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Working Paper Series

#2022-030

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Published 3 October 2022

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UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
UNU-MERIT

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Countries' research priorities in relation to the Sustainable Development Goals*

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Abstract

We analyse the extent to which countries' research priorities align with their greatest SDG challenges and whether misalignments are worse in certain SDGs. We develop a new method to identify research that is related to an SDG by examining research areas in WoS with a higher share of publications that contain text that is related to SDG policy outlets. Then, we use the SDG indicators to create a new score to assess the performance of countries in SDGs in relation to the top performers. We found that most research in the world focuses on issues unrelated to the SDGs and that, within SDG-related research, more than 90% is carried out in high and upper-middle income countries, where SDG challenges tend to be smaller. At the SDG level, our findings indicate a positive relation (alignment) between countries' research priorities and SDG challenges only for SDG1 (No poverty), SDG2 (Zero hunger), SDG6 (Clean water and sanitation) and SDG9 (Industry, innovation and infrastructure); meaning that countries with higher SDG challenges are relatively (or becoming) more involved in research related to those SDGs. For all other SDGs, we found a misalignment or inconclusive relationship between SDG challenges and research prioritisation. A particularly severe misalignment happens in SDG12 (Responsible consumption and production), where the countries that have the most unsustainable consumption/production patterns are high income countries that are not specialized in research related to SDG12.

Keywords: Science; SDGs; Research impact
JEL Codes: O33; O10

*We thank Agustina Colonna for invaluable research assistance. This paper has benefited from discussion with and suggestions by Valeria Arza, Rigas Arvanitis, Luis Bértola, Astra Bonini, Leslie Chan, Joanna Chataway, Maria Cortes-Puch, Enric Fuster, Oscar Goyeneche, Yaso Kunaratnam, Francesco Massucci, Claire Melamed, Irmgard Nübler, Ismael Ràfols, George Richardson, Miguel Sierra, Juergen Wastl, Patrick Wilson, seminar participants at the Foreign, Commonwealth and Development Office (FCDO), UK Collaborative on Development Research (UKCDR), Global Forum of Funders, and participants at the following conferences: EU-SPRI, International Conference on Scientometrics and Informetrics (ISSI), Concordi, Globelics, INET-OECD workshop. We gratefully acknowledge funding from the AHCRH/GCRF grant STRINGS – Steering Research and Innovation for the Global Goals (AH/S011501/1). All errors remain the responsibility of the authors.

1. Introduction

In recent years there is an increasing demand for science and research funding to be better aligned with societal challenges (Ciarli and Ràfols, 2019; Kuhlmann and Rip, 2018; Sarewitz and Pielke Jr., 2007). This shift has emerged since there is an increasing call for research funders and evaluation systems to prioritise concrete and pressing problems in society at large, alongside "scientific excellence" per se (Hicks et al., 2015). However, the capacity of science to meet societal challenges remains poorly understood.

Compared with conventional research evaluation approaches that assess research in terms of its "impact" or "excellence" via citation analysis or peer-review for example, the contribution of research to societal challenges is more complex and elusive. Societal challenges, such as the Sustainable Development Goals (SDGs), can be considered as "wicked problems" (Rittel and Webber, 1973) in the sense that there is no single solution to them. The research contributions that might help to solve a certain SDG target depend on the context and may need to combine diverse types of knowledge (e.g. interdisciplinary, transdisciplinary or indigenous).

Therefore, directing research priorities towards societal challenges is an exercise of developing research and problem-solving capacity related to certain themes (e.g. SDGs), and influencing the probability of generating solutions related to those themes by promoting interactions in the innovation system with actors that have that knowledge and capabilities related to those societal challenges.

Although the task of analysing the research priorities of countries in relation to their SDGs performance is highly challenging, these difficulties need not suppress ambitions or paralyse efforts. Given the urgency of the 2030 Agenda, and since funding resources are scarce and research funders need to make choices about the types of research they support, it is crucial to develop frameworks (as well as tools, datasets and methods) that allow for making informed choices and prioritising some research agendas over others.

In this paper, based on the notion that research capabilities are needed to address SDG challenges (see section 2), our core assumption is that a misalignment between a country's research priorities and its SDG challenges may reduce the efficacy of global investments in research to address sustainable development.

We operationalise the concept of "alignment" at three different levels: global, country and SDG. first, at the global level we compare the global production of SDG-related research in different country income groups in relation to their SDG challenges; second, at the country level, we compare to what extent the research done by the authors of specific countries is related to their country's major SDG challenges and; third, at the SDG-country level, we analyse if countries that face major SDG challenges produce more research than the average country related to that specific SDG.

By analysing (mis) alignments between the global production of research and the societal challenges related to the SDGs targets/indicators, we hope to help national policymakers and international donors in two crucial ways. First by providing examples of how certain countries are prioritising research areas (creating research capabilities) that are related (or not) to their main SDG challenges. Second to provide a global understanding of how misalignments between research priorities and SDG challenges might be worst in certain SDGs than in others. By analysing whether countries' research priorities align with their greatest SDG challenges, we are able to provide guidance that can help rebalance research priorities towards generating research capabilities to address countries' major challenges.

In the next section, we discuss the relevance of this paper, and how it may contribute to the discussion on research funding design and evaluation. Section 3 presents and discusses data and methods. Section 4 presents and discusses the main results, and Section 5 concludes.

2. Background

2.1. Steering research for the SDGs

Scientific research is a critical ingredient to develop knowledge-based economies, where knowledge is crucial to contribute to economic growth, but also to social well-being and solutions to address societal challenges. Without scientific capacity, the skills and capabilities available in a country are constrained, and therefore, the ability to absorb, adapt and develop new ideas and technologies is limited (Cohen and Levinthal, 1990; Radosevic and Yoruk, 2014).

However, the development of scientific capacity related to local societal challenges in a country is not sufficient, by itself, to solve those challenges. Research usually becomes significant through the complex interactions and feedback loops (Kline and Rosenberg, 1986) between many different players, including researchers, firms, local communities, and policymakers (Nelson, 1993). In the context of the SDGs, which include goals such as SDG1 (No poverty) or SDG5 (Gender equality), one cannot understand a challenge in a particular country without a profound understanding of its social and institutional context, and the different ways in which they are perceived. Many of the solutions that might help to solve these challenges are social and political, which go beyond scientific and technological advances alone (Kuhlmann and Rip, 2018). In this sense, SDGs can be considered as "wicked problems" which are societal challenges that are complex, unpredictable, and have poorly defined boundaries, while the so-called tame problems (e.g. engineering problems) are inherently different by resembling more typical scientific and technical problems (Rittel and Webber 1973).

Another distinctive aspect of challenges such as the SDGs is that they are broader in nature and require efforts/solutions that benefit from the combination of disparate types of knowledge. Consider, for example, SDG12 (Responsible consumption and production). It includes eleven targets related to sustainable management and efficient use of natural resources, reducing food waste, and environmentally sound management of chemical waste, among others. For each of its targets, one could think of a high number of disparate research trajectories that might contribute to this goal (e.g. research on materials engineering, life cycle assessment, circular economy, global value chains) knowing that some of them will contribute more to certain targets than others, and some will fail. This diversity suggests that public investment in research related to these challenges should keep a diverse portfolio of research strategies available (Jones, 2021; Wallace and Rafols, 2015), while also developing capabilities to confront novel challenges that are not predictable.

At the same time, we know that the main practical benefit of scientific research in a certain country is not the production of easily transmissible information, ideas and discoveries, but rather the construction of a problem-solving capacity, involving the transmission of often tacit knowledge through researchers mobility, training and face-to-face interactions (Pavitt, 1998). Similarly, the ability to operate technologies following ready-made manuals and information codified in academic publications may not lead to building capabilities across different parts of the society to innovate and address wicked problems (Bell and Pavitt, 1993). The benefits of research, therefore, tend to be geographically localized, meaning each country needs a pool of researchers who belong to international professional networks and exchange new scientific knowledge (Salter and Martin, 2001), and is connected to local users of the research. Even if knowledge from abroad can be used to solve national SDG challenges, by investing in research related to that SDG, national researchers will be in a better position to find different pathways to solve challenges and help translate and adapt that knowledge to the national context.

Because the type of research that contributes to meeting an SDG target depends on context and the complex interactions between national researchers and society, and given that relevant research capabilities are needed to develop solutions to address SDG targets, here we make the general assumption that a misalignment between a country's research priorities and its SDG challenges may reduce the effectiveness of investments in research to address those goals.

