target[33].

Indonesia's Ministry of Energy has set a target of 87% renewable energy by 2060, which will require an acceleration in investment. According to Dr. Han Phoumin, an energy economist at the Economic Research Institute for ASEAN and East Asia (ERIA), Indonesia has access to many renewable energy technologies and the expertise to deploy them, but its older energy infrastructure is entrenched, so a rapid transformation will incur high costs. Indonesia's power grid is also fragmented, consisting of many small grids supplying its thousands of islands, which creates additional technical challenges. Compounding the problem, believes Han Phoumin, is that net zero research in Indonesia is financed through governmental agencies, which are closely tied to incumbent energy systems.

A major part of Indonesian research funding comes from foreign organizations and funders. At the same time, foreign investment in technology deployment and industrial transition has been too low.

To make the necessary transition to a clean energy future, Indonesia's research and innovation activities, which we outline in this section, must support the development of a balanced and diverse renewable energy mix.

[31] https://www.g20.org

[32] https://www.globenewswire.com/en/news-release/2022/03/04/2396835/0/en/Mobilizing-finance-to-meet-Indonesia-s-renewable-energy-ambition-Difficult-but-not-impossible.html

[33] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_REmap_Indonesia_summary_2017.pdf?la=en&hash=F530E18BAFC979C8F1A0254AFA77C9EBC9A0EC44

Indonesia's NØEnergy research landscape

Among Global South countries, Indonesia ranks seventh in the volume of its output in NØEnergy research, with a small degree of specialization.

Indonesia's contribution to NØEnergy research between 2012 and 2021 amounted to 5.5% of its overall output and 1.0% of the global total. Given that the country contributed to 0.8% of global output in research across the board (in all fields and disciplines) over the same period, Indonesia has a slight degree of relative specialization towards NØEnergy research (with a RAI of 1.2).

Among the top 20 Global South contributors to NØEnergy research, Indonesia was surpassed by India (8.2%), the Russian Federation (2.0%), Iran (2.0%), Brazil (2.0%), Malaysia (1.2%), and Turkey (1.3%) in terms of the share of global output (Figure 2.11). Egypt (0.9%) and Pakistan (0.9%) follow after Indonesia (1.0%). In terms of RAI, Indonesia was surpassed by Algeria (2.3), Morocco (2.0), Malaysia and Bangladesh (both at 1.7), India and Tunisia (1.5), Pakistan (1.4), Viet Nam and Egypt (both at 1.3).

