European Commission

Provision and analysis of key indicators in research and innovation

Policy brief I – Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 on international partnerships

Focusing on SDGs 7–11 plus 16 (Prosperity)

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Research and Innovation

Provision and analysis of key indicators in research and innovation. Policy brief I – Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 on international partnerships. Focusing on SDGs 7–11 plus 16 (Prosperity)

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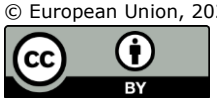

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Provision and analysis of key indicators in research and innovation

Policy brief I – Research trends on the Sustainable Development Goals (SDGs) and alignment with SDG 17 on international partnerships

Focusing on SDGs 7–11 plus 16 (Prosperity)

Prepared by

Science-Metrix

2021 Directorate-General for Research and Innovation EN

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EXECUTIVE SUMMARY

The 17 Sustainable Development Goals (SDGs), part of the United Nations' 2030 Agenda for Sustainable Development, are interconnected goals that aim at achieving a better and more sustainable future for all. Given the increasing emphasis placed by the European Commission's Framework Programmes for Research and Technological Development on achieving the SDGs, this policy brief first examines how European research, at the level of the European Union (EU-27) and the European Research Area (ERA), contributed to research for the Prosperity SDGs[1] (Energy (SDG 7), Economy (SDG 8), Infrastructure and industrialization (SDG 9), Reduce inequality (SDG 10), Cities (SDG 11) and Institutions (SDG 16)) using two publication output indicators:

- the number and share of publications by SDG; and
- the specialisation index, measuring the emphasis placed by individual countries, relative to the world and the whole of science, on each SDG.

Among the seventeen SDGs, SDG 17 on Partnerships[2] for the goals cuts across all other SDGs. It is intended, in part, to promote inclusive collaborations among a broad range of actors (e.g. North–South co-publications), with the aims of easing the emergence of solutions to global problems and ensuring such solutions are adapted to the needs of diverse actors and are broadly adopted. Accordingly, this brief also aims to assess whether European research (at the EU-27 and ERA levels) for the Prosperity SDGs is aligned with SDG 17 targets on Partnerships for the goals. More precisely, the analyses rely on bibliometric data to examine the evolution of collaboration practices along North–North and North–South dimensions in the conduct of scientific activities covering the Prosperity SDGs. Here, North and South are interpreted in terms of income level rather than geographic distribution, with North corresponding to high-income (e.g. high- and upper-middle-income countries according to the World Bank) and South corresponding to low-income (e.g. low- and lower-middle-income countries). Accordingly, all EU-27 and ERA countries (except Ukraine, Tunisia and Moldova) belong to the high-income category. The following collaboration indicators were used for this part of the brief:

- share of co-publications with high- or low-income countries; and
- diversity of international partners, particularly among low-income countries.

The bibliometric analyses presented in this brief rely on peer-reviewed scientific publications indexed in Scopus and published between 2002 and 2019. Where relevant, the findings for the EU-27 and ERA are contextualised by contrasting them with those of four other key international research contributors belonging to the high-income category: the United States, China, Japan and South Korea. As mentioned above, this brief focuses on the Prosperity SDGs. Two complementary briefs cover the remaining SDGs on the Planet and People thematics.

[1] OECD. (2019). *Measuring distance to the SDG targets 2019.* https://doi.org/10.1787/a8caf3fa-en

[2] Here, 'Partnerships' refers to scientific collaborations on research related to the SDGs. SDG 17, Partnerships for the Goals, aims to 'Strengthen the means of implementation and revitalize the global partnership for sustainable development': https://sdgs.un.org/goals/goal17

Q1: How large is the contribution of European research to the world publication output on the Prosperity related SDGs?

The data on the scientific publication output covering the thematic of the Prosperity SDGs show that the EU-27 region is generally performing better than the selected comparator countries, with some differences among SDGs.

Over the past two decades, the EU-27 region has contributed to about 20 % to 25 % of the world's scientific output in research covering the Prosperity SDGs. As of 2019, it was the second highest contributor, after the ERA, in SDG 8 (Economy), SDG 9 (Infrastructure) and SDG 11 (Cities). It was the third highest contributor in three more SDGs: ranked after China and the ERA, in SDG 7 (Clean energy), and after the ERA and the United States in SDG 10 (Reduce inequality) and SDG 16 (Institutions). Recall that the EU-27 accounts for most of the ERA's production.

- Among EU-27 countries, Germany, Italy and Spain were consistently among the top 3 scientific contributors in all Prosperity SDGs.
- France, the Netherlands and Sweden were also large contributors in all SDGs, and Poland and Portugal were well placed in SDG 7, SDG 8, SDG 9 and SDG 11.
- Combined with the United Kingdom, the three leading EU-27 countries (Germany, Italy and Spain) were involved in about half of all the ERA's papers in 2019.

Since 2002, the absolute volume of scientific output has been continuously growing for the EU-27, the ERA and other key international comparators. However, since 2017, the EU-27's (and ERA's) share of world publication output has generally declined by about 5 %, primarily in SDG 7, SDG 8, SDG 9 and SDG 11. This decrease is a generalised phenomenon affecting most Western nations. The strong growth of emerging countries such as China played a key role in producing this pattern and has more significantly affected other large scientific leaders such as the United States.

Our findings also indicate that over the past two decades European research within the EU-27 and ERA countries has, relative to the world, increasingly emphasised research on the Prosperity SDGs, reaching or exceeding the world level for specialisation for all except SDG 7. Specialisation in research covering SDG 7 on Energy appears much more prominent in China and South Korea. These two countries are known to invest more resources in engineering and applied sciences, which are at the core of research covering SDG 7, compared to other domains such as the natural and health sciences. Although China is not specialised in the other Prosperity SDGs, since 2002 it has been gradually putting more emphasis on these research fields and is now approaching the world average in SDG 8, SDG 9 and SDG 11.

According to these indicators, as of 2019, the EU-27 appeared to be well positioned in most Prosperity SDGs, exhibiting high publication shares relative to world output and strong specialisation. The only SDG in which the EU-27 did not perform as well was SDG 7. Over the years, China has been emerging as a key scientific contributor, leading in SDG 7 and closing the gap with the EU-27 and ERA in SDG 8, SDG 9 and SDG 11.

Q2: How much do European countries collaborate with international partners on the Prosperity related SDGs?

Based on the proportion of publications co-authored with international partners, the results show that all players have been increasing their share of international co-publications over time. Of the EU-27's and ERA's scientific publications in the period

2017–2019, 40 % to 50 % were co-published with high-income countries (which includes inter-European co-publications), while 4 % to 7 % involved low-income countries[3].

Over the past decade, the share of EU-27 co-publications has been growing with both high- and low-income countries, and this growth has been more substantial with the latter group. The average international co-publication shares of EU-27 countries with high-income countries have increased at a pace of 4.8 % annually in SDG 16, and at about 3 % to 4 % in SDGs 8–11, and 2.8 % in SDG 7. In contrast, the EU-27's share of co-publications has increased more sharply over the past decade with low-income countries, at a pace of 11 % annually in SDG 7 and between 6.3 % and 8.9 % in the other SDGs[4]. These findings point to a general tendency across all Prosperity SDGs for the EU-27's efforts to increasingly integrate with those of low-income countries.

- Among individual EU-27 members, France and Germany were consistently among the top 3 countries having the largest diversity of low-income partners in all Prosperity SDGs, with more than 45 different low-income countries. Italy completed the top 3 ranking in SDG 7 and SDG 11, the Netherlands in SDG 8 and SDG 9, Sweden in SDG 10 and Spain in SDG 16.

In general, the co-publication activity of EU-27 countries was not distributed evenly across the low-income countries but was instead dominated by a handful of countries. This is not surprising as the distribution of publication outputs among low-income countries is similarly skewed to that of high-income countries, with a few countries accounting for a large share of overall output. In this respect, India is to the low-income group what the United States or China are to the high-income group. It is thus not surprising that, in all SDGs, India was consistently the leading (or a top leading) partner with individual EU countries. Other countries were also showing a strong presence among the key low-income partners of EU-27 countries. Apart from India, among the top 5 low-income countries having a large number of bilateral links with EU countries, Pakistan, Ukraine and Vietnam were present in four out of six Prosperity SDGs.

During the most recent period (2017–2019), Japan exhibited the highest co-publication rates with low-income countries in all SDGs and among all comparators, except in SDG 7 in which it was second to South Korea. China ranked last except in SDG 10 and SDG 16, in which it performed slightly better than the United States. However, over the past decade, China stood out for exhibiting the most substantial annual increase in scientific co-publications with low-income countries, for all SDGs. China's co-publication rates with low-income countries grew two to three times faster than those of the EU-27 (and ERA). As it stands now, both the EU-27 and ERA regions globally participate more than China in scientific cooperation with low-income countries, with a higher share of co-publications. However, given China's fast growth in international collaborations it may rapidly close this gap and overtake the EU-27 (and ERA) in the coming decade.

One potential mechanism through which the EU-27 may maintain its leading position relative to other major scientific contributors (i.e. China and the United States) and widen its scientific collaborations in the Prosperity SDGs would be to stimulate the participation of EU-27 countries that currently co-publish little. Cooperation for the SDGs

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[3] Across all 16 SDGs, the overall rate of EU-27 international collaboration was the highest in SDGs 13–15 of the Planet thematic (63 %–70 %). The EU-27's international collaboration was generally the lowest in the Prosperity SDGs (SDG 7–11 and SDG 16; between 44 % and 53 %), except for SDG 4 (Education) of the People thematic (40 %).

[4] Given the lower collaboration rates with low-income compared to high-income countries, a small increase between two periods would naturally result in a larger annual growth with the former group. Nonetheless, these trends indicate positive changes in co-publication activities with low-income countries.

is likely to be reinforced through mission-oriented policies, as well as dedicated programmes, such as Horizon Europe, that promote research on the SDGs on a national scale across Europe. This cooperation could also be reinforced through a sustained support for research in low-income countries. Such efforts may have already been influential in SDG 7, SDG 11 and SDG 16, as collaborations between EU-27 countries and low-income countries have been more rapidly improving for these SDGs since the entry into force of the SDGs in 2016. However, a longer time period is required to reliably measure the influence of SDG-related policies on scientific co-publications in the context of international collaborations. Additionally, the recent improvements following the creation of the SDGs cannot be directly attributed to this event, since other confounding factors could be at play, which were not controlled for in this analysis.