2.2. Identifying research related to the SDGs

Previous research on mapping SDG related research has applied different approaches. For example, Nakamura and Pendlebury (2019), focused only on papers specifically mentioning "sustainable development goal(s)" and their citing papers. Duran-Silva et al. (2019) used natural processing methods to enrich an initial set of terms per SDG, which was built by extracting relevant terms belonging to the UN official goals, targets and indicators. Then, they applied those enriched queries to tag textual records (e.g. publications, projects, etc.). Jayabalasingham et al. (2019) and Wastl et al. (2020), applied, instead, a combination of query-based approaches and machine learning methods to identify research related to SDGs in their specific indexing systems (Scopus and Dimensions, respectively). Bautista-Puig et al. (2021), alternatively, used queries of SDG related terms applied to clusters of publications generated by citation relations in Web of Science (WoS). A similar approach is also developed by us and allows to incorporate relevant SDG related publications that do not explicitly use a specific SDG query term in their abstract/title. It expands the initial sample of publications with SDG related terms by also incorporating publications that cite (or are cited by) that initial set.

Given the heterogeneity of approaches to map SDG related research, Armitage et al. (2020) compared two of them (Jayabalasingham et al., (2019) and the one developed by themselves) and found that country rankings can be very different depending on the approach that is used. Within query-based approaches, they found that the choice of terms, how they are combined, and the way that the query is structured influences substantially results and therefore caution should be made when interpreting them. This was expected since SDGs are broad and the research trajectories that might contribute to each one of them can be quite disparate.

In our approach we are as comprehensive as possible to identify research related to specific SDGs. We combine text from different types of documents to build our initial queries, then we enrich our queries with relevant terms from other approaches, next we apply our queries to clusters of publications (research areas) to expand the publications identified with "related" ones, and finally we perform several methodological robustness checks.

3. Approach

Our results have two main dimensions of analysis: revealed research priorities and SDG challenges. First, we calculate the revealed research priorities of countries in certain SDGs by using queries of SDG related terms applied to clusters of publications (research areas) in all WoS. Second, we create an indicator of SDG challenges by country by combining all available indicators used to measure SDGs targets. Below we describe in detail how we calculate each of the two indicators.

3.1. Measuring revealed research priorities by country in each SDG

We calculated the revealed research priorities of each country by using a comparative specialization index (Balassa, 1965) that allows us to measure whether a country's research is more or less specialized in a certain SDG than the world average (Ciarli and Ràfols, 2019; Confraria and Wang, 2020). Our approach to identifying research related to a specific SDG is based on a two-stage method developed by the authors. The first stage involves building a query with a set of terms (or combinations of terms) that are strongly associated with a specific SDG. Second, we apply those SDG-related queries to groups of publications (clusters or research areas) generated by citation relations between all WoS publications (Waltman & van Eck, 2012). These research areas (version 2020: 4013 clusters of publications) are built using 2000-2019 data, however, given that the SDGs were only established in 2015 (United Nations, 2015), most of our analysis covers data from 2015 to 2019.

Since these research areas are obtained from a publication-level clustering algorithm based on direct backwards and forward citations, the advantage of this approach is that these research areas can be seen as research communities that address (or are related to) a specific area/field. In comparison, an approach based only on queries simply identifies individual publications with a direct reference (query term) to the SDG, and excludes the academic community efforts that shouldered that piece of research. In practice, our approach allows us to include relevant publications that do not explicitly use SDG query terms in their abstract/title, for instance because they use a different language, or focus on an issue that was not explicitly mentioned in SDG policy reports and publications. For example, with reference to SDG3 (Good health and well-being), policy documents may refer to some tropical diseases, but not all of them. Our approach allows expanding the initial set of individual publications that are retrieved by queries (or machine learning approaches) to other publications that are in the same research area. Since research is cumulative and it is the communities/groups of researchers that can build knowledge to solve challenges (rather than an individual research output), we believe this approach is more adequate for retrieving research related to SDGs.

In the first stage, the methodology used to obtain a final list of keywords per SDG consists of a series of steps. In the first step, we selected texts from various sources that contained descriptions of specific SDGs. Instead of relying only on official UN sources to identify relevant terms, we chose to search a wide array of policy reports, grey literature, scientific publications, web forums and official UN sources. In this way, we aim to capture a broader understanding of SDGs that is shared in different types of publications and authors. We then extracted relevant fragments from these texts, which referred to a particular SDG and met a certain criterion.[1] This step allowed us

[1] These fragments must contain text referring specifically to at least one SDG. The text must refer to problems associated to the SDG(s), making a clear connection between the problems and Goal(s) (e.g. using the term

to exclude text content that is not SDG specific and text that is about more than one SDG. Once selected, we partitioned the text referring to an SDG in different entries, respecting the authors' different ideas. Afterwards, we selected relevant keywords within these pieces of text using a combination of Textrank and Vosviewer algorithms. Finally, we carried out a manual selection of the keywords extracted through these filters and shared these lists with other team members and experts to check for missing or irrelevant terms.

In the second stage, after validating all 16 SDG queries, we applied those queries to the CWTS WoS dataset, in a sub selection of publications from 2015-2019, to search clusters of publications (the research areas) strongly associated with each other by their backward and forward references. We use a classification system generated by Waltman and Van Eck (2012) at CWTS that separates all WoS in 4013 micro-clusters of publications (edition 2020). This level of granularity is arguably optimal for normalisation (Ruiz & Waltman, 2015) and to be described by automatic labels (topics) and hence the preferred level to be used in our study. Then we run our 16 SDG queries in all publications of those micro-clusters, which we will refer to as research areas in this paper, to check which of these have a high share of publications which include our SDG related text in their abstracts and titles. We then associated with a certain SDG all publications that belong to research areas that have a relatively high share of publications with a certain SDG query term. Given that the distribution of the shares of publications retrieved by the SDG query across research areas differ between SDGs, we defined two thresholds for each SDG:

1. Strict: the share of publications containing the SDG keywords over all publications in the research area that identifies only research areas that the authors considered related to the SDG and its targets, based on information contained in the labels[2] of the research area (main topics of the cluster) and on abstract information of a sample of most cited publications.
2. Loose: the share of publications containing the SDG keywords over all publications in the research area that identifies a relevant number of research areas the authors considered related to the SDG and its targets, among some research areas less clearly relevant, based on information contained in the labels of the research area (main topics of the cluster) and on abstract information of a sample of most cited publications.

After this first initial analysis of what research areas are associated to what SDGs, we compared our results with the results obtained using the publicly available queries from the SIRIS approach.[3] By checking the differences between selected research areas using the two approaches, this comparison allowed us to improve our:

- Recall (type II error, false negative), namely research areas that are associated with a certain SDG but were not included when using the initial approach (first stage).
- Precision (type I error, false positives), namely research areas that were associated with a certain SDG using our initial approach (first stage) but shouldn't.

"Sustainable Development Goal" in their analysis of the problem). References to "sustainability" alone were not considered sufficient for the document to be included. References to issues associated to the SDGs (e.g. poverty or hunger) but with no explicit mention of the SDGs were also not considered sufficient for the document to be included.

[2] The analysis of most frequent keywords from relevant clusters in both approaches was crucial to check differences and understand which terms retrieve which clusters.

[3] http://science4sdgs.sirisacademic.com/

After comparing our results using the two queries and changing some of our terms to improve recall and precision, we recalculate the loose and strict thresholds and use the final set of research areas per SDG to do our country analysis. In this paper, the results correspond to our loose thresholds to allow a wider understanding of SDG related research.[4] We ran a sensitivity analysis between the loose and strict thresholds and the correlation of results between the two is extremely high. Each SDG specific threshold can be provided upon request, and the platform[5] that we use to understand which publication researcher areas are associated with an SDG is openly available (Rafols et al., 2021)

The metrics for comparisons between countries are created based on address criteria (the organisation of the authors), using the fractional-counting method (publication counts are equally divided by the number of countries). We are aware that (co-)authorship is an imperfect measure of research capacity. Particularly in low-income countries (LICs), the involvement of researchers is often associated just with data collection and contextualisation of results (Boshoff, 2009; Morton et al., 2022), and meaningful capacity strengthening is most effectively delivered in an environment where there is equal contribution to the development of research questions and study design from all collaboration partners. However, this was the best indicator available for our global country comparison.