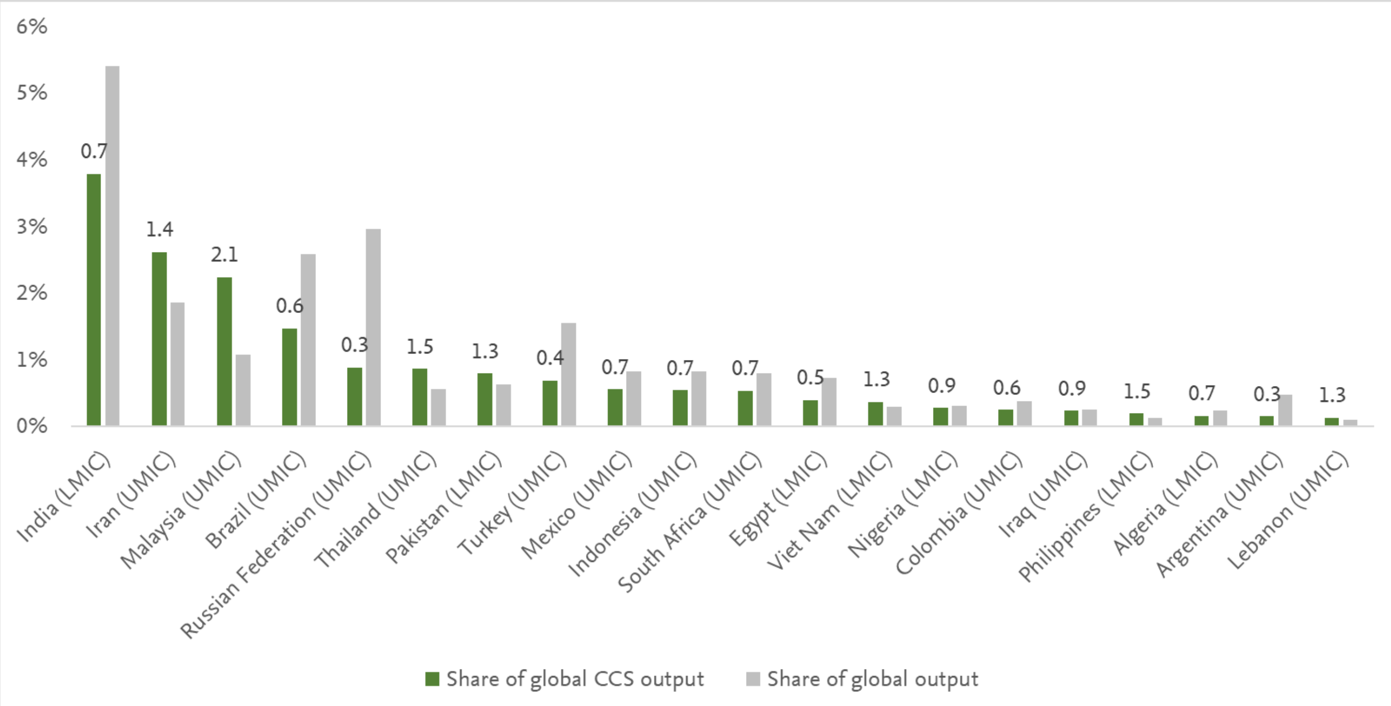


FIGURE 2-11
Share of NØEnergy research publications and all publications, with the resulting relative activity index (RAI), for the top 20 Global South countries, 2012–2021.
Source: Scopus

What are Indonesia's areas of focus in NØEnergy research?

Indonesia's NØEnergy research portfolio is evenly distributed across a mix of clean energy sources. Bioenergy, geothermal, hydro-, and marine energy technologies achieve higher levels of relative activity than world levels, with wind and solar generation activities at expected levels.

While Brazil and Egypt concentrate a large part of their NØEnergy research efforts on a single energy source, no such focus is evident in Indonesia. To determine Indonesia's position within the NØEnergy research landscape, therefore, we analyzed the distribution of its publications across various clean energy sources. In addition, a sizable portion of the country's NØEnergy research is oriented towards specific application areas such as electric vehicles or carbon reduction strategies such as carbon capture and storage (CCS). In this section, we use thematic queries, developed as part of European Commission work on its clean energy key priorities, rather than topic clusters.[34]

Our analysis reveals that Indonesia is specialized in multiple related fields of NØEnergy research (Figure 2.12). For example, the country is highly specialized in geothermal research (4.4% of its NØEnergy research output versus the global average of 1.2%). The country also demonstrates high relative activity in bioenergy (29% of its NØEnergy research output versus the global average of 13%), hydroelectricity (3.6% versus 1.8%), and marine energy (1.3% versus 0.8%). However, Indonesia shows a slightly lower than expected level of activity in wind power research (6% versus 8%). Indonesia is neither specialized nor un-specialized in solar energy, although this area does constitute a large proportion of its NØEnergy research portfolio (19% versus the global average of 18%). No other country among the top 10 Global South producers of NØEnergy research holds such diverse and strong specializations.

34 European Commission, Directorate–General for Research and Innovation. (2021). *Publications as a measure of innovation performance: selection and assessment of publication indicators : provision of technical assistance and study to support the development of a composite indicator to track clean-energy innovation performance of EU members*. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/43576