Overall, the current results are indicative of positive changes over the years at the EU level regarding enhanced international interactions with both high- and low-income countries in the conduct of scientific activities. This coincides with a wealth of recent or upcoming initiatives across Europe aiming to boost collaborations with developing countries (e.g. EU–Africa collaborations under Horizon Europe[5], the EU-CELAC Strategic Partnership[6], the Partnership on Research and Innovation in the Mediterranean Area (PRIMA)[7], and the UKRI's Global Challenges Research Fund[8]). Given how geared Horizon Europe is towards achieving the SDGs[9], it would appear relevant to monitor its contribution to such thematics. Since partnerships were leveraged as cross-cutting issues in delivering prior FPs, it would also appear sensible to monitor Horizon Europe's contribution to the SDGs (1 to 16) from the perspective of SDG 17 on Partnerships for the goals. Such monitoring could, for example, implement a research design that enables the attribution of observed changes to Horizon Europe, and it could embrace a few cross-cutting issues from H2020 (e.g. collaboration across countries, sectors and disciplines).

[5] https://ecdpm.org/wp-content/uploads/International-collaboration-in-HEU-a-new-approach-to-partnering-with-A...-1.pdf

[6] http://alcuenet.eu/policy.php

[7] https://ec.europa.eu/info/research-and-innovation/research-area/environment/prima_en

[8] https://www.ukri.org/our-work/collaborating-internationally/global-challenges-research-fund/

[9] https://ec.europa.eu/info/sites/default/files/research_and_innovation/ec_rtd_he-presentation_062019_en.pdf

1 Introduction

The 17 Sustainable Development Goals (SDGs), part of the United Nations' 2030 Agenda for Sustainable Development, are aimed at achieving a better and more sustainable future for all. They are interconnected goals (Le Blanc, 2015) that are intended to be achieved by 2030. As with every long-term project, progress must be monitored on a multitude of dimensions to ensure that objectives are met in time. Since most SDGs require or otherwise benefit from conducting new scientific research, it is worthwhile tracking trends in related scientific outputs. Although the number of scientific publications related to the goals would alone provide valuable information about their uptake in scientific research, other aspects, such as changes in related collaboration patterns, could also yield valuable insights. For example, SDG 17 on Partnerships for the goals cuts across all other SDGs, promoting inclusive collaborations among a broad range of actors to implement a successful plan towards achieving the SDGs. On the research front, SDG 17 points to various types of collaborations, such as the following[10]:

- **International collaborations (especially North–South and South–South):** 'Enhance North–South, South–South and triangular regional and international cooperation on and access to science, technology and innovation' (Target 17.6).

- **Inter-sectoral collaborations (e.g. public–private):** 'Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the sustainable development goals in all countries, in particular developing countries' (Target 17.16) and 'Encourage and promote effective public, public–private and civil society partnerships, building on the experience and resourcing strategies of partnerships' (Target 17.17).

- **Cross-disciplinary collaborations:** Although not explicit among SDG 17's targets, cross-disciplinary collaborations are now broadly recognised as key drivers for generating solutions to the increasingly complex issues facing societies in the 21st century (e.g. climate change). Pre-eminent policies and interventions targeting cross-disciplinary collaboration as policy goals include, for example, the European Commission Framework Programmes' (FPs), the Horizon 2020 programme and the European Commission COST actions.

When these types of scientific collaborations are combined towards attaining translational research outcomes with profound societal impacts – while also ensuring the end users are involved in co-creating and co-achieving the targeted outcomes – they are often collectively referred to as transdisciplinary research (Defila & Giulio, 2001). Transdisciplinary research has been recognised on multiple occasions as a promising approach to the SDGs (Hummel et al., 2013; Mauser et al., 2013; Salite et al., 2016). This vision has recently been reiterated in designing the European Commission's upcoming FP, Horizon Europe, which emphasises research for the attainment of the SDGs (European Commission, 2019; Mayer & Schuch, 2019)[11].

In a European context, especially in light of the upcoming Horizon Europe, it therefore appears highly relevant to monitor trends, not only in the contribution of the FPs to the SDGs (e.g. in terms of share of SDG-relevant publications supported by the FPs) but also in terms of the extent of transdisciplinarity that led to these outputs. This policy brief relies on bibliometrics, a quantitative field studying the production of new knowledge,

[10] https://www.un.org/sustainabledevelopment/globalpartnerships/

[11] https://www.swisscore.org/Documents/Programme_Science_Briefing_Transdisciplinary_Research.pdf

mostly in the form of peer-reviewed publications[12]. Numerous aspects of transdisciplinary research are thus beyond the scope of this policy brief, which emphasises the analysis of trends in the dynamic interplay between geographic locations that have been at the heart of European research towards achieving the SDGs[13]. Accordingly, the following set of indicators were used to assess whether European research for the goals has been increasingly aligning with SDG 17, especially since the entry into force of the SDGs on 1 January 2016:

- number and share (relative to the world) of peer-reviewed publications by SDG;
- the research specialisation of countries/regions in each SDG; and
- shares of international co-publications within peer-reviewed publications and shares of North–South and North–North co-publications (measuring collaborative international work, particularly work that brings together Global South and Global North countries).

These indicators were computed for the European Union (EU-27), the European Research Area (ERA)[14], the world and four key international comparators: the United States, China, Japan and South Korea.

The analyses are based on worldwide publications indexed in the Scopus database that cover the SDG thematics and that were published between 2002 and 2019. This period thus extends from FP6 (2002–2006) to Horizon 2020 (2014–2020) and encompasses FP7 (2007–2013), which has already been shown to contribute importantly to the SDGs, with 72 % of the European Commission's financial contribution to FP7 falling within SDG-relevant areas (Mayer & Schuch, 2019). However, this contribution was not distributed uniformly across the SDGs, highlighting the importance of analysing output and collaboration trends by SDG. This policy brief focuses on those SDGs pertaining to the Prosperity thematic[15]: Energy (SDG 7), Economy (SDG 8), Infrastructure and industrialization (SDG 9), Reduce inequality (SDG 10), Cities (SDG 11) and Institutions (SDG 16) (OECD, 2019). Two complementary briefs focus on the SDGs pertaining to People and Planet. As a transversal SDG, SDG 17 is, per design, covered in all three briefs. Given how geared Horizon Europe (2021–2027) is towards the 2030 Agenda for Sustainable Development, in part through funding for transdisciplinary research, follow-up monitoring of transdisciplinary trends will be important in assessing the extent to which the EU-27 and the ERA contribute to SDG 17 in delivering knowledge for the goals. Such monitoring efforts should also be more inclusive with regard to the underlying dimensions of transdisciplinary research – for example, covering co-publications across sectors and disciplines.

In the context of the European collaborations along the North–North and North–South axes, a subdivision of the world relative to Global North (or developed counties) and

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[12] Here using Scopus, the largest abstract and citation database of peer-reviewed literature: https://www.scopus.com/search/form.uri?display=basic

[13] As is the case for transdisciplinary research in general, the bibliometrics community has yet to develop a single quantitative indicator suitable to track the complex/diverse collaborations characterising this mode of research. Using additional indicators covering, for example, collaborations across sectors and disciplines is beyond scope of this policy brief.

[14] Due to space restrictions, individual country data for the EU-27/ERA are not presented in this brief. Instead, the analyses focus on the aggregate results for the EU-27 and ERA, and top contributors, compared to selected international comparators.

[15] The Peace and Prosperity SDGs were merged, see https://www.oecd.org/sdd/measuring-distance-to-the-sdg-targets-2019-a8caf3fa-en.htm

Global South (or developing/emerging countries) may be problematic. This is because several countries that are generally highly active and productive in scientific research, with capacities comparable to Western countries, would fall in the Global South category. For example, China is currently the top publishing country overall, ahead of the United States, and falls among upper-middle-income economies. Such a division of countries would strongly overestimate the collaboration patterns of the Global South. We therefore used an alternative classification method based on the countries' gross national income per capita, which offers a division of countries more reflective of their overall levels of research activity. This classification separates high-income from low-income countries and follows the classification of countries by income as drawn by the World Bank. Consequently, since all EU-27 countries, most ERA countries (except Ukraine, Tunisia and Moldova) and the other key international comparators (i.e. the United States, China, Japan, South Korea) belong to high- and upper-middle-income economies (collectively referred to as high-income countries in the present context, see Section 2.3), the North–North and North–South collaborations of Europe will now reflect the high–high income and high–low income collaborations.

2 Methods

2.1 Data source

The data sets for each SDG were built using Elsevier's Scopus database of scientific literature, which contains roughly 44 million peer-reviewed documents published in over 50 000 journals since 1996. The document types included in the data sets are journal articles, reviews, short surveys and conference papers, covering the period 2002–2019. These documents are collectively referred to as 'publications' or 'papers' in this policy brief.

2.2 SDG topical data sets

A bibliometric study of research related to the SDGs presents challenges, the main ones pertaining to the creation of relevant publication data sets. As an example, each goal's scope is broad, rendering the task of reliably covering all relevant literature intractable; in other words, this implies that a diversity of topics (i.e. the targets within each SDG) must be covered extensively and accurately to reliably trace developments in these areas. For this policy brief, Science-Metrix implemented a bottom-up approach to the construction of SDG-relevant publication data sets, whereby data sets were first constructed by SDG target, and then aggregated at the SDG level. Details of this approach are presented in the Annex.

2.3 Geographical regions and collaboration partners

This policy brief focuses on the dynamic interplay between geographic locations that have been at the heart of European research towards achieving the SDGs. Therefore, the data were aggregated for the EU-27, the ERA[16] and the world. They were also provided for four international comparators (the United States, China, Japan and South Korea).