We only consider independent countries that have more than 500 publications in 2015-2019 because the relative specialisation across SDGs for countries with smaller number of publications is highly fluctuating. Revealed research priorities of countries by SDG are calculated using a comparative specialisation index (Balassa, 1965) that allows to compute if a country's research output is more or less specialised in a certain SDG than the world average (Ciarli and Ràfols, 2019; Confraria and Wang, 2020). The scientific research specialisation (*SI_Pub*) can be expressed as follows:

$$SI\_Pub_{cs} = \frac{P_{cs}/\sum_s P_{cs}}{P_s/\sum_s P_s} \qquad (1)$$

where P is the number of publications in country $\boldsymbol{c}$ in SDG $\boldsymbol{s}$. This index can be interpreted as a "revealed comparative advantage". If country $\boldsymbol{c}$ has a higher relative publication specialisation in SDG $\boldsymbol{s}$, it means that country $\boldsymbol{c}$ has more scientific research focused on SDG $\boldsymbol{s}$ than the world average ($SI\_Pub > 1$). The calculation of this index (1) implies that the values are necessarily null or positive but are not bound by an upper limit. For this reason, later we normalize the specialization level between -1 and 1, where 1 = high specialization; 0 = world average; and -1 = low specialization.

$$RCA_{cs} = \frac{(SI\_Pub_{cs} - 1)}{(SI\_Pub_{cs} + 1)} \qquad (2)$$

[4] As an example of the different coverage between thresholds, if we apply the strict threshold to SDG6 (Clean water and sanitation) we identify research areas mostly related to "life and earth sciences" (e.g. water footprint, sanitation, submarine groundwater discharge) and "physical sciences and engineering" (e.g. water distribution network, nanofiltration membrane, biosorption). If we apply the loose threshold, we identify all "strict" research areas plus other ones that also relate to "social science and humanities" (e.g. ecological footprint, disaster risk reduction) and "biomedical and health sciences" (e.g. norovirus, legionella).

[5] https://public.tableau.com/profile/ed.noyons#!/vizhome/UKStringsSDGtocommunities/Dashboard1

3.2. Measuring SDG challenges by country

To analyse the performance (challenges) of countries in different SDGs, we build a score per SDG that combines data from two different sources: i) UN SDG database; ii) SDG Index. We checked which indicators have fewer missing values for all countries and years of interest, and built a unique dataset with 80 different indicators. After compiling this dataset of indicators per SDG, we run a principal component analysis per SDG to obtain a single score by country/SDG for which data is available. We followed the next steps: First, for the selected indicators, we calculate the logarithm of those that are not percentages or indexes (e.g. per capita); then, we do a linear transformation, by converting each indicator/country to a score between 1 (Best) and 0 (Worst):

$$n_{cti} = \frac{Worst_{ti} - x_{cti}}{Worst_{ti} - Best_{ti}} \quad \text{c (country), t (period), i (indicator)} \quad (3)$$

We reverse some variables for consistency, forcing higher values to represent better results. After calculating 80 variables (between 0 and 1) for each country, for each variable, we compute the relative distance ($d_{cti} = p95_{ti} - n_{cti}$) of each indicator/country to the frontier of that indicator (top5% - percentile 95), and we changed all values below zero to zero. After this transformation, higher values represent worst results with respect to the SDG targets (higher challenges relative to countries at the frontier). Then, we calculate z-scores for each relative distance to the frontier (top5%).

$$z_{cti} = \frac{d_{cti} - \mu}{\sigma} \quad \mu \text{ (average)}, \sigma \text{ (std. deviation)} \quad (4)$$

Finally, we compute a principal component analysis (PCA) (Jackson, 1991) for each SDG with more than one indicator available, and we forced the PCA to estimate only one component per SDG (eigenvalues and eigenvectors can be provided upon request). We predict the scores of all SDGs for all countries and we normalised the results between -1 (High performance - 'frontier') and 1 (1 = Low performance).

Countries with a high SDG score are those furthest away from the 'frontier' in that specific SDG, meaning that those countries face a higher SDG challenge (or gap) in achieving that goal. Countries with a low score are those at the 'frontier' in that specific SDG. Since SDG scores are not size dependent, we can directly compare them to the revealed SDG research priorities.

3.3. Analytical approach

Our investigation is done at three different levels: global, country and SDG. One of the main contributions of our study is precisely related to the development of analytical methods at different levels, which allow to understand empirically the concept of "alignment" of countries' research priorities versus societal challenges (SDGs).

We start by comparing descriptively the proportion (global share) of SDG-related research produced by four income country groups (as classified by the World Bank) with the level of SDG challenges that they face on average. Our objective here is to have a general overview between SDG research priorities and SDG challenges in the globe and to provide evidence on whether, in absolute terms, countries that face higher SDG challenges are building the capabilities through academic research that may be used to address those challenges.

Second, we graphically compare the SDG research priorities measure of specific countries (and country groups) in relation to their major SDG challenges measures. Answering this question provides descriptive examples of how countries may assess and rebalance research priorities towards topics closer to countries' major challenges.

Third, to study whether SDG challenges in earlier years influence countries' the research agenda in later years (Ciarli and Ràfols, 2019; Confraria and Wang, 2020), we study at the SDG-country level if countries facing a major SDG challenge also prioritise more research related to that specific SDG. We use the same two indicators computed above and calculate country scores by SDG. We begin this analytical section by plotting the SDG revealed research priorities of countries in 2015–2019, versus the SDG challenges between 2008 and 2017, in order to maximize the number of observations (these are the time intervals for which we can calculate more data points for all countries/SDGs).

Then we use multiple regression analysis (OLS) to assess if the correlations previously identified hold when controlling for other factors, and to understand how changes in SDG challenges dynamically influence SDG research priorities. We ask three main research questions that correspond to the three equations below:

- RQ1: Are countries that score worst in a certain SDG specialized in research related to that SDG? (5)

- RQ2: Do countries that score worst in a certain SDG tend to change their specialization towards research related to that SDG? (6)

- RQ3: Is a change in SDG scores associated to a change in SDG research specialisation? (7)

To avoid endogeneity issues in our regression analysis, our dependent variable will be the SDG revealed research priorities of countries in 2018–2019 and our main independent variable the SDG scores of countries in 2013-2017.

First, we estimate the static, cross country, relation between research specialization by SDG-country in 2018-2019, and the past SDG Score (2013-2017), controlling for previous research specialization (2013-2014) due to the path-dependant nature of scientific production:

$$RCA_{c,s,t} = \alpha + \beta_1 RCA_{c,s,t-1} + \beta_2 I_{c,s,t-1} + \varepsilon_{c,s,t} \quad (5)$$

Where $RCA_{c,s,t}$ is the relative specialisation (revealed research priority) of country *c*, in SDG *s*, in period *t*=2018-2019; $RCA_{c,s,t-1}$ is the same index for period t-1=2013-2014; $I_{c,s,t-1}$ the SDG score (challenge, between -1 and 1) for country *c*, in SDG *s*, in period *t*=2013-2017; $\varepsilon_{c,s,t}$ is the error term.

Second, we estimate the relation between the difference between research specialization by SDG-country in 2018-2019 and research specialization by SDG-country in 2013-2014, and the past SDG Score (2008-2012), controlling for research capacity (the number of publications per capita in a specific SDG-Country (2013-2014)):

$$\Delta RCA_{c,s,t} = \alpha + \beta_1 PUBS_{c,s,t-1} + \beta_2 I_{c,s,t-1} + \varepsilon_{c,s,t} \quad (6)$$

Where $\Delta RCA_{c,s,t}$ is the difference in relative specialisation (revealed research priority) of country *c*, in SDG *s*, between 2018-2019 and 2013-2014; $PUBS_{c,s,t-1}$ is the number of publications per capita in SDG *s* in t-1=2013-2014; $I_{c,s,t-1}$ the SDG score (challenge, between -1 and 1) for country *c*, in SDG *s*, in period *t*=2008-2012.

Third, we estimate the relation between the difference between research specialization by SDG-country in 2018-2019 and research specialization by SDG-country in 2013-2014, and the difference in the SDG score between 2013-2017 and 2008-2012, controlling for research capacity (the number of publications per capita in a specific SDG-Country (2013-2014)):

$$\Delta RCA_{c,s,t} = \alpha + \beta_1 PUBS_{c,s,t-1} + \beta_2 \Delta I_{c,s,t-1} + \varepsilon_{c,s,t} \quad (7)$$

Where $\Delta I_{c,s,t-1}$ the difference in the SDG score (challenge, between -1 and 1) for country *c*, in SDG *s*, between 2013-2017 and 2008-2012.

4. Results

According to our approach (using the loose threshold), around 50% of all research in WoS is related to at least one SDG during 2015-2019.[6] Most SDG related research is associated with SDG3 (Good health and well-being) (~33%), and the SDG with the smallest share of research associated with it (~1%) is SDG1 (No poverty). An important aspect worth noting before we dive into our analysis is that our results depend greatly on the threshold used (please see Fig A.1.). For example, the amount of research related to SDG1 while using the loose threshold is more than 15 times higher than while using the strict threshold. In SDG3, SDG7 (Affordable and clean energy) and SDG15 (Life on land) the differences are not that large (< 2 times). This finding relates to the idea that there is a variety of understandings regarding the connection between research and SDGs, and this might change across SDGs (Armitage et al., 2020). In all our remaining analyses in this paper, we will only present results using the loose threshold to allow a broader understanding of what is SDG related research.