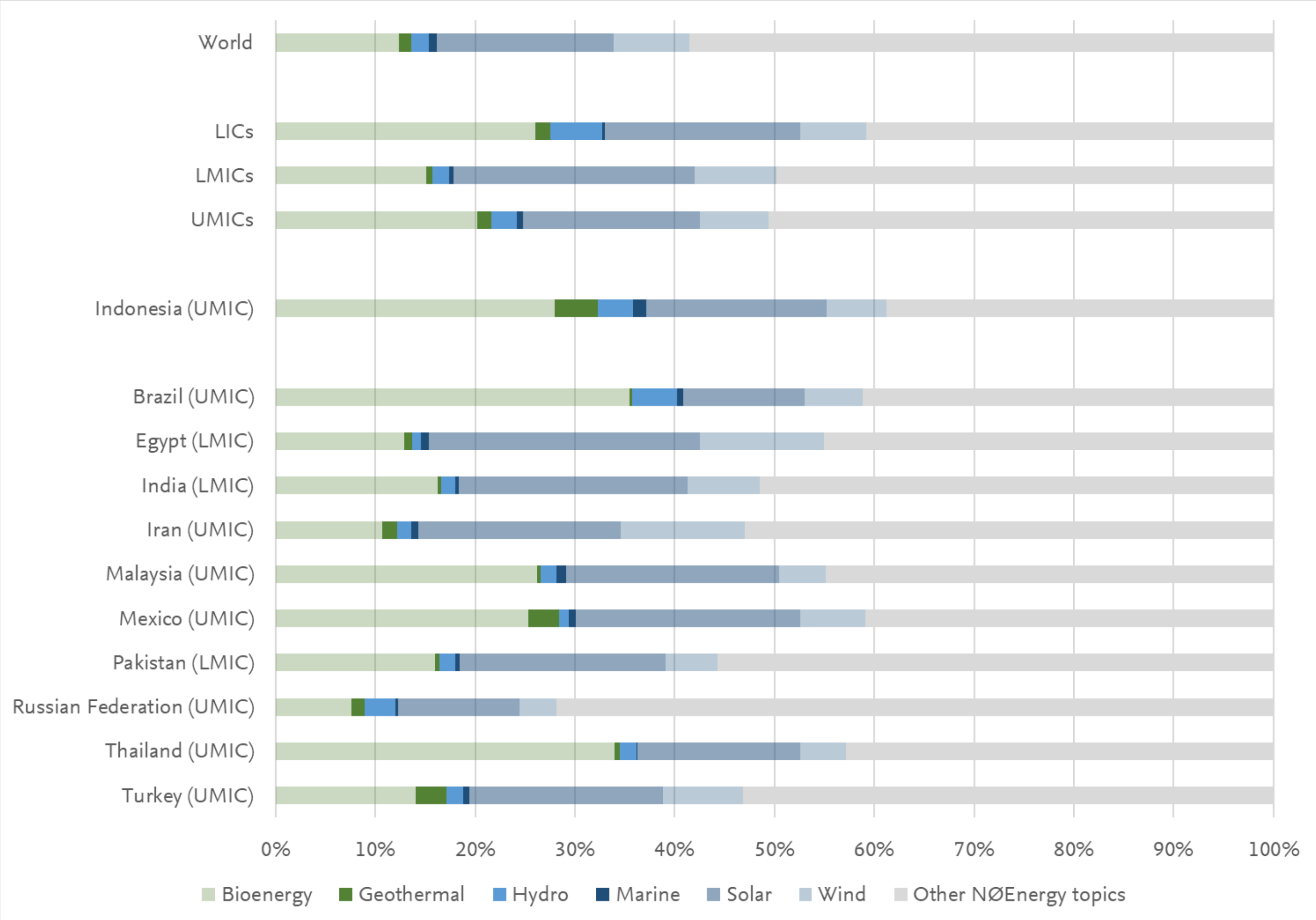


FIGURE 2-12
Distribution of publications by clean energy technology for the top Global South producers of NØEnergy research, LICs, LMICs, and UMICs, 2012–2021.
Source: Scopus

Indonesia's NØEnergy research focus by topic cluster

Indonesia's most highly cited NØEnergy research publications are in topic clusters relating to solar energy and electric batteries. Topic clusters in bioenergy show the highest levels of South–South and South–North co-publications, while energy economics and policies are the most cross-disciplinary.

In this section, we look at which topic clusters in Indonesia's NØEnergy research show the highest levels of citations, international collaboration, and multidisciplinarity (FIGURE 2-13).

The highest citation levels are seen in the topic clusters *Solar Energy | Solar Radiation | Photovoltaic Cells* (16% highly cited publications) and *Lithium Alloys | Secondary Batteries | Electric Batteries* (15%). These performances are on par with global levels of highly cited NØEnergy publications, which stand at 15%.

The topic cluster *Engine Cylinders | Biodiesel | Diesel Engines* has the largest share of South–South co-publications (at 16%), while *Pyrolysis | Coal | Gasification* (which primarily deals with bioenergy) has the highest share of South–North co-publications by some way (at 29%), followed by *Energy / Economics / Electricity* (at 24%).

In terms of cross-disciplinarity, *Energy / Economics / Electricity* is the only topic cluster with high shares of both multidisciplinary (29%) and interdisciplinary publications (18%). Other topic clusters have high levels of multidisciplinary publications but average or lower than average levels of interdisciplinary publications. These include: *Microbial Fuel Cells / Anaerobic Digestion / Bioreactors* (25% highly multidisciplinary publications versus 11% highly interdisciplinary publications); *Solar Energy / Solar Radiation / Photovoltaic Cells* (20% versus 7%); and *Engine Cylinders / Biodiesel / Diesel Engines* (18% versus 5%).