To assess whether European research for the goals is increasingly being aligned with SDG 17, in terms of international collaborations, co-publication patterns were analysed between geographical regions of interest (i.e. the EU-27, the ERA, the United States, China, Japan and South Korea) and international partners based on their income level. In the present context of Partnership for the goals, two world subdivisions were considered

[16] The ERA is composed of EU-27 countries plus 19 associated countries (Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, Georgia, Iceland, Israel, Kosovo, Liechtenstein, Moldova, Montenegro, North Macedonia, Norway, Serbia, Switzerland, Tunisia, Turkey, Ukraine and the United Kingdom).

following the most recent country classification of the World Bank[17]: (1) high-income and upper-middle-income economies, collectively referred to as *high-income countries* (n=118), and (2) low-income and lower-middle-income economies, referred to as *low-income countries* (n=79) (Figure 1). The bulk of countries classified as low-income economies closely mirrors existing lists of countries that receive development assistance[18]. All EU countries and several ERA countries (except Ukraine, Tunisia and Moldova)[19], as well as the United States, China, Japan and South Korea, belong to the high-income category. The co-publications of these geographical regions were therefore measured with international partners sharing either a similar, high level of income (high–high collaboration), or a smaller, low level of income (high–low collaboration). In the analyses, we used a static categorisation of countries by income, based on the World Bank's 2019 classification, even though the economic status of countries is constantly in flux. We note, however, that such classification has been fairly stable since 2010, with large countries such as China, Brazil, Turkey and Iran, for example, having already transitioned from lower- to higher-income economies. Within the past decade, 12 smaller countries have changed economic status: three countries joined the low-income category in 2019 (Algeria, Angola and Tunisia), one country (Sri Lanka) switched from low-income to high-income in 2018 and back to low-income in 2019, and eight countries joined the high-income category in 2019 (Armenia, Georgia, Guatemala, Guyana, Indonesia, Kosovo, Paraguay and Samoa).

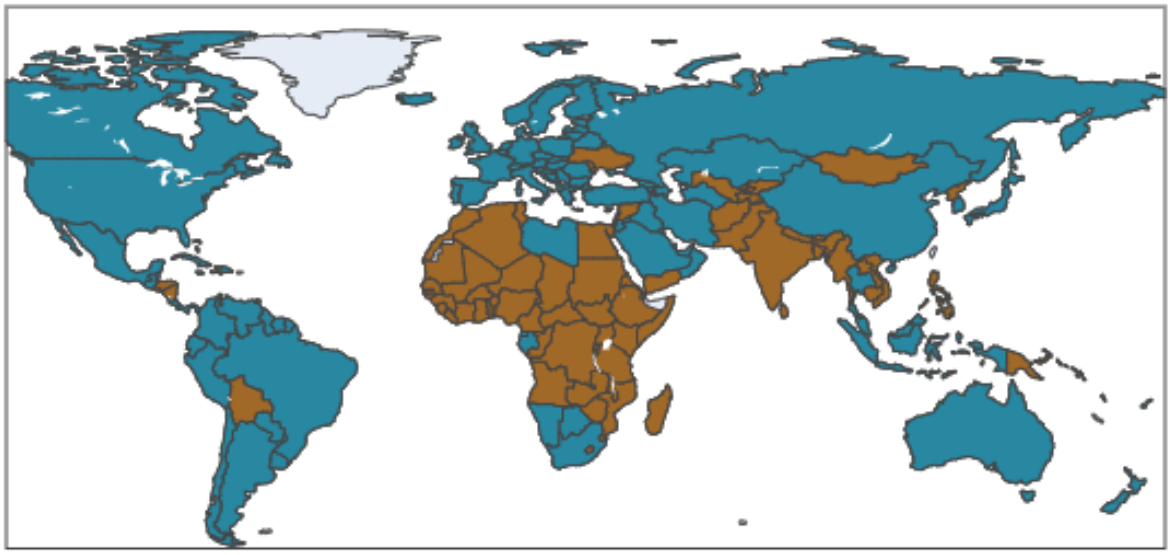


Figure 1 Country classification by income level in 2019

Note: The classification is based on that of the World Bank. High-income countries, n=118 (blue); low-income countries, n=79 (brown)
Source: World Bank

[17] High-income economies are defined as those with a gross national income (GNI) per capita, calculated using the World Bank Atlas method, of USD 12 536 or more in 2019, and upper-middle-income economies are those with a GNI per capita between USD 4 046 and USD 12 535. Low-income economies are those with a GNI per capita of USD 1 035 or less, and lower-middle-income economies are those with a GNI per capita between USD 1 036 and USD 4 045. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

[18] https://ida.worldbank.org/about/borrowing-countries

[19] Among ERA counties, Ukraine, Tunisia and Moldova are lower-middle-income economies. They were thus included in the output of the low-income countries in computing co-publications data for the high–low collaboration dimension. Including them instead among high-income countries since they are part of the ERA does not change the overall results.

2.4 Bibliometric indicators

Publications (or papers): The number of peer-reviewed journal articles, conference papers and reviews produced by a country or region. Counts are based on author addresses, whereby each author on a paper is attributed an equal fraction of the paper. Author fractions on a paper are then aggregated to the desired level (e.g. country) based on the authors' affiliations on the paper.

Specialisation index: The specialisation index (SI) indicates how much a given entity's total output in Scopus is concentrated in one SDG relative to the equivalent concentration for the whole of Scopus (i.e. the world). For instance, if 20 % of a given country's publications cover a specific SDG (e.g. SDG 10), whereas 15 % of all papers published worldwide are in this SDG, then this country's research activities are said to be *specialised* in this SDG. In other words, the country puts more emphasis on that research domain than is normally the case elsewhere in the world. The SI reference value is 1 (i.e. the world level). An SI score above 1 indicates that an entity proportionately puts more emphasis than the world on a given area, and an SI score below 1 indicates the opposite.

Share of international co-publications: This is the share of publications by a country that include at least one other author from a different country. This share is obtained by dividing the number of international co-publications of an entity by its total number of publications, both measured using full counting – that is, by attributing a full count of 1 to the country of interest regardless of the number of authors from that country. The international co-publication rates of a country collaborating with high- or low-income countries is computed as the distinct count of its co-publications with all high- or low-income countries, taken as a group, divided by its publication count (using full counting). For example, a publication with authors from France, Germany, Italy and Kenya will be counted at the level of France as one co-publication with high-income countries (thus taking Germany and Italy as a group) and one co-publication with low-income countries. At the regional level (e.g. for the EU-27 or ERA), the shares of international co-publications – overall as well as with high- or low-income countries – are computed as weighted averages. In other words, they are computed as the sum of co-publications of each EU-27/ERA country with all high- or low-income countries, taken as a group, over the sum of each EU-27/ERA country's publications; as to the example above, the number of co-publications of each individual EU-27/ERA country is calculated as the number of publications that include another author from a high- or low-income country. Each co-publication is counted once, even if it involves more than two countries from the same income group (which may include other EU-27/ERA countries).

Compound annual growth rate: To obtain a reliable signal across years, the number of co-publications (and publications) were first aggregated across three-year running periods, moving in steps of one year, from 2011 to 2019. The compound annual growth rate (CAGR) measures the annual rate (%) at which a country's or region's score changed from a starting value (SV) in the starting period (SP) to an ending value (EV) in the ending period (EP) ($CAGR = (SV/EV)^{(1/(EP-SP))}-1$). This applies to all indicators.

We considered the 2011–2019 period because, first, it offers little fluctuation in terms of country classification by income, as indicated above, making the analyses less prone to potential variations due to that classification across years. Second, it encompasses the end period of FP7 through until after 2016, the year the SDGs came into force, thereby enabling the analysis of changes relative to the inception of the SDGs. To quantify yearly changes in the three-year running scores, the CAGR was estimated between the first three-year period (2011–2013) and the most recent period (2017–2019)[20]. The annual

[20] Note that the trends over a longer period, since 2002, are also shown in the histograms of Tables 2–7 on co-publication rates.

growth was also estimated over a much shorter period, with the entry into force of the SDGs (i.e. 2016) being used as the reference point. For instance, the CAGR was computed between 2014–2016 (taken as the start period) and 2017–2019 (i.e. the end period). This recent growth was compared to the annual growth that occurred during a previous time period preceding the start of the SDGs – that is, between 2011–2013 and 2014–2016.

3 Results

3.1 Global output and specialisation trends towards the Prosperity SDGs

GLOBAL OUTPUT

KEY FINDINGS

- The EU-27 was, as of 2019, contributing about 20 % to 25 % of the world's output in the Prosperity SDGs. During the last few years of the study period, its share of worldwide output decreased by about 5 % in SDG 7, SDG 8, SDG 9 and SDG 11. This decrease is mostly due to the strong growth of emerging countries such as China.
- As of 2019, the EU-27 was the second largest contributor in SDG 8, SDG 9 and SDG 11, and the third largest contributor in SDG 7, SDG 10 and SDG 16. The ERA region was leading or on the point of becoming the leader in five Prosperity SDGs (SDGs 8–11 and SDG 16).
- China was the leading contributor in SDG 7 and, if its annual growth remains unchanged in the coming years, it may also reach the leading position in SDG 9 and SDG 11.
- Despite the recent decline in Europe's share of world output in the Prosperity SDGs, its raw volume of scientific publications has been continuously growing in these areas.

In 2019, 337 240 papers were published worldwide on research topics pertaining to the Prosperity SDGs (SDGs 7–11 and SDG 16). Most of these publications covered SDG 7 on Energy, accounting for 45 % of the output in the Prosperity SDGs, for 18 % of publications across all SDGs (i.e. SDGs in the Prosperity, Planet and People thematics exclusive of SDG 17), and for 5 % of all publications in Scopus. The publication shares in the other SDGs were lower and are shown in Table 1.

The world's publication output grew gradually from 2002 to 2019 in all Prosperity SDGs (grey bars, Figure 2). The annual growth over the past two decades was the most prominent for SDG 7, with about 12 000 publications in 2002 and 151 000 in 2019, resulting in a CAGR of 16 %. The annual publication growth in the other SDGs was somewhat lower, with CAGRs ranging from 10 % to 12 %. Total output in 2019 reached roughly 60 000 publications for SDG 9 and SDG 11, and 35 000 for SDG 8, SDG 10 and SDG 16. As a reference point, overall growth in publication output in Scopus stood at 5 % annually over the same period.