4.1 Global relations between SDG challenges and research production per income group

We start by analysing the relation between our SDG score and the proportion of SDG related research produced in different country income groups by SDG. The main result from Figure 1 is that while LICs and lower-middle income countries (LMICs) score worst in most SDGs, researchers from those regions are involved in only a small fraction of SDG-related research, and therefore in the creation of research capabilities related to these themes. Most SDG related research is heavily concentrated in high income countries (HICs), where SDG scores are better in most SDGs, rather than in LICs, which need the most the research that can contribute to addressing their SDGs challenges. This suggests that one of the expected sources of misalignment between SDG research production and SDG challenges happens at the global level due to the vast inequalities that exist in research capabilities and funding across countries.

The 29 LICs contribute to less than 0.3% of the SDG-related publications, while they have 8.2% of the world population. The negligible involvement of researchers from LICs in SDG related research, limits the extent to which that research can have an impact on those contexts. Research done by locals usually brings advantages related to ownership of the results, trust, sharing of expertise between researchers and policymakers, and increased contextualisation of findings. Without research capabilities, policymakers (and research users) in these countries, need to rely on research done elsewhere, which is likely to be less relevant to their contexts (Kraemer-Mbula et al., 2020). The relatively small amount of research produced in LICs relates mostly to SDG1 (No poverty), SDG2 (Zero hunger), in SDG3 (Good health and well-being), SDG5 (Gender equality), SDG13 (Climate action) and SDG15 (Life on land) which, together, represents more than 50% of all the research done in the region.

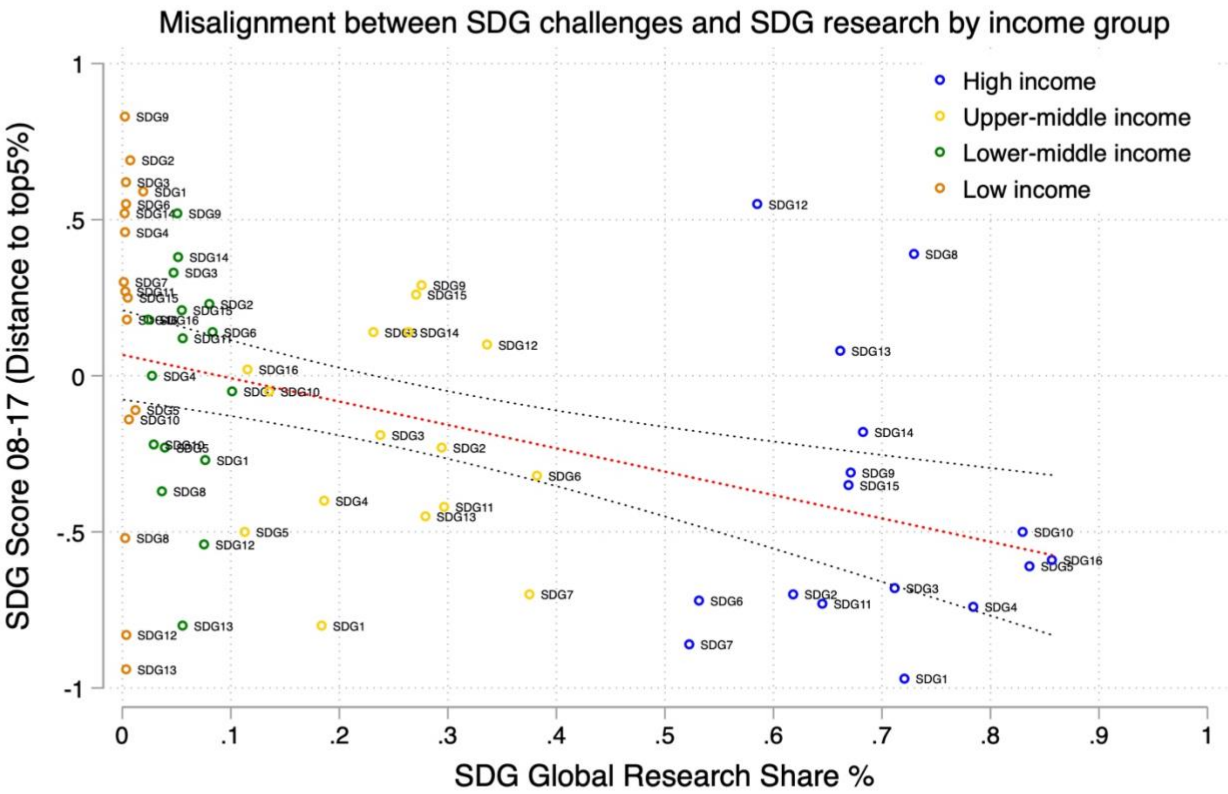
The 104 upper- and lower-middle income countries (UMICs and LMICs) produce proportionally less SDG-related research in all SDGs (32%) than what they produce globally in all areas (37%). When we look in detail, we find that this group of countries is more specialized than the world average in research relating to SDG6 (Clean water and sanitation) and SDG7 (Affordable and

[6] The remaining research can be seen as research not directly related to the SDGs' targets, indicators and objectives. Some WoS Categories that we found that have particularly low levels of SDG related research include Astronomy & Astrophysics, Nuclear Physics, Poetry and Mathematics.

clean energy), and less specialized in SDG5 (Gender equality), SDG10 (Reduced inequalities) and SDG16 (Peace, justice and institutions). China, India, Brazil and Russia, which comprise more than 75% of the world's population and 27% of global research, are included in this middle-income group and shape substantially these results.

The 72 HICs produce the majority of all SDG-related research (68%), while having only 16% of the global population, and are relatively specialized in SDG4 (Quality education), SDG5 (Gender equality), SDG10 (Reduced inequalities) and SDG16 (Peace, justice and institutions). Their major SDG challenges are instead related to SDG8 (Decent work and economic growth)[7], SDG12 (Responsible consumption and production) and SDG13 (Climate action).

Figure 1. Relation between SDG challenges (2008-2017) and SDG research share (2015-2019) by income group



Source: Own calculation based on CWTS WoS version, UN, SDG Index and World Bank data.

Notes: The y-axis shows the average country score of SDG challenges by income group. A score of 1 indicates a major challenge (country furthest away from the frontier in this SDG), and a score of -1 indicates a country at the frontier. The x-axis shows the global share of SDG-related research by income group. Each colour represents an income group.

[7] Interestingly, in relation to **SDG 8** (Decent work and economic growth) dividing countries by income groups might not provide the most useful insights. For SDG 8, some indicators include the annual *growth rate* of real GDP per capita/employed person, rather than *the level* of per capita income. Since LICs and LMICs grew more during 2008-2017, they score more highly than HICs on this indicator.

4.2 Analysing alignment for individual countries

The previous analysis gives us a broad picture of the misalignment between SDG challenges and SDG research capabilities in different income groups in the world. The next question we explore is whether the SDG research priorities of specific countries are related to the major SDG challenges they face. Figure 2 is meant to better illustrate what we mean by misalignments, and the source of variation that we exploit in our main analysis. We use Tanzania (LMIC), Argentina (UMIC) and Germany (HIC) as examples to show how this type of analysis might provide guidance to rebalance research priorities towards topics closer to countries' major challenges.

Tanzania faces several challenges that are usually more problematic in LICs and LMICs. These include issues relating to SDG1 (No poverty), SDG2 (Zero hunger), SDG3 (Good health and well-being), SDG4 (Quality education), SDG6 (Clean water and sanitation), SDG7 (Affordable and clean energy) and SDG9 (Industry, innovation and infrastructure). In terms of research priorities, although Tanzania produces a very low share of world research (less than 0.03%), research in the country appears strongly related to almost all SDGs. The exception is SDG7 (Affordable and clean energy), in which Tanzania is one of the countries furthest away from the SDG frontier.

Argentina instead shows a low alignment. It faces significant challenges in relation to SDG9 (Industry, innovation and infrastructure), SDG10 (Reduced inequalities) and SDG15 (Life on land), whereas its research priorities relate to SDG2 (Zero hunger), SDG6 (Clean water and sanitation), SDG13 (Climate action), SDG14 (Life below water) and SDG15 (Life on land).

The high level of research specialization in SDG2 (Zero hunger) is surprising since hunger is not a major problem in Argentina compared with other countries. This specialization might be related to Argentina's strong trade in cereal, soya and meat production[8], and the consequent importance of agricultural productivity to the economy. This pattern of intensive agriculture might, in some cases, lead to unsustainable practices of land use and damage to terrestrial ecosystems, leading to a trade-off with SDG15 (Life on land), which presents a particular challenge in this country. Therefore, it is interesting to note the high research specialization in SDG15, which focuses on issues such as the effects of land use in intensive cultivations on local biodiversity (Newbold et al., 2015) and the importance of soil science in challenges such as food security, water scarcity, climate change, biodiversity loss and health threats (Keesstra et al., 2016). On the other hand, the lack of research prioritization in SDG9 (Industry, innovation and infrastructure) and SDG10 (Reduced inequalities) is worrying, given the significant challenge that Argentina faces in relation to these SDGs relative to other countries (e.g. Arza and López, 2021; Cimoli and Katz, 2003).