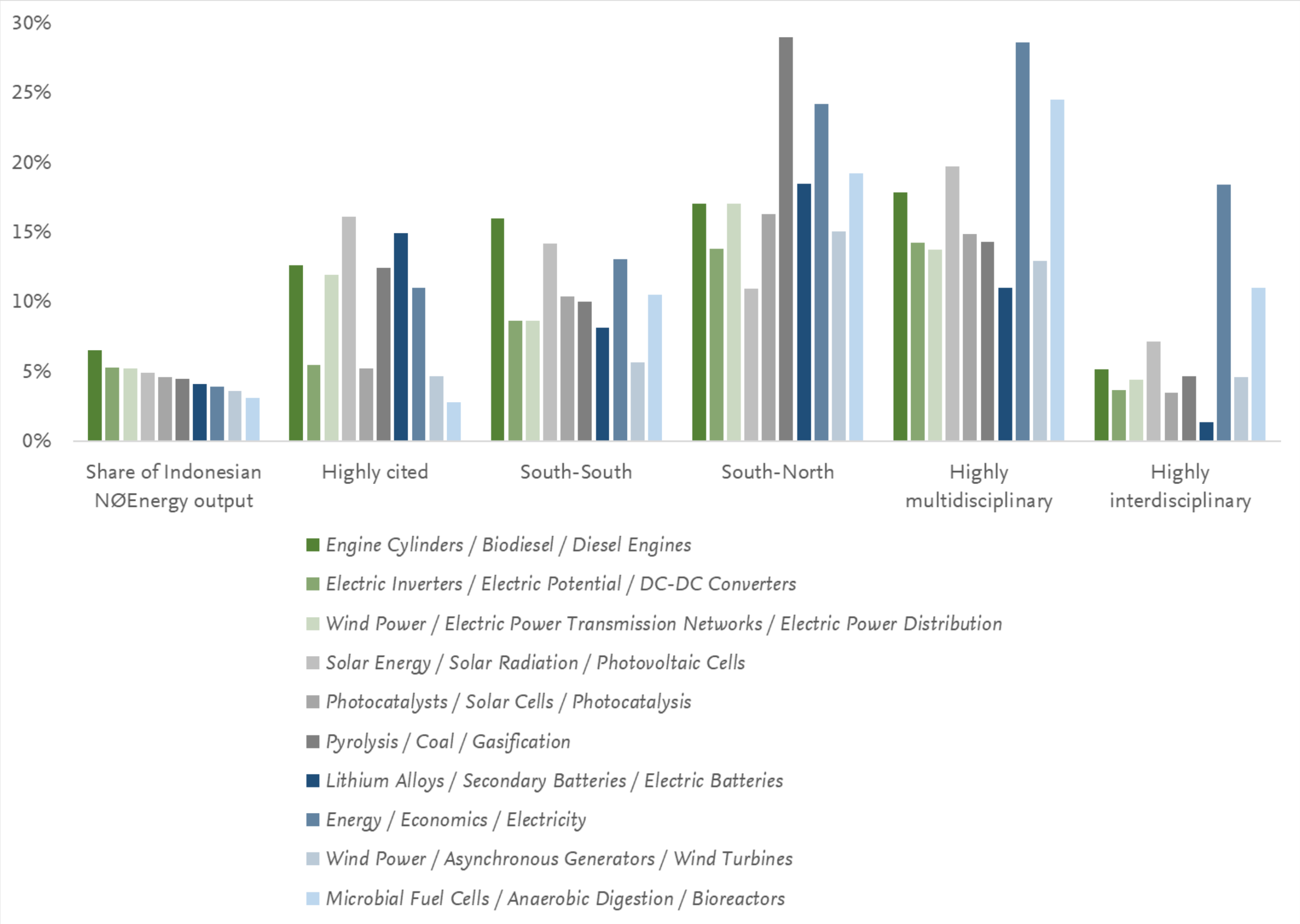


FIGURE 2-13
Top 10 largest topic clusters in Indonesia's NØEnergy research output, with citation impact, international co-publication, and cross-disciplinarity profiles, 2012–2021.
Note: In this figure, individual publications with authors from three or more countries could be included both in indicators of shares of South–South co-publications (e.g., two South contributors and one North contributor) and shares of South–North co-publications. Thus, the two categories of co-publications are not fully mutually exclusive.
Source: Scopus

Indonesia's collaboration in carbon capture and storage research

To advance research in the key area of carbon capture and storage, Indonesia may need to foster more collaboration with the Global North, which has higher levels of relative activity in this field.

Indonesia, like many other ASEAN countries[35], tends to rely on collaborations with the Global North to develop capacity in net zero research areas such as carbon capture, utilization and storage (CCUS). The distribution of relative activity on this research front, in terms of productivity and capacity, is concentrated in the Global North.

"We are looking to disseminate best experiences in CCUS to ASEAN countries [but] we still lack technical understanding and need to catch up. [So] we bring in experts from abroad."

Dr. Han Phoumin, ERIA

Within the Global South, LMICs, India (considered separately in this analysis), and UMICs all report RAIs of 0.7 in CCS research, below the global average of 1.0 (FIGURE 2-14). LICs perform even less well, with a RAI of only 0.4 in this research field. Between 2012 and 2021, LMICs contributed to just 2.8% of global publications in CCS compared with 4.0% overall, while India contributed to 3.8% of all CCS publications compared with 5.4% of publications across the board. UMICs (the income group within which Indonesia is classified for this report) perform slightly better, contributing to 11% of global CCS research publications compared with 15% overall.

By comparison, Global North countries perform much better. China recorded the highest RAI in CCS (at 1.5), contributing to 29% of global publications in the field compared with 19% overall. Other HICs (excluding China, the EU-27, and the United States) contributed to 29% of global publications in this field compared with 21% overall (a RAI of 1.4). The UK recorded a RAI of 1.2, contributing to 8.2% of CCS publications (compared with 6.7% overall). Among HICs, the EU27 and United States have with the lowest RAIs in CCS research at 1.0 and 0.9, respectively, below other countries in this category.

Our analysis of individual Global South countries reveals nuances to these overall trends, which indicate that some national research systems are specialized in CCS (FIGURE 2-15). Between 2012 and 2021, India made the largest single contribution to CCS research in the Global South, followed by Iran, which contributed to 2.6% of CCS publications compared with 1.9% overall (with a RAI of 1.4). Malaysia was the third largest producer of CCS research in the Global South, contributing to 2.2% of publications compared with 1.1% overall and with the highest RAI within this section of countries of 2.1.