Table 1 Share of publication output in each Prosperity SDG in 2019

SDGs	Themes	Share of publication output		
		relative to the Prosperity SDGs	relative to all 16 SDGs	relative to all Scopus output
SDG 7	Energy	44.7%	18.2%	5.2%
SDG 8	Economy	11.5%	4.7%	1.3%
SDG 9	Infrastucture	20.1%	8.2%	2.3%
SDG 10	Reduce inequality	10.5%	4.3%	1.2%
SDG 11	Cities	17.4%	7.1%	2.0%
SDG 16	Institutions	9.8%	4.0%	1.1%

Note: The share is the number of publications in each SDG divided by the output of all Prosperity SDGs (337 240 publications), the output of all 16 SDGs (827 445 publications, covering the Prosperity, Planet and People thematics), or the output of all Scopus publications (2 906 422). Some papers cover more than one SDG, which is why the sum of the shares of papers relative to the Prosperity thematic is above 100 %.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

At the level of geographical regions (or key comparator countries) contributing to worldwide publication output, major changes have occurred since 2002 (coloured lines in Figure 2). As of 2019, **the EU-27 generally contributed to about 20 % to 25 % of the world's output, being involved in roughly 68 700 publications across all Prosperity SDGs**, with Germany, Italy and Spain consistently standing among the top scientific contributors (which is consistent with the size of these countries). France, the Netherlands and Sweden were also among the top contributors in all SDGs (but not necessarily in that order), and Poland and Portugal were well placed in SDG 7, SDG 8, SDG 9 and SDG 11. Outside the EU-27 in Europe, the United Kingdom was the main ERA country involved in SDG-related publications, followed by a group of countries that included Norway, Switzerland and Turkey. Contributions from the United Kingdom, Germany, Italy and Spain accounted for about half of all ERA papers in 2019. ERA countries, as one group, roughly contributed to one third of all publications in each Prosperity SDG.

In the last two to three years of the study period, the EU-27 and ERA shares of world publication output generally declined by about 5 % each, primarily in SDG 7, SDG 8, SDG 9 and SDG 11. This was despite the continuous growth in the size of their publication outputs. SDG 7 was the only SDG where the EU-27 and ERA were overtaken by China; China also closed the gap to the EU-27 in SDG 11. This recent trend is in sharp contrast to the trend in the United States' share of world output in the same SDGs, which continuously dropped over the last two decades by about 5 % annually. The United States' output trend also dropped, but to a lesser extent (about 2 % annually), for SDG 10 and SDG 16. Although less influential in terms of world publication share, Japan has also lost ground over the years across all Prosperity SDGs. The most profound change in Japan's output is related to research covering SDG 7 on Energy, with a share of world output of 13 % in 2002 dropping to 3 % in 2019.

The gradual decrease in the share of world output for the United States and Japan, and more recently for the EU-27 and ERA, was contrasted by a concomitant increase in the shares of other countries. In particular, China gradually appeared as a key contributor to global output in the Prosperity SDGs, with the annual increase in its share of world output ranging from 6 % to 8 % except for SDG 10 (4 %). As a result, China's share experienced a two- to four-fold (typically a three-fold) increase from 2002 to 2019 across all Prosperity SDGs. By raw publication volume in the Prosperity SDGs, China is becoming a world leader in research related to SDG 7, surpassing the EU-27 and ERA, and is also performing strongly in research related to SDG 11 and SDG 9. In 2019, China caught up to the volume of output of the EU-27 in SDG 11. It is noticeable that, among the

comparators, South Korea contributed the least in all SDGs, with a share in 2019 of 4 % in SDG 7 and less than 2 % in the other SDGs.

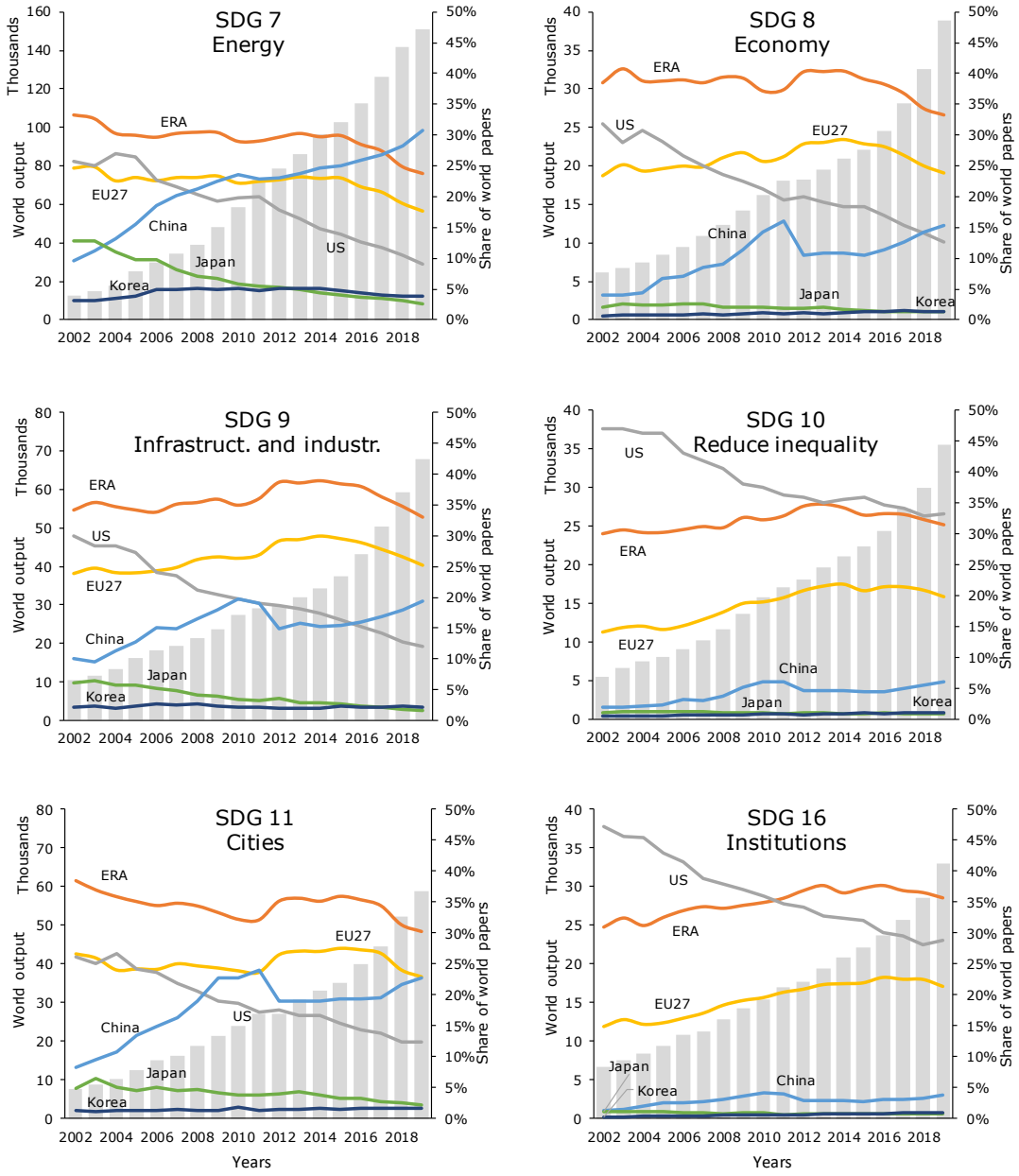


Figure 2 **World publication output and share of publications per region, by Prosperity SDG, 2002–2019**

Source: Computed by Science-Metrix using Scopus (Elsevier) data

SPECIALISATION

KEY FINDINGS

- Among the selected comparators, the EU-27 and ERA regions were the only ones to show stronger relative emphasis than the world in most Prosperity SDGs.
- Their SI was growing, and was near or above world level, in five out of six SDGs. Only in SDG 7, on Energy, the EU-27 and ERA were not specialised; the SI of the EU-27 was on par with world level in SDG 10. In contrast, Asian countries were generally not specialised in the Prosperity SDGs except for SDG 7.
- No clear shifts in the specialisation patterns of presented regions and countries were observed after the entry into force of the SDGs in 2016.

The SI of a country (or region) in a given research domain portrays how much emphasis this country allocates to research in that domain relative to the world's equivalent. **At the level of the EU-27 and ERA, there has been growing relative emphasis in research areas related to all Prosperity SDGs (apart from SDG 7) since 2002.** The SI of both regions generally increased from close to or below world level in 2002 to above world level in 2019 (Figure 3). This specialisation pattern is in sharp contrast with the selected comparators, especially those in Asia. The United States was the only other comparator specialised in at least two Prosperity SDGs in 2019. It was the country with the highest SI among the presented SDGs and comparators in research topics covering SDG 10 (Reduce inequality) and SDG 16 (Institutions); its SI was about twice the world level in both cases. Like both the EU-27/ERA regions, the specialisation of the United States was weakest in SDG 7, standing below world level.

In Asia, China and South Korea were well above world level for specialisation in SDG 7, while they maintained a low degree of specialisation in the other research areas. Despite its lack of specialisation in SDG 8, SDG 9, SDG 10, SDG 11 and SDG 16, China remained a major research contributor, by volume of output, in SDG 8, SDG 9 and SDG 11. Although Japan was initially specialised in SDG 7, this was no longer the case in 2019, and its SI was well below the world level in all other SDGs. Overall, these results reflect a general trend in that western countries, relative to Asia, put more emphasis on the natural and social sciences, and less so on the applied sciences. However, it is important to recall that current databases of peer-reviewed scientific literature do not provide a full account of worldwide research, especially research published in Asia (Rousseau, 2015). Accordingly, it is possible that these broad differences between the specialisation patterns of western and Asian countries are biased.