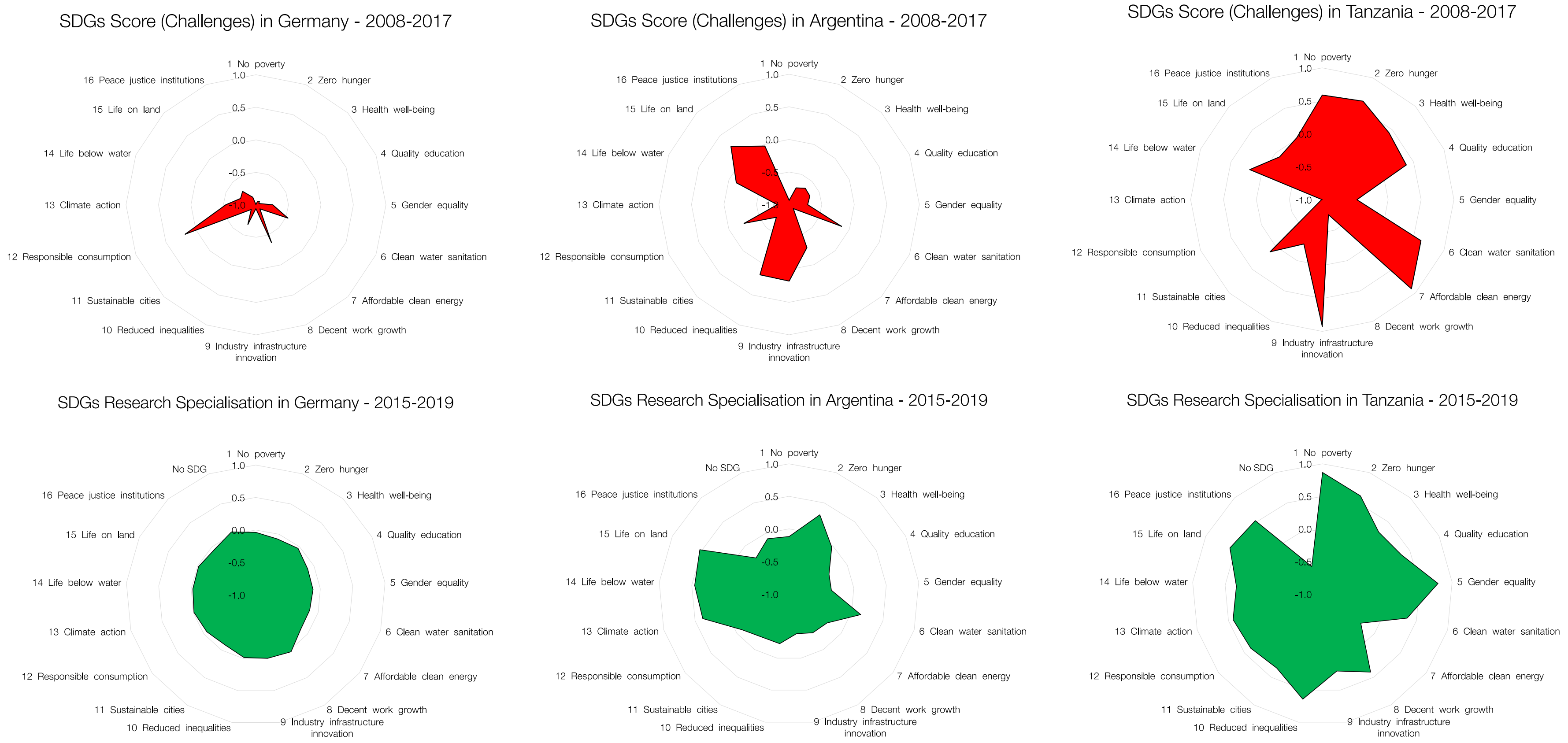
Finally, Germany only has major SDG challenges, relative to the rest of the World, in SDG12 (Responsible consumption and production) and SDG13 (Climate action). These are the two SDGs which most HICs perform worst and have higher challenges. However, the country does not specialise in research related to these SDGs. Their SDG research specialisation is in line with the World average (0), which is considered a misalignment.

On average, we find that LICs and LMICs show more variation in SDG challenges and SDG research specialisation (see Fig. A.2 in appendix). HICs and UMICs show less variation in SDG research specialisation and smaller SDG challenges (on average). We also calculated the correlation

[8] https://oec.world/en/profile/country/arg?depthSelector1=HS4Depth

coefficient between SDG research priorities and SDG challenges, and plotted this new variable against a research concentration intensity score (Chi-square of sectoral specialization used by Laursen (2000)). In Fig. A.3, in the appendix, we didn't find any significant relationship between these two variables. However, we find that LICs and LMICs tend to exhibit higher levels of SDG research concentration (narrow knowledge base) and HICs a broader knowledge base. Neither income level nor SDG research concentration seem to explain the levels of alignment (correlation between SDG challenges and SDG research priorities) of different countries.

Figure 2. Germany, Argentina, and Tanzania main SDG challenges versus SDG research specialisation



Note 1: A score of 1 indicates a major challenge (country furthest away from the "frontier" in this SDG), and a score of -1 indicates a country at the "frontier" in this SDG (best performer). Research specialisation above 0 indicates that a country is relatively specialised in research related to that SDG, and the opposite for a research specialisation below 0.

Note 2: Some of the SDG Scores (challenges) were not computed, since some countries (e.g. India for SDG10) don't have data available for at least one SDG indicator from a given SDG during 2008-2017.

4.3 Relations between SDG challenges and research priorities by SDG across countries

To study whether SDG challenges in previous years influence countries' research priorities in later years we analyse econometrically at the SDG level if countries facing higher SDG challenges tend to prioritise research related to that specific SDG.

We start to exemplify our analysis with four scatter plots for illustrative purposes. In Fig. 3, we analyse how the alignment between research priorities and major challenges differs for SDGs 2, 6, 12 and 13 (results for all other SDGs are in Fig. A.4). We found a pattern of alignment for SDG 2 (Zero hunger) and SDG 6 (Clean water and sanitation), meaning that those countries with more significant challenges in these SDG areas are conducting more research related to those SDGs than the average country. On the other hand, our analysis shows a misalignment pattern for both SDG12 (Responsible consumption and production) and SDG13 (Climate action), meaning that countries with greater challenges in these SDGs (mostly HICs) are conducting relatively less research on those challenges than the average country. This is an undesirable pattern, since it shows that the countries that have unsustainable consumption/production patterns and generate more CO_2 emissions are usually HICs that are not specialized in research related to these challenges.

These patterns are based on correlations between research specialization and the SDG score, and do not take into account underlying confounding factors that may influence a country's specialisation in particular research topics. To address this, we use multiple regression analysis to control for factors such as path dependence (previous research specialization) and country research productivity (number of publications per capita). We use the approach explained in section 3.3 to ask three main research questions (see Table 1): Are countries that score worst in a certain SDG specialized in research related to that SDG? (RQ1); Do countries that score worst in a certain SDG tend to change their specialization towards research related to that SDG? (RQ2); Is a change in SDG scores associated to a change in SDG research specialisation? (RQ3).

Overall, we would expect a positive association in all these questions across all SDGs, given that a misalignment between research areas and SDG achievements may reduce the effectiveness of research to address those goals. However, we find an inconclusive relationship or misalignment between relative research specialization and SDG challenges for most SDGs in all three research questions.

For RQ1, we find positive significant associations in SDG1 (No poverty), SDG2 (Zero hunger), SDG3 (Health and Well-being), SDG6 (Clean water and sanitation), SDG7 (Affordable Clean Energy) and SDG10 (Reduced inequalities). These are encouraging findings since they indicate that countries with serious challenges in these SDGs are indeed specialized in research related to them, which should enable the development of research capabilities on issues that are relevant to these countries. However, for SDG3, SDG7 and SDG10 this relation is not statistically significant when we control for previous specialization and scientific productivity in our regression analysis (RQ1* in Table 1). This implies that the positive association between research specialisation and SDG challenge for SDG3, SDG7 and SDG10 is mainly due to historical and long-term research specialization in these areas, rather than to a reorientation of research priorities to changes in SDG challenges. These results were expected for SDG3, for example, since it is well known that LICs and LMICs have historically been specialized in health sciences (UNESCO, 2015), mainly due to the research funding priorities of aid agencies, philanthropists and other international funders (Confraria and Wang, 2020; Kozma et al., 2018).