[35] Association of Southeast Asian Nations, including Indonesia, Malaysia, Thailand and seven other nations. https://asean.org/

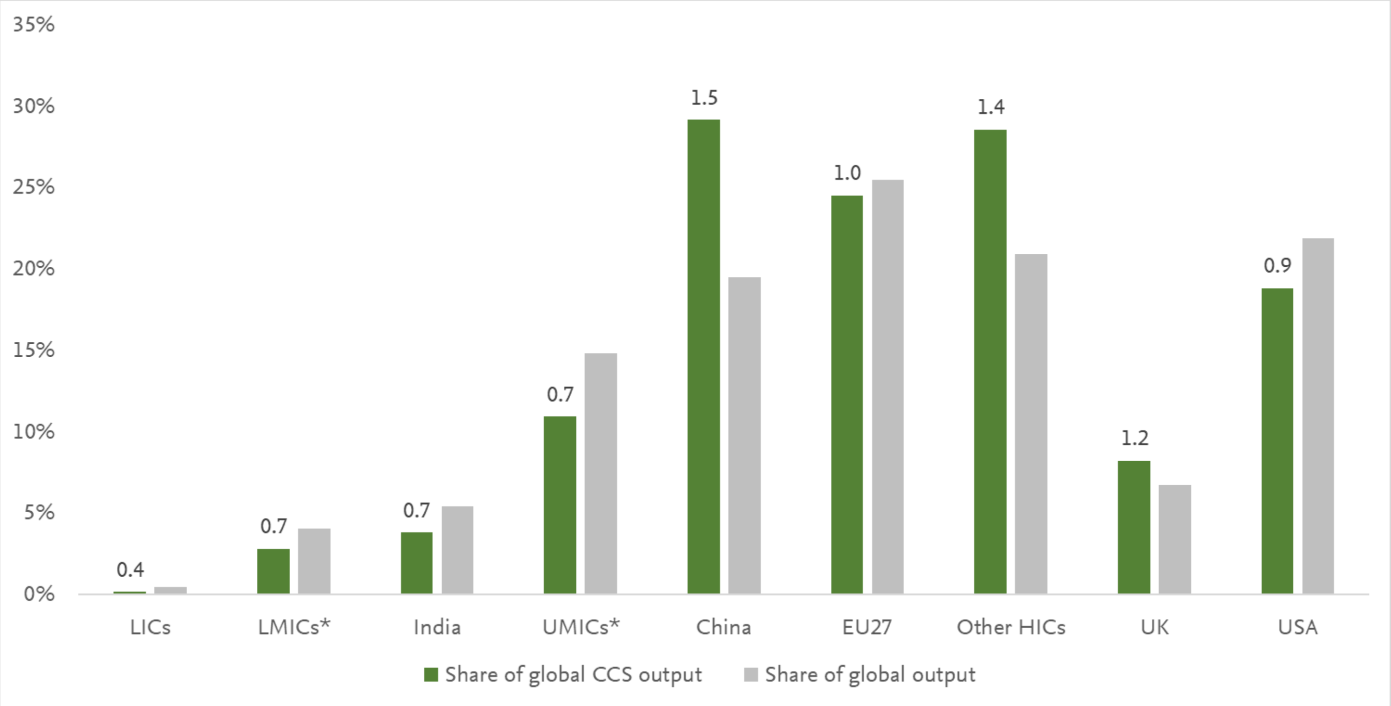


FIGURE 2-14
Share of carbon capture and storage (CCS) publications and all publications, with the resulting relative activity index (RAI), by income group or country, 2012–2021.
Note: LMIC and UMIC categories in this analysis do not include India and China, respectively, as they are presented separately.
Source: Scopus

Within the Global South, Thailand, the Philippines, Pakistan, and Viet Nam are among other top producers of CCS research showing relative activity levels above the global average (RAIs between 1.3 and 1.5).

Indonesia, for its part, follows the trend of other UMICs with a RAI of 0.7, contributing to 0.5% of global CCS research versus 0.8% overall. This finding, combined with Han Phoumin's observation that Indonesia needs more capacity in CCS research, points towards a need for greater South–North collaboration in this area, or greater South–South collaboration with neighboring countries such as Malaysia or Thailand, which have stronger relative activity profiles in this area.