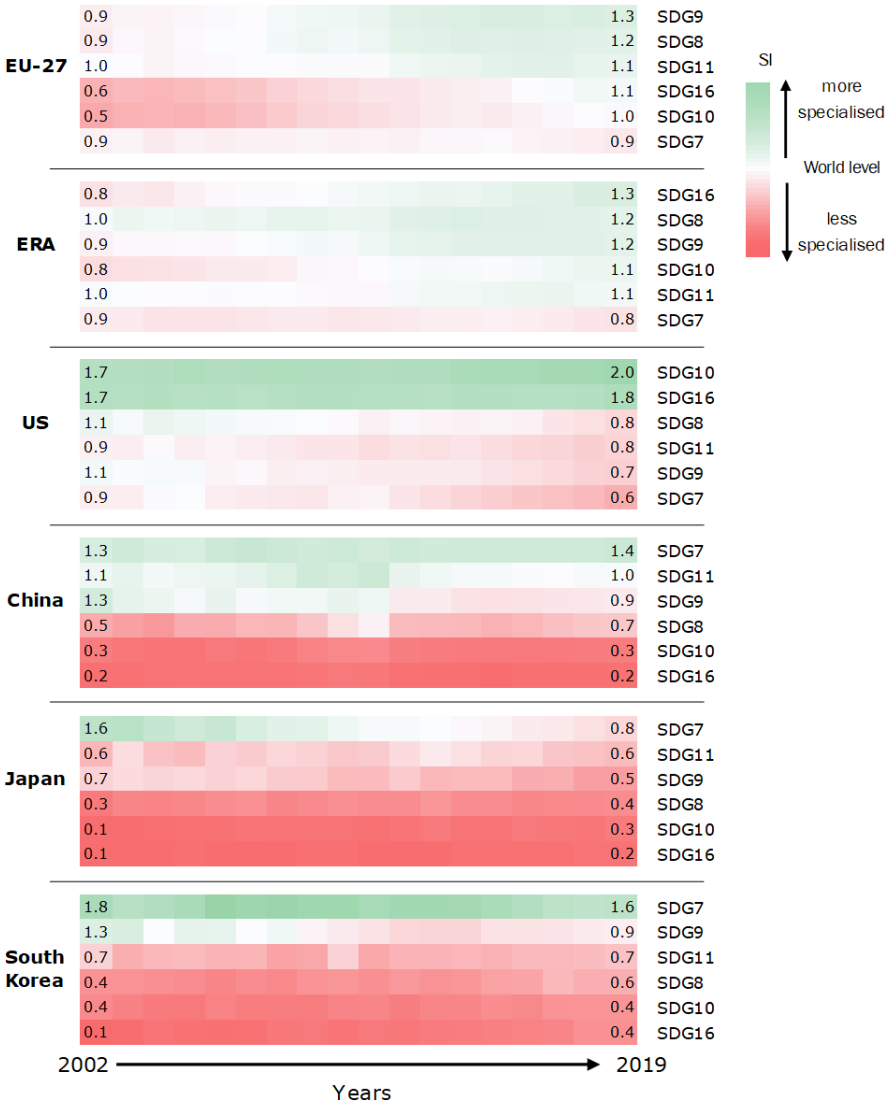


Figure 3 Specialisation trends across the Prosperity SDGs per region, 2002–2019

Note: The SI is indexed to 1.0, which represents no change relative to world level. Numbers in each heat map represent SI scores for 2002 and 2019. The scores are coloured from red (below index level) to white (at index level) to green (above index level).

Source: Computed by Science-Metrix using Scopus (Elsevier) data

It is noteworthy that differences in specialisations between SDGs and countries may also reflect, to some extent, differences in international collaboration patterns. Countries may be less specialised in those SDGs where the propensity for international collaboration is highest since their joint contribution will reduce the size of their respective contribution; in other words, because a country's publication output is determined in fractional counting, its relative share of publications will be smaller in the fields in which it has the most international collaborations. Thus, the most collaborative countries in a given SDG may score lower in SI, or reduce their specialisation lead, compared to the least collaborative countries. This relationship is mainly observed at the level of individual countries rather than regions (see Section 3.2).

3.2 International co-publication trends towards the Prosperity SDGs along the high- and low-income dimensions

KEY FINDINGS

- Given the much larger research output of high-income versus low-income economies, the collaboration rate of all presented regions/countries was much higher with the former group than with the latter in the Prosperity SDGs.
- During the period 2017–2019, the EU-27 and ERA co-published about 40 % to 50 % of their output with high-income countries, and about 4 % to 7 % with low-income countries. Of interest, the growth of their collaboration rates over the past decade was systematically larger with the low-income group.
- While the EU-27 and ERA were relatively well placed for the share of their output co-published with low-income countries, they experienced a growth in co-publication rates considerably smaller than China's growth on this dimension.
- A similar pattern is observed for collaboration with high-income countries, but with smaller gaps to the growth rates of other large scientific contributors such as the United States and China. If these trends remain unchanged, the findings suggest that the placement of the EU-27/ERA as of 2017–2019 could shift to fall behind other global research leaders in the coming decade, especially China.

Since 2002, the degree of international collaboration in scientific publications has been growing for EU-27 countries (Figure 4, right panel), with the bulk of these collaborations involving high-income countries (Figure 4, left panel). During the most recent period (2017–2019), roughly 40 % to 50 % of the EU-27 publications in topics covering the Prosperity SDGs were co-published with high-income countries (which include inter-European co-publications). These co-publications predominantly involved collaborations with the United States and China, as well as larger European countries, such as Germany, the United Kingdom, France, Spain, Italy and the Netherlands (data not shown).

From the period 2011–2013 to the period 2017–2019, the average international co-publication shares of EU-27 countries with high-income countries was increasing, with the fastest annual growth in SDG 16 (CAGR of 4.8 %) (Figure 4, blue bars, right panel). It was followed by research covering SDG 8 and SDG 11 with a CAGR of about 3.8 %, SDG 9 and SDG 10 with about 3.4 % growth, and finally SDG 7 with 2.8 % growth.

Conversely, the EU-27 collaborated with low-income countries on less than 6.5 % of its publications, on average (Figure 4, left panel). Of particular interest, **the rate of co-publication between EU-27 countries and low-income countries over the past decade has been increasing more sharply than with high-income countries in all research topics covering the Prosperity SDGs**, with a CAGR of 11 % for SDG 7 and between 6.3 % to 8.9 % in the other SDGs (Figure 4, right panel)[21]. This pattern is largely due to an increase in the proportion of new, low-income countries active in SDG research (from 60 countries on average in the period 2011–2013 to about 70 countries in 2017–2019), as well as to an increase in the intensity of co-publication links between EU-

[21] Given the lower collaboration rates with low- compared to high-income countries, a small increase between two periods would naturally result in a larger annual growth with the former group. Nonetheless, these trends indicate positive changes in co-publication activities with low-income countries.

27 countries and developing countries, with India playing a predominant role in all SDGs (data not shown). It is noteworthy that the growth in co-publication rates between EU-27 countries and low-income countries – for SDG 7, SDG 11 and SDG 16 – has been particularly boosted since the SDGs came into force in 2016. The CAGR for co-publications with low-income countries increased by a factor of about 1.8 for SDG 7, by a factor of 3 for SDG 16 and 5 for SDG 11, from before to after the entry into force of the SDGs[22]. These trends may suggest that SDG 17 had a positive influence on enhancing international cooperation with low-income economies in performing research for SDG 7, SDG 11 and SDG 16. However, it is important to consider that a longer time period is required to reliably measure the influence of SDG policies on scientific co-publications.

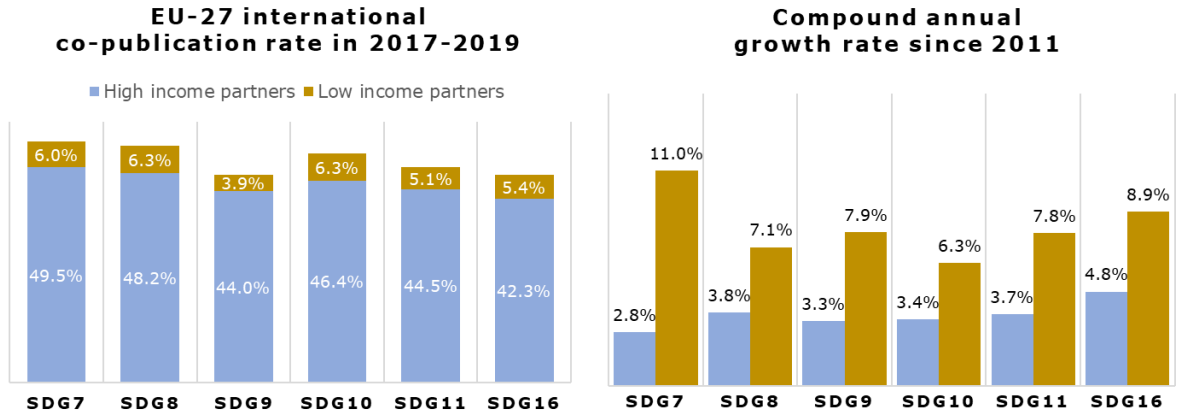


Figure 4 International co-publication rates between the EU-27 and high- and low-income countries, as well as their annual growth, by Prosperity SDG

Note: The CAGR estimates the annual growth between the period 2011–2013 and the period 2017–2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

The average international collaboration patterns of ERA countries appeared similar to those of the EU-27, in terms of both the share and the annual growth of co-publications with high- and low-income countries (see Table 4 to Table 9). This is expected since EU-27 countries account for most of the ERA's publication output (see Figure 2).

In terms of co-publication rates, both the United States and Japan co-published with high-income countries on around 35 % to 45 % of their papers covering all SDGs in 2017–2019, with the notable exceptions of the United States for SDG 10 (Reduce inequality, Table 5) and SDG 16 (Institutions, Table 7). In these SDGs, only 20 % of the US papers were internationally co-authored with high-income countries. The international co-publication rates of China with high-income countries yielded a somewhat opposite pattern to the United States, with research pertaining to SDG 10 on Reduce inequality and SDG 16 on Institutions involving more collaborations (about 35 %) than research related to the other SDGs (about 25 %). However, the growth in China's co-publication rates over the past decade has been similar to that of the United States and Japan. All three countries displayed a noticeable increase in the number of co-publications with high-income countries beginning in the period 2011–2013, with a CAGR of about 5 % to 8 % in four of the SDGs (SDG 7, SDG 8, SDG 9 and SDG 11; Table 2 to Table 4, and

[22] The potential influence of SDG-related policies on international cooperation was explored by comparing the CAGRs of co-publications relative to the time the SDGs came into action in 2016. The CAGR before the 'SDG epoch' was determined using 2011–2013 as the starting period and 2014–2016 as the ending period. The CAGR during the 'SDG epoch' was determined using 2014–2016 as a starting period and 2017–2019 as the ending period.