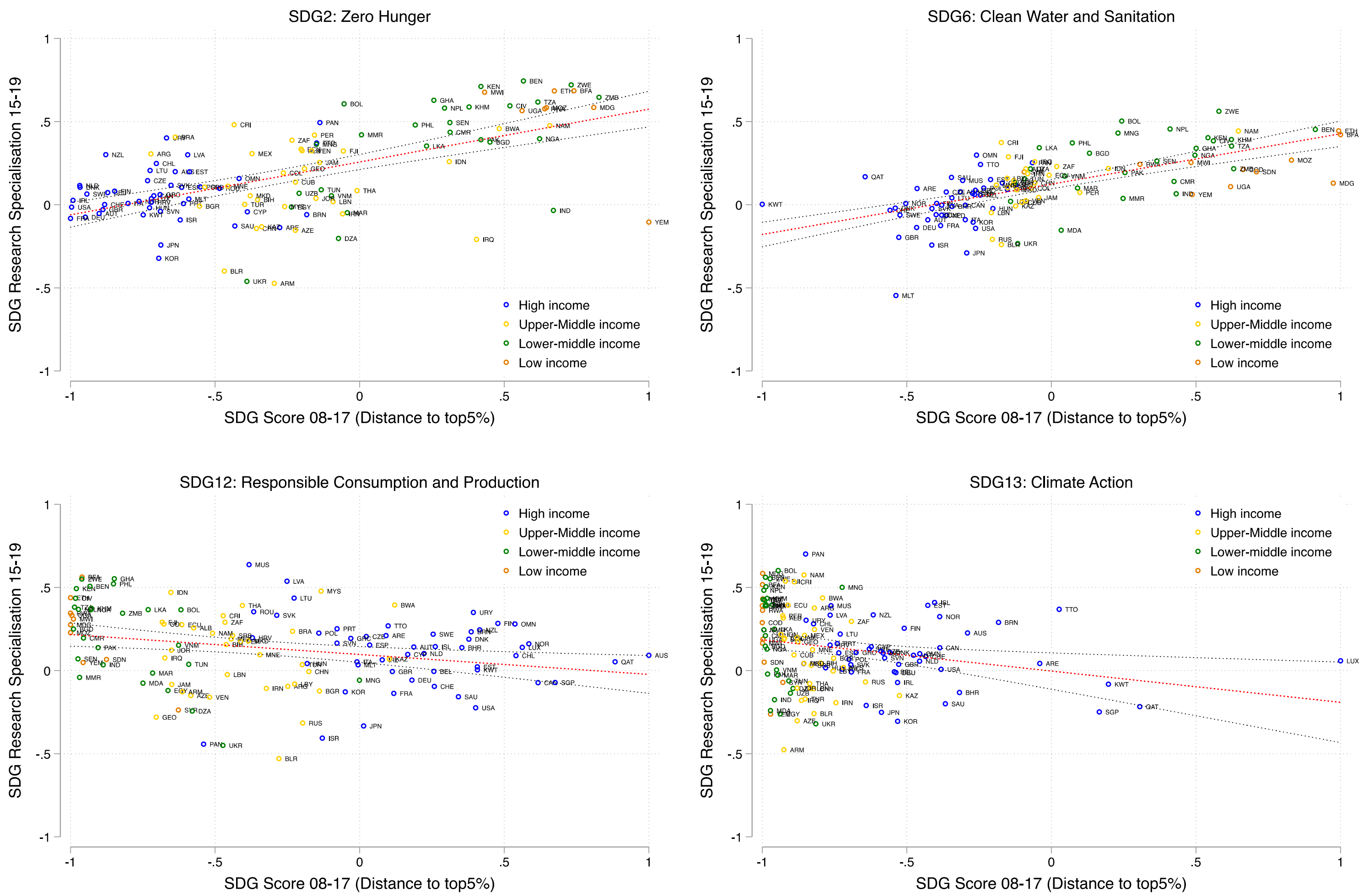
The SDGs for which we found a positive significant association between the severity of an SDG challenge and their relative SDG research priorities (RQ1*), or dynamic changes in research priorities (RQ2), are SDG1 (No poverty), SDG2 (Zero hunger), SDG6 (Clean water and sanitation) and SDG9 (Industry, innovation and infrastructure). For SDG6, for example, this means that the countries furthest from the frontier are specialized or becoming specialized in research related to SDG6. The five countries in which research on SDG6 represents the largest share of the SDG-related research portfolio are Bolivia, Benin, Ethiopia, Nepal and Zimbabwe. These countries are all LICs and LMICs which have experienced recent problems related to water governance (for example, the Cochabamba Water War in Bolivia[9]), extreme droughts (for example, 2015–2016's El Niño-induced drought in Ethiopia[10]) and sanitation challenges (such as lack of access to sanitation and water services in Nepal[11]). The good match between research priorities and SDG challenges, in this case, might be related to the occurrence of particular shocks, which incentivize national and international research funders to solve these issues. However, further research is needed to understand the causes for other alignments and misalignments between research priorities and SDG challenges.

For all other SDGs, we found no alignment or a negative alignment. In the case of SDG12 (Responsible consumption and production), the countries that have higher challenges are HICs that have unsustainable consumption and production patterns (RQ1*) and are becoming less specialised in research on these SDGs (RQ2). The most specialized countries in research areas related to SDG12 are LICs and LMICs. This is clearly a severe misalignment since the countries producing more waste are expected to prioritise research related to sustainable use/management of resources and recycling processes.

The results summarised in column RQ3 (Table 1) also suggest that alignment has been improving in SDG3 (Good health and well-being) and SDG13 (Climate action), indicating that countries with a growing (diminishing) challenge, are more likely to increase (decrease) their research specialisation on these SDGs. Given that for SDG13 the coefficients in RQ1, RQ1* and RQ2 are negative, this is an encouraging result. Although the countries contributing more to climate change in relative terms (e.g. Qatar, Singapore, Kuwait) are not the ones prioritising research related to SDG13, the ones that are getting worst (e.g. China, Vietnam, Colombia, Turkey) are increasing their specialisation on SDG13 related research.

[9] https://en.wikipedia.org/wiki/Cochabamba_Water_War
[10] https://medium.com/@UNmigration/overcoming-the-drought-in-ethiopia-afde894014bf
[11] https://www.unicef.org/nepal/water-and-sanitation-wash

Figure 3. Scatter plots of relations between SDG challenges (2008-2017) and SDG research priorities (2015-2019) in SDGs 2, 4, 6 and 13



Notes: The y-axis reveals the research specialisation of authors from a country in a certain SDG. The x-axis shows country scores for certain SDG challenges. A score of 1 indicates a major challenge (country furthest away from the "frontier" in this SDG), and a score of -1 indicates a country at the "frontier" in this SDG (best performer). Countries have different colours based on their income group.

Table 1. Multiple regression results for the relation between SDG challenges and SDG research priorities for all countries

	RQ1 $t \rightarrow t+1$	RQ1* $t \rightarrow t+1$	RQ2 $t \rightarrow \Delta$	RQ3 $\Delta \rightarrow \Delta$
1 No poverty	**+ 0.13*** **	**+ 0.04*** **	**+ 0.05*** **	0.08
2 Zero hunger	**+ 0.20*** **	**+ 0.06*** **	**+ 0.06*** **	-0.16
3 Health well-being	**+ 0.19*** **	0.01	0.01	**+ 0.23*** **
4 Quality education	-0.05	0.01	0.02	-0.07
5 Gender equality	0.05	0.01	-0.01	0.20
6 Clean water sanitation	**+ 0.18*** **	**+ 0.06*** **	**+ 0.07*** **	-0.18
7 Affordable clean energy	**+ 0.08** **	0.03*	0.02	0.22
8 Decent work growth	-0.12*	-0.09	**- 0.11** **	0.09
9 Industry infrastructure innovation	-0.04	**+ 0.11*** **	**+ 0.11*** **	**- 0.40** **
10 Reduced inequalities	**+ 0.14** **	0.01	0.01	0.15*
11 Sustainable cities	0.05	0.01	0.02	-0.13
12 Responsible consumption and production	**- 0.14*** **	**-0.05** **	**- 0.05** **	0.25
13 Climate action	**- 0.11*** **	-0.00	-0.01	**+ 0.46*** **
14 Life below water	-0.00	-0.01	-0.01	-0.07
15 Life on land	-0.09	-0.03	-0.02	-0.04
16 Peace justice institutions	0.01	-0.01	-0.02	-0.17
Controls	No	Yes	Yes	Yes
Observations	1,617	1,617	1,635	1,538
R-squared	0.05	0.82	0.23	0.25

Notes: In table 1 we display the results for three research questions (RQ) in different columns. In all RQ we highlight in bold the significant coefficients (0.05) of our independent variable of interest (SDG score dummies). In column "RQ1" we use scientific specialization by SDG/country in 2018-2019 as our dependent variable, and SDG Score (2013-2017) as our main independent variable. In column "RQ1*" we use scientific specialization by SDG/country in 2018-2019 as our dependent variable, and SDG Score (2013-2017) as our main independent variable, controlling for previous research specialization (2013-2014) and number of publications per capita in a specific SDG/Country (2013-2014) due to the path-dependant nature of scientific production. In column "RQ2" we use the difference between scientific specialization by SDG/country in 2018-2019 and scientific specialization by SDG/country in 2013-2014 as our dependent variable, and SDG Score (2008-2012) as our main independent variable, controlling for number of publications per capita in a specific SDG/Country (2013-2014). In column "RQ3" we use the difference between scientific specialization in 2018-2019 and 2013-2014 as our dependent variable, and the difference between SDG Scores in 2015-2019 and 2010-2014 as our main independent variable controlling for number of publications per capita in a specific SDG/Country (2013-2014).