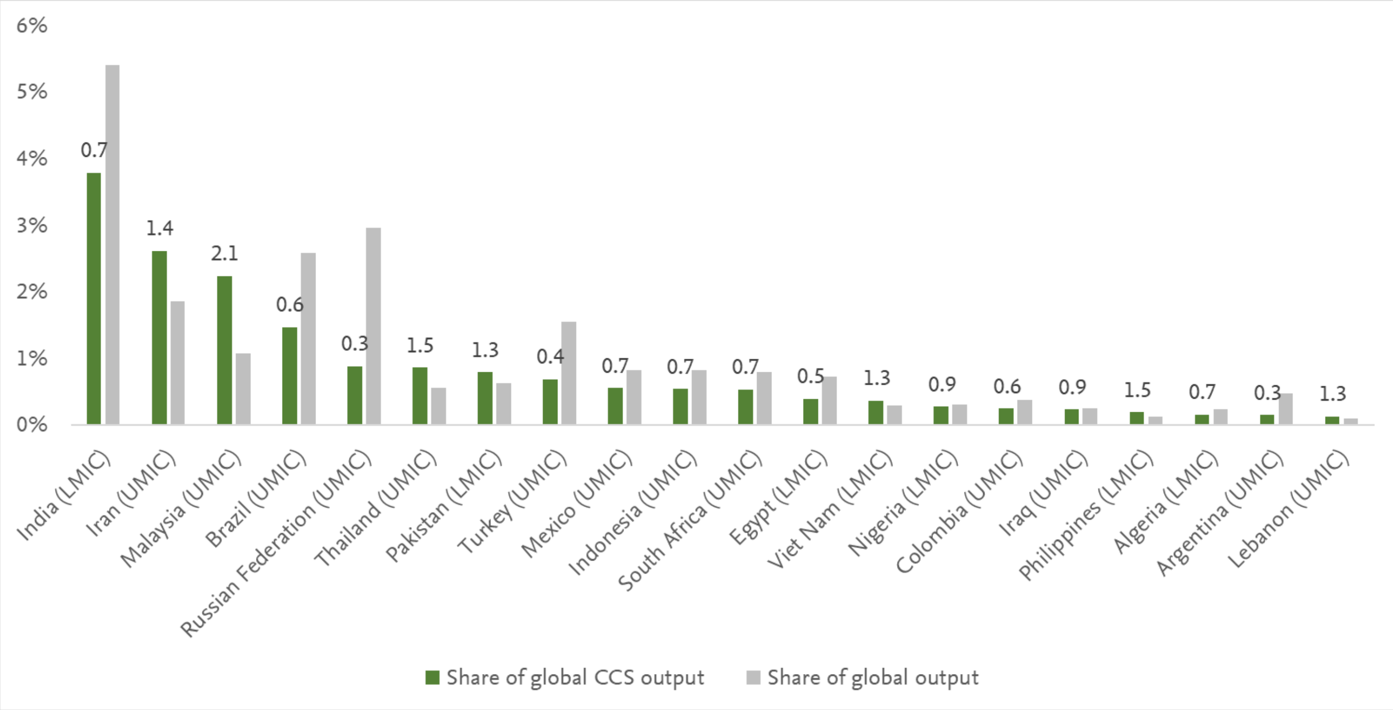


FIGURE 2-15
Share of carbon capture and storage (CCS) publications and all publications, with resulting relative activity index (RAI), by top-producing Global South country, 2012–2021.
Source: Scopus

Conclusions and future outlook

The Global South is likely to be disproportionally affected by climate change. In the past, levels of net zero research in the Global South have been low, but that is now changing. Net zero research in the Global South is growing apace and provides examples of how the transition to a clean energy future can be most effectively supported.

In this report, we set out to understand how net zero research in the Global South is contributing to the transition towards a clean energy future both in general terms and in three particular countries, Brazil, Egypt, and Indonesia. Together with our previous report, this analysis shares a concern in optimizing research systems with a view to maximizing carbon neutrality outcomes.

Net zero research in the Global South faces some unique challenges in terms of financial barriers and access to equipment and other resources. Since these nations are likely to be disproportionally affected by changes in the climate, effective routes must be found to facilitate the transition towards clean energy.

Key findings

The fast pace of growth in NØEnergy output in the Global South indicates that these countries are likely to benefit from increased support of research focused on net zero objectives.

Our analysis provides support for developing and supporting more complex projects in net zero research spanning multiple Global South countries, with or without the participation of the Global North. While such projects are associated with higher coordination costs, they should be supported with commensurate additional resources.

Low absolute levels of collaboration between Global South countries suggest the need for policy and funding measures to support this type of collaboration better. However, our analysis indicates that there are unique benefits for Global South researchers in this collaborative scenario. The high levels of multidisciplinarity seen in South–South collaborations puts these countries in a strong position to address the complex societal and environmental challenges presented by climate change and the transition to clean energy.

Going forward, researchers, institutions, and funding bodies in the Global South may want to consider promoting South–South as much as South–North collaborations to balance benefits with equity.

Future research

Further analyses of Global South participation and South-centric collaborations in net zero and other areas of research should, ideally, be expanded to consider gender equity as well. Women researchers in the Global South face a unique set of challenges to participation in net zero research, which warrant further investigation and analysis.[36]

Considering academic–corporate collaboration, policy-related uptake, patent citation and portfolio analyses would also have been highly useful to track the socio-economic

[36] C40 Cities Finance Facility & Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (2021). *Solar energy in Brazil: which are the barriers and opportunities for women professionals in the field?* https://www.c40cff.org/knowledge-library/solar-energy-in-brazil-which-are-the-barriers-and-opportunities-for-women-professionals-in-the-field

outcomes of NØEnergy research in the Global South but were beyond the scope of the current report.

As observed in Brazil's BIOEN case study, but also in recent discussions around COP27 priorities,[37] there is a need to understand and better characterize open data sharing needs in Global South-centric analyses of net zero research, as a first step in building infrastructure in this area. In this respect, it might be possible to leverage recent experiences in open data sharing practices for research on COVID-19.