Table 6). The growth rate in all these SDGs was higher than that observed for EU-27 or ERA countries. For SDG 10 (Table 5) and SDG 16 (Table 7), the growth rate in the co-publication rates of the United States and China with high-income economies was similar to that of the ERA region, while that of Japan was smaller

South Korea, compared to China, was proportionately involved in a similar or higher number of international collaborations with high-income countries in 2017–2019. However, its co-publication rates since 2011–2013 have only been increasing by about 3.7 % for SDG 7 and SDG 11, while they remained stable for SDG 8, SDG 9 and SDG 10, and even declined for SDG 16.

Japan generally exhibited the highest degree of co-publication with low-income countries in the most recent period (2017–2019). It only fell behind South Korea in SDG 7. South Korea generally followed in second place, sometimes only slightly above (SDG 9, SDG 10, SDG 11) or below (SDG 8) the ERA, which also ranked second in SDG 7 and SDG 16. China was ranked last except for SDG 10 and SDG 16, in which it performed slightly better than the United States.

Despite the relatively good placement of the EU-27/ERA along the collaboration dimension in the Prosperity SDGs with low-income countries compared to the United States and China, it did not exhibit the fastest growth over the years. The fastest growth was observed for China (between 17 % and 25 %)[23]. While all selected countries experienced a stronger growth rate than the EU-27/ERA for SDG 7, the United States and South Korea also exhibited a notably higher growth rate for SDG 16, as did Japan for SDG 9. If these trends remain unchanged, the slower pace at which the EU-27's (and ERA's) propensity to partner with low-income economies has been increasing in the context of the Prosperity SDGs indicates that its placement as of 2017–2019 could be threatened by other global research leaders (especially by China). Despite this, the collaboration rates of the EU-27 and ERA with low-income countries still grew faster than with high-income countries, which suggests a tendency, in all SDGs, to increasingly integrate the EU-27's and ERA's efforts for the Prosperity SDGs with those of low-income countries.

[23] Note that China's co-publication share with low-income countries was very low in the period 2011–2013, which explains why its growth appears outstanding compared to other countries.

Table 2 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 7 on Energy, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	32.1%	40.6%	4.0%	
ERA	Global	44.0%	53.6%	3.3%	
	High income	42.4%	50.6%	3.0%	
	Low income	3.1%	6.1%	11.7%	
EU-27	Global	43.8%	52.6%	3.1%	
	High income	42.1%	49.5%	2.8%	
	Low income	3.2%	6.0%	11.0%	
US	Global	28.0%	45.6%	8.5%	
	High income	26.8%	43.2%	8.3%	
	Low income	1.8%	4.2%	15.1%	
China	Global	16.1%	24.4%	7.3%	
	High income	15.8%	23.4%	6.8%	
	Low income	0.5%	1.9%	25.0%	
Japan	Global	24.7%	36.7%	6.8%	
	High income	22.9%	33.1%	6.3%	
	Low income	2.7%	5.7%	13.2%	
South Korea	Global	24.1%	30.1%	3.8%	
	High income	22.1%	25.3%	2.3%	
	Low income	2.9%	7.7%	17.5%	

Note: The green colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR. CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

Table 3 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 8 on Economy, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	36.6%	44.9%	3.5%	
ERA	Global	41.3%	52.0%	3.9%	
	High income	39.4%	49.4%	3.9%	
	Low income	4.5%	6.9%	7.5%	
EU-27	Global	40.4%	50.5%	3.8%	
	High income	38.6%	48.2%	3.8%	
	Low income	4.2%	6.3%	7.1%	
US	Global	31.0%	41.2%	4.9%	
	High income	28.5%	37.9%	4.9%	
	Low income	4.0%	6.6%	8.6%	
China	Global	20.2%	30.0%	6.8%	
	High income	19.7%	27.3%	5.7%	
	Low income	1.2%	4.7%	24.8%	
Japan	Global	34.7%	46.7%	5.1%	
	High income	29.9%	39.6%	4.8%	
	Low income	8.0%	12.2%	7.2%	
South Korea	Global	39.8%	40.1%	0.1%	
	High income	36.4%	37.2%	0.4%	
	Low income	5.7%	6.6%	2.3%	

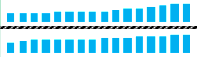
Note: The green colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR. CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

Table 4 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 9 on Infrastructure, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	31.6%	39.8%	3.9%	
ERA	Global	38.7%	47.8%	3.6%	
	High income	37.4%	45.9%	3.5%	
	Low income	2.6%	4.1%	8.4%	
EU-27	Global	37.5%	45.8%	3.4%	
	High income	36.2%	44.0%	3.3%	
	Low income	2.4%	3.9%	7.9%	
US	Global	26.5%	37.6%	6.0%	
	High income	25.0%	35.5%	6.1%	
	Low income	2.3%	3.6%	7.9%	
China	Global	16.1%	26.3%	8.5%	
	High income	15.8%	25.1%	8.1%	
	Low income	0.6%	2.3%	24.5%	
Japan	Global	25.4%	36.9%	6.4%	
	High income	24.0%	33.4%	5.6%	
	Low income	2.2%	5.8%	17.3%	
South Korea	Global	29.0%	30.2%	0.7%	
	High income	26.4%	26.8%	0.3%	
	Low income	3.5%	5.6%	8.5%	

Note: The green colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR. CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

Table 5 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 10 on Reduce inequality, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	32.0%	40.1%	3.9%	
ERA	Global	39.1%	49.1%	3.9%	
	High income	37.1%	46.9%	4.0%	
	Low income	4.8%	7.2%	7.1%	
EU-27	Global	39.8%	48.3%	3.3%	
	High income	38.0%	46.4%	3.4%	
	Low income	4.4%	6.3%	6.3%	
US	Global	17.7%	21.7%	3.5%	
	High income	16.1%	19.9%	3.5%	
	Low income	2.5%	3.7%	6.7%	
China	Global	29.7%	38.4%	4.4%	
	High income	29.1%	36.3%	3.7%	
	Low income	1.7%	4.6%	17.5%	
Japan	Global	37.7%	44.9%	3.0%	
	High income	33.7%	38.4%	2.2%	
	Low income	7.8%	11.4%	6.6%	
South Korea	Global	41.9%	40.3%	-0.6%	
	High income	38.3%	37.3%	-0.4%	
	Low income	5.8%	7.3%	3.7%	

Note: The colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR (green represents an increase and red a decrease). CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

Table 6 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 11 on Cities, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	32.0%	41.1%	4.3%	
ERA	Global	38.6%	48.6%	3.9%	
	High income	36.7%	46.2%	3.9%	
	Low income	3.4%	5.4%	8.3%	
EU-27	Global	37.7%	46.7%	3.6%	
	High income	35.9%	44.5%	3.7%	
	Low income	3.2%	5.1%	7.8%	
US	Global	29.1%	42.1%	6.3%	
	High income	27.1%	39.7%	6.5%	
	Low income	3.1%	4.5%	6.7%	
China	Global	16.0%	26.4%	8.8%	
	High income	15.7%	25.3%	8.3%	
	Low income	0.6%	2.2%	25.4%	
Japan	Global	26.6%	40.1%	7.1%	
	High income	23.3%	34.3%	6.7%	
	Low income	5.0%	9.0%	10.5%	
South Korea	Global	28.9%	35.5%	3.5%	
	High income	25.7%	32.0%	3.7%	
	Low income	4.6%	7.1%	7.8%	

Note: The green colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR. CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

Table 7 **International co-publication trends of regions across the global, high–high and high–low income dimensions for SDG 16 on Institutions, 2002–2019**

Region	Partners	2011 to 2013	2017 to 2019	CAGR	Trend since 2002
World	--	27.6%	37.3%	5.1%	
ERA	Global	31.6%	43.1%	5.3%	
	High income	30.2%	41.3%	5.4%	
	Low income	3.5%	6.0%	9.4%	
EU-27	Global	33.2%	43.9%	4.7%	
	High income	31.9%	42.3%	4.8%	
	Low income	3.2%	5.4%	8.9%	
US	Global	16.4%	22.6%	5.5%	
	High income	15.0%	20.3%	5.2%	
	Low income	2.3%	4.3%	11.0%	
China	Global	24.7%	37.1%	7.0%	
	High income	24.3%	34.8%	6.2%	
	Low income	1.4%	5.2%	25.0%	
Japan	Global	36.4%	38.1%	0.8%	
	High income	31.8%	34.4%	1.3%	
	Low income	8.1%	9.1%	2.0%	
South Korea	Global	38.2%	35.4%	-1.3%	
	High income	38.2%	33.2%	-2.3%	
	Low income	0.7%	4.4%	35.9%	

Note: The colouring scale highlights the degree of co-publication between each region and income partner, as well as the intensity of the CAGR (green represents an increase and red a decrease). CAGRs were calculated between the period 2011–2013 and the period 2017–2019. The histograms show the data from 2002 to 2019.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

TOP EUROPEAN CONTRIBUTORS

Among the 10 largest EU scientific contributors to the Prosperity SDGs output (see Table 8), France systematically had the highest share of co-publications (number of co-publications / total output) with low-income countries over the most recent period (2017–2019), except in SDG 16 in which it stood second after Belgium. France had a co-publication share of about 12 % to 15 % in SDG 7 (Energy), SDG 8 (Economy), SDG 10 (Reduce inequality) and SDG 11 (Cities), and about 8 % to 9 % in SDG 9 (Infrastructure) and SDG 16 (Institutions). Belgium had the second highest co-publication share with low-income countries in SDGs 8–11, and the third highest, after Sweden, in SDG 7. During the same period, and among the 10 largest EU contributors to the Prosperity SDGs, Italy had among the lowest shares of co-publications with low-income countries in all six Prosperity SDGs, along with Spain in four SDGs (SDG 8–10 and SDG 16), the Netherlands in SDG 7, and Poland in SDG 11.