5. Discussion

This paper provides different perspectives (global, country and SDG) to analyse the extent to which countries' research priorities align with their major SDG challenges.

We find that at the global level, while the vast majority of SDG challenges are worse in LICs and LMICs, only a small fraction of SDG-related research takes place in those regions. This suggests that a major source of misalignment between research priorities and SDG challenges in the world is related to the vast inequalities that exist in research capabilities and funding across countries. Research users in LICs and LMICs need to rely on research done elsewhere, which may be less relevant to their contexts.

At the country level, we created a methodology and visualizations that allow countries to have a better understanding (and more productive discussions with relevant stakeholders) of the research being prioritized, the capabilities created in the country, and the factors that might have led to the absence of research in areas related to their main SDG challenges. Our findings indicate that this kind of mapping might be particularly relevant for countries that have greater societal challenges (LICs and LMICs), since it is easier to identify clearer misalignments.

At the SDG-country level, our findings indicate a positive relation between SDG challenges and SDG research prioritisation by country in some SDGs, including SDG1 (No poverty), SDG2 (Zero hunger), SDG6 (Clean water and sanitation) and SDG9 (Industry, innovation and infrastructure). This indicates a certain degree of alignment between research priorities and SDG challenges across countries in these SDG areas. These are encouraging findings since they imply that countries with serious challenges in these SDGs are indeed specialized (and becoming specialized) in research related to them, which can enable the application of scientific knowledge on issues that are relevant to these countries. As for SDG3 (Health Well-being), SDG7 (Affordable Clean Energy) and SDG10 (Reducing Inequalities), we also found a positive alignment pattern between SDG challenges and SDG research priorities, however, when controlling for other factors we found that these patterns seem to be more related to historical patterns of research specialization (and potential international research funding patterns) than to research priorities chosen based on the challenges themselves.

We instead found a negative or inconclusive relationship between research prioritization and SDG challenges for all other SDGs. In SDG12 (Responsible consumption and production), the countries that have the most unsustainable consumption/production patterns are usually HICs that are not specialised (or becoming specialised) in research related to these themes. This is a severe misalignment since the countries producing more waste are expected to prioritise research related to sustainable use/management of resources and recycling processes which would enable them to create solutions to these unsustainable consumption/production patterns.

In conclusion, we find that research prioritization should be more responsive to national SDG challenges. We find a certain degree of alignment for some countries (and SDGs), but the wider picture is of misalignment between research priorities and SDG challenges. Furthermore, since most SDG challenges are worst in LICs and LMICs, and they tend to focus their research on issues related to the SDGs, we also suggest that increasing funding in these countries would potentially boost research related to the SDGs.

Lastly, we need to mention that this study has some limitations, related to the uncertainty and ambiguity of our estimates of SDG research priorities (Armitage et al., 2020) and SDG challenges (Miola and Schiltz, 2019). Our results are conditional on the assumptions made, and are designed more as a tool to explore potential misalignments between research priorities and SDG-related challenges than as an accurate measurement of those (mis)alignments.

Further research is needed on the marginal impact of increasing SDG-related research investments on the achievement of a particular SDG. This impact may not be the same for all SDGs. Local research in health (SDG3) may lead to significant improvements in the health outcomes of a country, but more local research on poverty (SDG1), for example, may not produce similar improvements in reducing poverty. Future studies should look carefully at these differences and consider synergies and trade-offs between SDGs. These factors may help improving research prioritization and enable the building of research capabilities to address specific challenges.

Another important theoretical aspect to have in mind when thinking about developing research capabilities to address societal challenges, such as the SDGs, is that influencing scientists to change their research trajectories is costly and hard (Myers, 2020). The increasing specialisation of expertise (Jones, 2009), the nature of scientific incentives and culture (Azoulay et al., 2019; Bhattacharya and Packalen, 2020), and the lower probability of researchers to have higher impact in different fields (Hill et al., 2021; Zeng et al., 2019), might make them to avoid new research directions. Therefore, research funders need to be aware of such barriers when steering research funds to areas related to SDGs, especially in LICs and LMICs where the existence of critical mass across fields is lower (Confraria et al., 2017).

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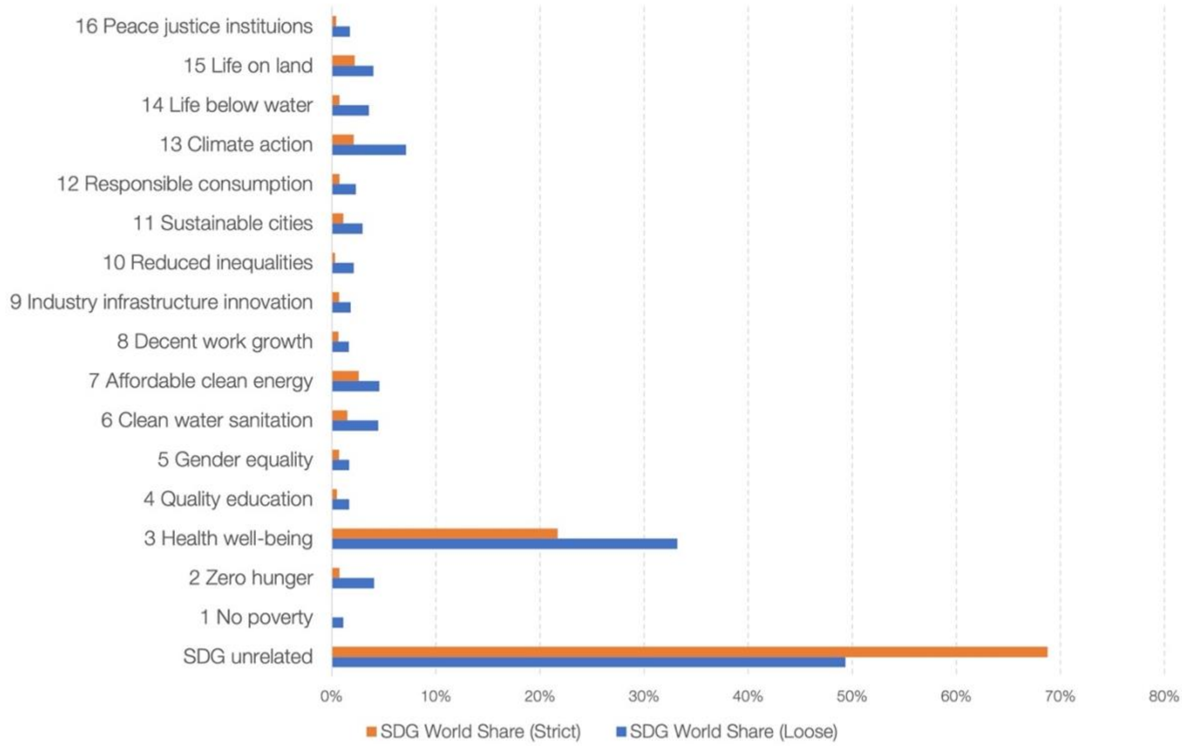
Zeng, A., Shen, Z., Zhou, J., Fan, Y., Di, Z., Wang, Y., Stanley, H.E., Havlin, S., 2019. Increasing trend of scientists to switch between topics. Nat. Commun. 2019 101 10, 1–11. doi:10.1038/s41467-019-11401-8

3. Appendix.

Figure A.1. Share of publications associated to an SDG between 2015 and 2019 in the World.