However, we must be cognizant that open data sharing and re-use needs may be very different in the net zero field, where one primary need is for data to feed techno-economic and policy analysis. This focus towards sharing of techno-economic datasets may require very different pathways for data validation and circulation.

Finally, we recognize that bibliometrics provides a somewhat narrow view of the research and innovation process. More qualitative evidence and comprehensive case studies of research-driven net zero innovation in the Global South are needed.

Nevertheless, the findings in this report provide some encouraging signs that the region is growing its net zero research portfolio and expertise, which will benefit Global South researchers and support the transition towards a clean energy future.

"We do not have much data about gender dimensions in the Brazilian energy [sector]. We [have] found that only 30% of professionals in the solar sector in Brazil are women. Women in the same position and level of education earn 30% less than their male colleagues. [Yet] women professionals in the field have a higher level of education compared with men."

Kathlen Schneider, Director, Ideal and Co-Founder and Coordinator, Rede MESol

[37] Mutiso, R. M. (2022). Net-zero plans exclude Africa. *Nature*, **611**(10), https://doi.org/10.1038/d41586-022-03475-0

Appendix A

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Appendix B

Glossary of terms

Bibliometrics

The quantitative data used in this report are analyzed using bibliometric techniques. Bibliometrics is a set of methods that use data from databases indexing records of scientific publications and patents, as well as other R&I outputs of growing interest such as designs and trademarks, to derive new insights into these outputs' corresponding funding and performance. Within bibliometrics, the branch of scientometrics examines the records of research publications to measure scientific activity. It is also increasingly looking at related types of outputs such as research data sets and protocols. The branch of technometrics focuses on patent records as a proxy measure for innovation. It is being actively expanded to cover other forms of innovation that are not well captured by patents, such as those covered by designs and trademarks.

Compound annual growth rate

The compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

Collaboration or co-publication

Research collaboration is measured by counting publications resulting from the efforts of two or more authors. Such publications are referred to as co-publications throughout the report. Collaboration can be categorized into various types; in this report, we focus on the following three:

- International collaboration/co-publication—where the affiliations listed by the authors of a publication include institutions from two or more countries or regions
- South–South international collaboration/co-publication—where the affiliations listed by the authors of an international co-publication include distinct authors from at least two distinct Global South countries. Note that South–South co-publications involving researchers three or more distinct countries may well also double as either South–North or even North–North co-publications, except where noted.
- South–North international collaboration/co-publication—where the affiliations listed by the authors of an international co-publication include distinct authors from at least one Global South country and at least one Global North country. Note that South–North co-publications between distinct authors from at least three distinct countries must also be counted as either South–South or North–North co-publications, except where noted.
- South–South, South–North, and North–North bilateral links—refer to the number of *unique* combinations of pairs of countries within the author affiliations of a single publication. A publication authored by three researchers from Brazil, one from France and five from Nigeria contains three bilateral links: one South–South link (Brazil–Nigeria) and two South–North links (Brazil–France and Nigeria–France), irrespective of the number of authors from each country.

Global South and Global North

The term *Global South* refers to three groups of countries: Upper-Middle-Income Countries (UMICs), Lower-Middle-Income Countries (LMICs) and Low-Income Countries (LICs), in line with World Bank definitions.[38] In this report, the Global South category excludes China, which is normally considered a UMIC country. This is because although China is a recipient of some development aid, it is also a scientific powerhouse. China collaborates routinely because of its high academic status rather than because of development-oriented scientific collaboration.

Global North countries are divided into four categories: China, EU-27 countries (including Bulgaria), the United States and an aggregate of the remaining High-Income Countries (HICs), as defined by the World Bank, which includes Australia, Canada, Israel, Japan, Saudi Arabia, South Korea, Switzerland, and the United Kingdom.

Highly cited publications

Citations are used by researchers to indicate the intellectual foundations on which their work is built. A citation count is therefore used in bibliometrics as an indication of influence within the research community. However, because citation practices vary over time and across disciplines, simply counting citations would give a skewed picture of influence. Accordingly, citation counts for individual papers are normalized by the average citation count of all papers published in the same year and in the same subfield of science.

Citation scores are highly skewed, with the majority of citations directed toward a small minority of papers. Contributions to this set of highly cited publications (HCP) are therefore often used as a proxy for research excellence. If citation behavior was random, one would expect that every researcher would contribute equally to the population of HCP. For instance, each researcher would have 10% of their publications among the top 10% most cited worldwide. Measuring the divergence from this benchmark is used to track how consistently a researcher contributes to this set of exceptionally highly cited publications.

These indicators have been subfield-, year- and document type- normalized. In this study, it captures the share of publications falling within the top decile ($HCP_{10\%}$) of most highly cited publications for a given subfield, year, and document type. The world level on this indicator is 1.0 in a given subfield. Note however that NØEnergy research is composed of cuts across numerous of the subfields used in the citation normalization process, and therefore the NØEnergy research average of highly cited publications is higher than 1.0.