While the above analyses depict the proportion of publications that EU-27 countries co-authored with low-income countries (Table 8), , it does not indicate how inclusive these collaborations were across low-income economies. Table 9 depicts the the number of low-income countries and the Gini coefficients[24] of the distribution of co-publication links with low-income countries for the top EU-27 scientific contributors and the Prosperity SDGs.

[24] The Gini coefficient is a measure of statistical dispersion that is usually used to highlight inequalities in the income distribution of nations' residents. In the present context, the indicator is used to assess whether the distribution of the number of co-publications between a country and its low-income partners might be skewed towards a few partners driving most of the collaboration activities. In that case, the Gini coefficients will be close to 1.00, the maximum level of inequality. On the contrary, if all the values are equal in the distribution, the distribution will be uniform leading to a Gini coefficient of 0.

Table 8 Share and number of international co-publications of the top European scientific contributors and key comparators along the low-income dimension across the Prosperity SDGs, 2017–2019

Countries or regions	SDG7		SDG8		SDG9		SDG10		SDG11		SDG16	
	Share	# of co-pubs	Share	# of co-pubs	Share	# of co-pubs	Share	# of co-pubs	Share	# of co-pubs	Share	# of co-pubs
EU-27	**6.0%**		**6.3%**		**3.9%**		**6.3%**		**5.1%**		**5.4%**	
top contributors												
France	15.1%	1,918	12.8%	366	8.8%	507	11.7%	301	12.4%	574	7.8%	148
Sweden	7.7%	472	6.9%	135	4.2%	149	9.7%	166	7.6%	178	7.1%	125
Belgium	7.2%	246	11.9%	146	5.4%	101	11.6%	137	10.1%	164	11.5%	127
Portugal	5.6%	232	3.8%	55	3.3%	83	5.2%	45	4.0%	89	4.2%	39
Poland	5.5%	289	4.4%	79	4.3%	144	5.2%	40	2.2%	75	5.5%	39
Denmark	5.4%	278	7.1%	79	5.1%	97	7.3%	69	5.3%	60	6.7%	64
Finland	5.4%	172	6.5%	69	3.7%	71	5.2%	40	5.5%	62	5.5%	49
Spain	4.9%	579	3.5%	151	2.3%	145	2.6%	85	3.0%	182	2.1%	79
Austria	4.8%	133	5.9%	59	3.1%	61	4.1%	28	7.2%	93	5.5%	40
Germany	4.0%	899	8.1%	422	3.0%	353	5.6%	247	6.4%	389	5.0%	190
Italy	3.7%	578	3.5%	162	2.2%	208	3.7%	117	2.5%	249	3.0%	90
Netherlands	3.5%	187	10.5%	264	4.8%	166	8.5%	205	6.0%	213	7.3%	200
ERA	**6.1%**		**6.9%**		**4.1%**		**7.2%**		**5.4%**		**6.0%**	
Top contributors												
Norway	8.8%	265	7.9%	91	3.1%	54	8.1%	89	6.1%	73	8.3%	102
United Kingdom	7.7%	1,585	9.3%	786	6.2%	749	9.2%	953	7.6%	749	6.5%	735
Turkey	5.6%	312	7.3%	100	3.0%	68	5.0%	43	2.8%	61	3.3%	29
Switzerland	3.2%	156	9.8%	144	4.7%	110	13.9%	214	7.7%	142	13.1%	171
Key comparators												
South Korea	7.7%	1,480	6.6%	120	5.6%	266	7.3%	91	7.1%	222	4.4%	45
Japan	5.7%	920	12.2%	222	5.8%	243	11.4%	127	9.0%	434	9.1%	71
United States	4.2%	2,531	6.6%	1,193	3.6%	1,059	3.7%	1,288	4.5%	1,211	4.3%	1,213
China	1.9%	2,585	4.7%	759	2.3%	847	4.6%	295	2.2%	813	5.2%	191

Note: The share of co-publications is the number of international co-publications divided by the total output (determined by full counting). The shares for the EU-27 (or ERA) region are computed as weighted averages across all EU-27 (or ERA) countries. Only the top 10 EU-27 scientific contributors, considered for each SDG separately, and the top 4 ERA countries that are not part of the EU-27, are shown. The green colouring scale highlights the degree of co-publication share. The data are sorted according to the highest score in SDG 7.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

In 2019, France and Germany were consistently among the top 3 EU-27 countries having the largest diversity of low-income country collaborations in all Prosperity SDGs (see Table 9). Italy completed the top 3 in SDG 7 and SDG 11, the Netherlands in SDG 8 and SDG 9, Sweden in SDG 10 and Spain in SDG 16. Among the largest ERA countries not included in the EU-27, the United Kingdom and Switzerland scored close to or above the top 2 EU-27 countries for the diversity of the low-income countries they collaborated with. Other EU-27 countries also had a fairly diverse set of low-income country collaborations, as depicted in Table 9.

These results, combined with those presented above, indicate that, compared to other EU-27 countries, France had both a large diversity of low-income country partners (Table 9) in all SDGs and a high share of co-publications with these countries (Table 8). Sweden and Belgium also exhibited such a relationship, while Italy and Germany, and to a lesser extent Spain (mainly in SDG 16), exhibited the opposite – that is, a large diversity of collaborating countries but a lower proportion of co-publications relative to their output volume in the Prosperity SDGs. The United Kingdom and Switzerland, two ERA countries not part of the EU-27, scored well from both perspectives, although less so based on share of co-publications with low-income countries than in terms of diversity of low-income country partners.

Among international comparators, the United States collaborated with a more diverse pool of low-income countries (between 55 and 70 countries) than any individual EU-27 country in all Prosperity SDGs, while China did so in SDGs 7–9 (between 44 and 50

countries) (see Table 9). Japan and South Korea had fewer low-income collaborators than the United States, China and the top EU collaborators, but the diversity of their partners was comparable to several of the top 10 EU scientific contributors. The United States and China also stood out as having some of the most uneven distributions of co-publications across low-income countries across the Prosperity SDGs: a pattern similar to countries having the largest number of low-income country partners.

Table 9 Diversity of collaborations between top European scientific contributors and key comparators along the low-income dimension across the Prosperity SDGs, 2017–2019

	SDG7		SDG8		SDG9		SDG10		SDG11		SDG16	
Top scientific contributors	# of partners	Gini	# of partners	Gini	# of partners	Gini	# of partners	Gini	# of partners	Gini	# of partners	Gini
EU-27												
France	47	0.83	45	0.61	43	0.76	63	0.53	58	0.72	57	0.45
Germany	45	0.76	53	0.62	41	0.68	62	0.54	51	0.60	56	0.55
Italy	38	0.72	42	0.52	36	0.64	49	0.45	51	0.60	49	0.44
Sweden	37	0.72	42	0.51	29	0.57	57	0.51	46	0.55	51	0.50
Belgium	35	0.62	41	0.56	36	0.51	53	0.42	45	0.50	52	0.46
Netherlands	35	0.63	46	0.58	39	0.55	52	0.55	49	0.57	53	0.48
Spain	33	0.76	38	0.54	30	0.61	52	0.46	49	0.59	55	0.48
Denmark	25	0.74	36	0.48	18	0.69	47	0.44	46	0.48	46	0.41
Poland	24	0.82	25	0.63	17	0.74	41	0.43	43	0.56	41	0.39
Portugal	24	0.64	39	0.40	22	0.59	47	0.41	43	0.49	47	0.41
Austria	23	0.62	28	0.46	20	0.60	39	0.33	44	0.51	43	0.35
Finland	22	0.64	32	0.48	18	0.54	39	0.37	44	0.47	42	0.38
ERA												
United Kingdom	51	0.80	63	0.69	45	0.72	69	0.66	59	0.70	65	0.62
Switzerland	28	0.69	51	0.52	45	0.51	60	0.48	55	0.48	61	0.48
Norway	27	0.71	30	0.53	18	0.55	48	0.45	45	0.50	51	0.49
Turkey	24	0.71	24	0.63	18	0.58	40	0.39	43	0.53	41	0.36
Key comparators												
United States	56	0.84	67	0.71	55	0.76	70	0.66	65	0.73	69	0.64
China	50	0.85	49	0.77	44	0.81	51	0.62	54	0.73	49	0.54
Japan	39	0.81	38	0.65	31	0.66	44	0.48	45	0.68	44	0.42
South Korea	30	0.86	25	0.62	20	0.76	48	0.45	39	0.73	43	0.39

Note: Only the top 10 EU-27 scientific contributors, considered for each SDG separately, and the top 4 ERA countries that are not part of EU-27, are shown. The green colouring scale highlights the degree of collaboration diversity. The data are sorted according to the highest score in SDG 7.
Source: Computed by Science-Metrix using Scopus (Elsevier) data

In general, the co-publication activities of EU-27 countries were not distributed evenly across the various low-income countries (see Gini coefficients in Table 9). This is to be expected since the production size of low-income countries is also skewed, with India being dominant. For instance, because India is a large scientific producer, it accounted for the largest share of co-publications with most of the top EU-27 contributors. Interestingly, the Gini coefficients of these EU countries were generally smaller in SDGs 16, 10 and 8 (Table 9). This is due in part to India's lead in publication volume, relative to the second most publishing low-income country, not being as large in these SDGs (especially compared to SDGs 7 and 9). In some cases, other factors such as cultural/colonial ties appeared to have contributed to the observed concentration of a country's co-publications with specific low-income countries. For example, France had strong links with French-speaking North African countries: Algeria, Tunisia and Morocco in SDG 7, SDG 9 and SDG 11, and Tunisia in SDG 8.

At the level of the EU-27, apart from India who was the leading low-income collaborator in all Prosperity SDGs, a few other low-income countries also stood out. The top 10 low-income countries with whom the EU-27 co-published the most in each SDG are listed in Table 10. Among them, Algeria was the 2nd highest collaborating partner with the EU-27

in SDG 7. Kenya was a common partner (ranked 2nd) in SDG 8, SDG 10 and SDG 16, while Ukraine and Vietnam were ranking 2nd in SDG 9 and SDG 11, respectively.

Table 10 Share of EU-27 co-publication with individual low-income countries across the Prosperity SDGs, 2017–2019

	SDG 7			SDG 8			SDG 9			SDG 10			SDG 11			SDG 16		
Low-income partners	Rk	EU-27 Share	Trend	Rk	EU-27 Share	Trend	Rk	EU-27 Share	Trend	Rk	EU-27 Share	Trend	Rk	EU-27 Share	Trend	Rk	EU-27 Share	Trend
India	1	1.47%		1	1.03%		1	1.06%		1	0.79%		1	0.84%		1	0.60%	
Algeria	2	0.76%		17	0.11%		7	0.22%		28	0.07%		4	0.37%		26	0.07%	
Tunisia	3	0.67%		9	0.25%		3	0.31%		10	0.25%		3	0.37%		20	0.10%	
Pakistan	4	0.55%		3	0.46%		4	0.31%		6	0.32%		6	0.32%		9	0.23%	
Morocco	5	0.52%		11	0.21%		8	0.21%		22	0.11%		5	0.34%		23	0.08%	
Egypt	6	0.49%		7	0.30%		5	0.27%		13	0.19%		7	0.30%		12	0.16%	
Ukraine	7	0.47%		4	0.46%		2	0.35%		9	0.25%		8	0.22%		8	0.24%	
Vietnam	8	0.34%		4	0.46%		6	0.25%		3	0.41%		2	0.39%		5	0.28%	
Bangladesh	9	0.11%		12	0.21%		12	0.08%		7	0.30%		10	0.15%		11	0.20%	
Ethiopia	10	0.09%		6	0.39%		9	0.12%		5	0.36%		9	0.17%		6	0.25%	
Ghana	11	0.06%		8	0.26%		11	0.09%		4	0.38%		12	0.13%		10	0.22%	
Nigeria	11	0.06%		13	0.18%		16	0.05%		8	0.26%		14	0.11%		6	0.25%	
Kenya	14	0.05%		2	0.53%		10	0.10%		2	0.42%		11	0.15%		2	0.45%	
Tanzania	15	0.04%		10	0.22%		13	0.07%		12	0.23%		16	0.10%		3	0.30%	
Uganda	24	0.02%		14	0.15%		17	0.05%		11	0.24%		21	0.06%		4	0.29%	

Note: Only the top 10 low-income collaborating countries, in each SDG, are shown. The green colouring scale highlights the degree of co-publication share. The data are sorted according to the highest share in SDG 7. As a reference, in 2017–2019 the EU-27 co-published with India on 1 422 (SDG 7), 308 (SDG 8), 579 (SDG 9), 180 (SDG 10), 373 (SDG 11) and 136 papers (SDG 16).

Source: Computed by Science-Metrix using Scopus (Elsevier) data

4 Conclusion

The analyses presented in this policy brief first examined the output and specialisation in research pertaining to the Prosperity SDGs across the EU-27, ERA and key comparators. Second, it aimed at addressing whether scientific research within the EU-27 has been increasingly aligned with SDG 17 targets on international Partnerships for the goals. A special emphasis was placed on North–South collaborations (here interpreted in terms of ties between high- and low-income countries) and the analyses were performed for each of the Prosperity SDGs. Here, we highlight key findings based on the evolution of publication patterns since 2002, and on collaborations with international partners based on their income level.

- **In 2019, the EU-27 generally contributed to about 20 % to 25 % of the world's output in the Prosperity SDGs. During the last couple of years, the EU-27's share of world output has slightly decreased overall, by about 5 % in SDG 7, SDG 8, SDG 9 and SDG 11.** This decrease was paralleled by an increase in China's share of world output, which has placed it as the top contributor in SDG 7 since 2018, above the ERA and EU-27. In addition, if these trends are maintained in the coming years, China may reach the EU-27's level of output in SDG 9, and even surpass it in SDG 11.

- **Except for SDG 7 on Energy, the EU-27 and ERA specialisation in the Prosperity SDGs has been increasing over the past two decades**, with values now standing near (only EU-27 in SDG 10) or above world level. Overall, the EU-27 has put more emphasis on research for these SDGs compared to China and South Korea, which were only specialised in SDG 7, and Japan, which was not specialised in any of the Prosperity SDGs. The EU's specialisation was also above that of the United States, except in SDG 10 and SDG 16, the only two Prosperity SDGs in which the United States was specialised, with values well above world level. No clear shift was observed in the specialisation patterns of presented regions and countries since the entry into force of the SDGs in 2016.

- Among the EU-27's and ERA's scientific publications, 40 % to 50 % were co-published in the last three years with high-income countries, while 4 % to 7 % involved low-income countries. Importantly, over the past decade, **the collaborations of the EU-27 and ERA with low-income countries have increased at a higher pace than those with high-income countries**, pointing to a general tendency, in all SDGs, to increasingly integrate the EU-27's and ERA's effort for the Prosperity SDGs with those of low-income countries. In addition, this integration appears to have been boosted since the SDGs were set in 2016, particularly for SDG 7, SDG 11 and SDG 16. However, caution must be taken before formalising this finding since it is based on a short time span of only since 2016. Moreover, the observed intensification of growth following the creation of the SDGs cannot be directly attributed to this event as other confounding factors could be at play and were not controlled for in the analysis.

- Progress on the collaboration rate of the EU-27 (and ERA) with low-income countries was generally comparable to that of the selected comparators, except for China, which experienced a considerable growth in co-publication rates during the past decade. If these trends remain unchanged, the findings indicate that in the coming decade the EU-27 and ERA could fall behind China for their intensity of collaborations with low-income countries in all Prosperity SDGs.

- Over the past decade, the EU-27, as well as the selected comparators, experienced an increase in co-publication activity and in the number of partners along the low-income dimension. Together with the previous findings, this highlights a growing inclusion of low-income countries in the international collaboration network for the SDGs.

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ANNEX

DATA SET CONSTRUCTION

For this policy brief, SDG-relevant publication data sets were constructed using a bottom-up approach, whereby data sets were first constructed by SDG target and then aggregated at the SDG level. Because some research topics covering the SDGs may be relevant to more than one SDG, some publications may therefore be also represented in more than one SDG. However, due to our bottom-up approach, which is built on specific research topics covering each SDG target (see below), the overall level of overlap was limited and did not exceed 10 % in most cases.

Building the seed data set for each target within an SDG: First, a brainstorming session took place for each SDG. Each session served to challenge the views of three analysts on the definition of each target within an SDG, this to reach a consensus on their interpretation in bibliometric terms. To ensure the highest standards of quality, the subsequent work of harvesting the literature of relevance to the agreed definitions was performed manually by analysts skilled in balancing both the recall and precision of bibliometric data sets. The first step in building a topical data set was to define a set of core terms and specialist journals whose specificity to the target at hand was very high. These terms and journals were then used to retrieve matching publications from the Scopus database to obtain a seed data set. This is often the most sensitive part of the process, as the core terms/specialist journals must be very precise and cover all pertinent aspects of the target. Where possible, this was achieved by an analyst familiar with the target at hand. Otherwise, the process was informed by a literature review, which was conducted as a complement to the above brainstorming sessions, thereby offering an elementary understanding of the target. The fact that at this stage targets were more specific than the overarching SDGs made this an easily approachable task. The papers returned by each query were then inspected to ensure high precision of the seed data set. Queries that returned proportionally too much noise were removed or limited by combination with supplementary terms. At this stage, precision was prioritised (aiming for at least 95 %) at the expense of recall, which remained low (< 60 %) in some cases. Precision is the percentage of relevant papers in a random sample of publications in the seed data set. Recall is the percentage of publications from the specialist journals that are captured by the selected search terms.

Expanding the seed data set for each target within an SDG: The seed data set was then expanded by broadening the keyword-based query. To simplify this step and all subsequent ones, a data set helper tool was developed. The tool first computed the term frequency–inverse document frequency (TF–IDF) of all noun phrases (extracted using a natural language processing algorithm) appearing in the papers of the seed data set, to ease the identification of additional relevant terms[25]. It also computed the number of additional publications each of these terms would add, to help prioritise the selection of additional terms towards increasing recall from the seed. The tool enabled tracking the precision of each search expression before its inclusion in the query. This was achieved by enabling analysts to rate the pertinence of individual papers within random samples of matching publications. The recall figure was continuously updated as the query was expanded. Recall sets other than the seed were also specified to test the recall. During the process, the tool computed the share of each journal's output appearing in the expanding data set. Using this information, analysts looked for journals that had a high share of papers included in the data set and analysed their scope to decide whether it would be worth adding them in full. Work continued until no more relevant terms or

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journals were worth adding, at which point recall was good (> 70 %) and precision was high (> 90 %).

Final verifications for the expanded data set for each target and merging into a final SDG data set: At this stage, further verifications were performed with the tool's help. The first involved looking for queries with a low contribution to recall yet a very high number of returned papers, as this is often the signature of a search expression that is off-topic or an indication that the seed or other reference data set is missing a portion of relevant research. Another verification was to look at the subfields of science[26] in which the papers were classified to identify those that could be related to off-topic papers. Finally, the recall was also measured for each journal appearing in the data set to search for potential biases across the subject matters of relevance to a given topic (i.e. some specialist journals having lower recall than others).

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The Key indicators for Research and Innovation project was a three-year project designed to support the development and implementation of the Commission's R&I policies with evidence at the EU, country and regional levels. As a result, 11 publications reflecting the work of the project were produced:

- The final study report makes a summary of the work done for each of the six work packages of the project;
- The final study approach report covers the methodology applied to collect and treat the data and the computation of the indicators;
- The ten policy briefs provide an in-depth analysis of different research questions with the aim of formulating policy recommendations in support of evidence-based policymaking.

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