Homophily and heterophily (in Global South and Global North bilateral links)

When considering bilateral links, both South-South and North-North bilateral links are considered homophilic, because they associate countries from the same (broad) income category. South-North bilateral links are considered heterophilic because they associated countries from different (broad) income categories.

Heterophilic links are often deemed particularly desirable in research planning and strategy as a mean to increase actor diversity and inter-sectoral or cross-disciplinarity exchanges within teams or networks. Nevertheless, in the context of this report, homophilic South-South bilateral links were also studied as being of potential interest as a support target.

[38] See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519

Interdisciplinarity / conceptual diversity

The interdisciplinarity indicator captures diversity in the disciplines associated with the prior findings on which a research publication is based and that are cited within the publication (i.e., the thematic subfields associated with the references). This indicator captures the conceptual underpinnings of research and is referred to as *conceptual diversity*.

This indicator captures the share of publications falling among the top decile of most highly interdisciplinary publications in their subfield and year. Scores for this indicator are 1.00 at the global level (for a given subfield and year): a field will score above 1.00 if it is more diverse than the global average or less than 1.00 if it is below the global average.

Lead authorship

Lead authorship encompasses the first, last, or corresponding author positions on a scientific publication. These author positions are commonly attributed to those researchers that have made the largest contributions to a publication, either in designing and positioning a study against the background of the current state of the art (last or senior author position), or in leading the implementation of the study (first author position). Corresponding authors are typically the first or last author of a study.

Note that where scientific publications have multiple corresponding authors, all are included in the analysis. However, some publications provide contact information for all authors. These publications were excluded from the analysis.

On the basis of this information, it is possible to compute the average (at publication level) share of lead authorship positions held by South and North researchers.

Multidisciplinarity / collaborative diversity

The multidisciplinarity indicator captures the diversity arising from collaboration between co-authors from different disciplines (i.e., the topics associated with the prior publications of the authors). This indicator captures the collaborative underpinning and team composition of research. In this report, we refer to this as *collaborative diversity*.

This indicator captures the share of publications falling among the top decile of most highly multidisciplinary publications in their subfield and year. Scores for this indicator are 1.00 at the global level (for a given subfield and year): a field will score above 1.00 if it is more diverse than the global average or less than 1.00 if it is below the global average.

Relative activity index or specialization index

The relative activity index (RAI) indicator is defined as the share of a country's article output in a topic cluster relative to the global share of articles in the same topic cluster. A value of 1.0 indicates that a country or region's research activity in a field corresponds exactly with the global activity in that field; a value higher than 1.0 implies a greater emphasis; and a value lower than 1.0 suggests a lesser focus.

Scholarly output

The terms output, articles, and publications refer to peer-reviewed articles, reviews, and conference papers published in journals and conference proceedings; book chapters and books; all which must be indexed in the Scopus database for inclusion in the study.

Sustainable Development Goals

The Sustainable Development Goals (SDGs), which were launched by the United Nations in 2015,[39] are defined as "the blueprint to achieve a better and more sustainable future for all",[40] by addressing the global challenges we face. Since their launch, Elsevier has worked with the research community to map the landscape of sustainability science, starting with the *Sustainability Science in the Global Research Landscape* report (2015),[41] developed with SciDev.net. Since then, we have mapped publications in Scopus to 16 of the 17 SDGs, combining expert-led search queries with machine learning models.

The methods and queries for the SDG publication sets are available here:
https://elsevier.digitalcommonsdata.com/datasets/9sxdykm8s4/1

Topics and topic clusters

Topics (or Topics of Prominence) refer to nearly 96,000 research topics created using the citation patterns of Scopus-indexed publications. The methodology for using citation patterns to define research topics was developed through an Elsevier collaboration with research partners.[42] The advantage of taking a citation-based approach to identify research topics is that one need not rely on identifying all the relevant keywords to define a research area. Rather, the research area is delineated by citation patterns in the topic, whereby research that appears in the same citation network is clustered together in the same topic. This approach provides a more nuanced definition of the research topic.

Topic clusters are a higher-level aggregation of these research topics and are based on the same direct citation algorithm that creates the topics. While topics are easy for subject experts to understand, they are more difficult for subject generalists to comprehend. To help in the discovery and understanding of the topics, Elsevier has aggregated them into around 1,500 topic clusters. When the strength of the citation links between topics reaches a threshold, a topic cluster is formed. Topic clusters are named by the three most relevant key phrases within the cluster—for example, *Wind Power / Electric Power Transmission Networks / Electric Power Distribution* or *Deforestation / Forest / Conservation*.

Both topics and topic clusters are mutually exclusive: a publication belongs to only one topic and only one topic cluster. More information on topics is available at
https://www.elsevier.com/solutions/scival/releases/topic-prominence-in-science and
https://service.elsevier.com/app/answers/detail/a_id/28428/

[39] See https://sdgs.un.org/
[40] See https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[41] See https://www.elsevier.com/research-intelligence/resource-library/sustainability-2015
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