Source: WoS

Figure A.2. Radar graphs of SDG challenges (2008-2017) versus SDG research priorities (2015-2019) per income group

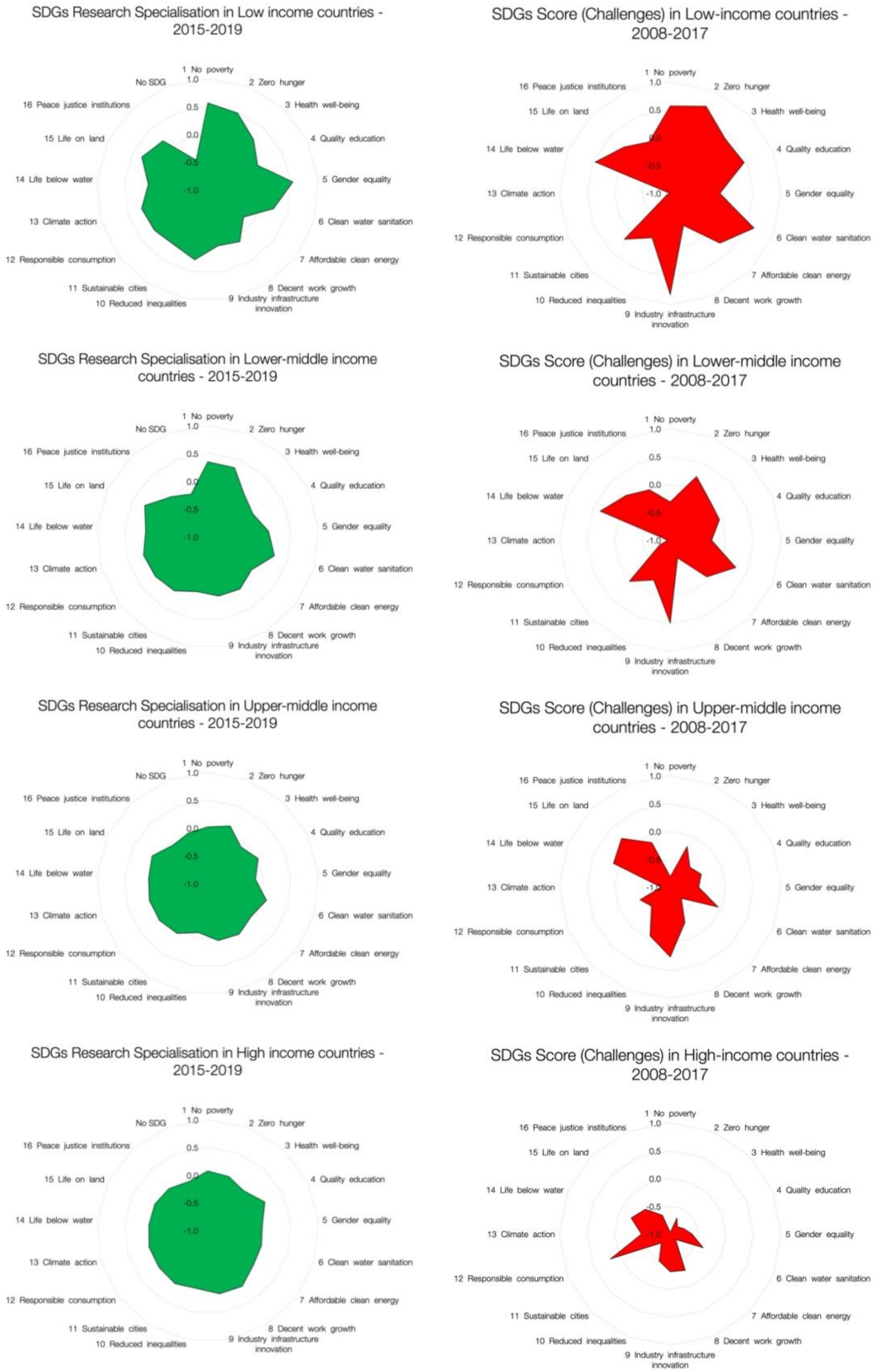


Figure A.3. Countries alignment of SDG research priorities/challenges vs SDG research concentration

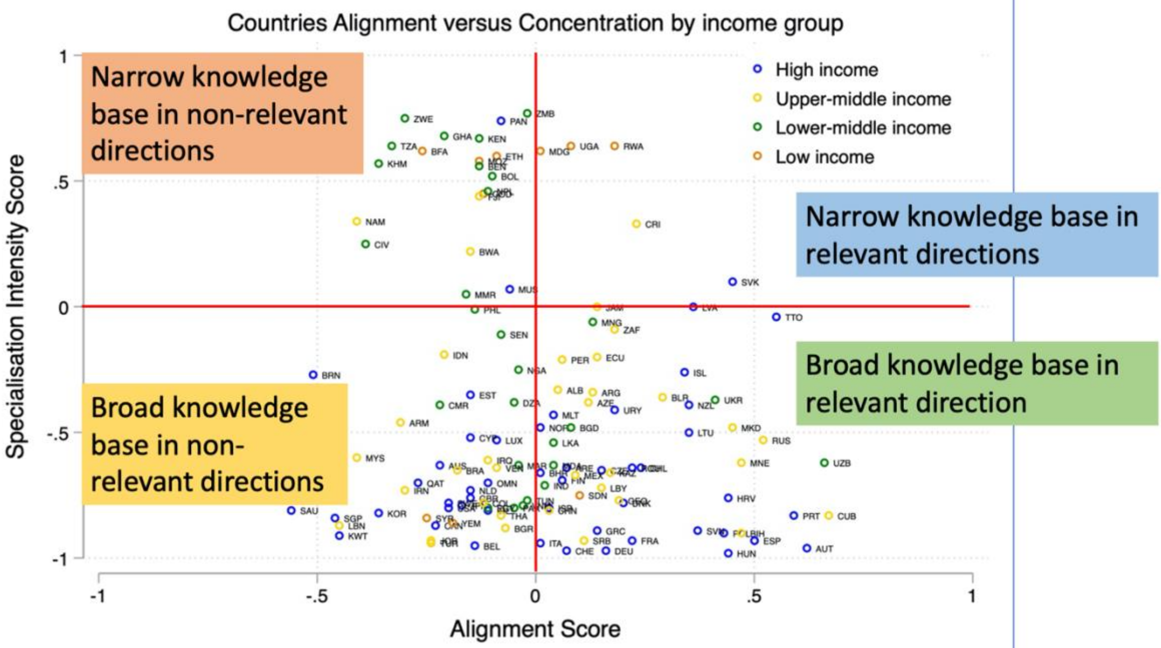
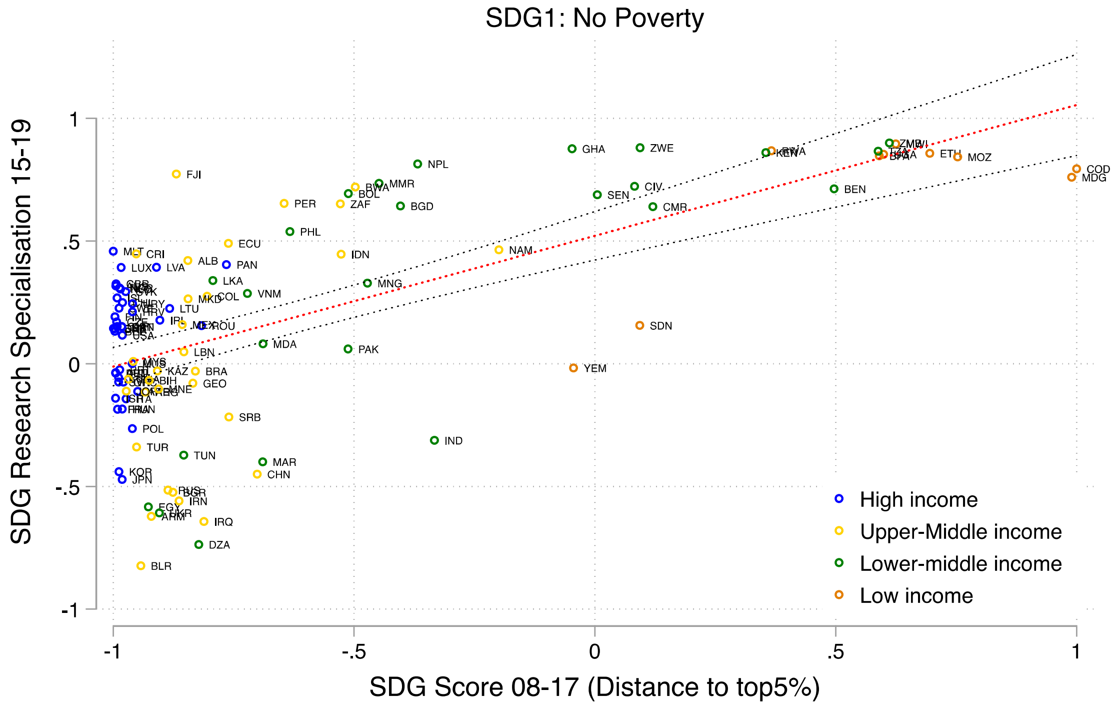
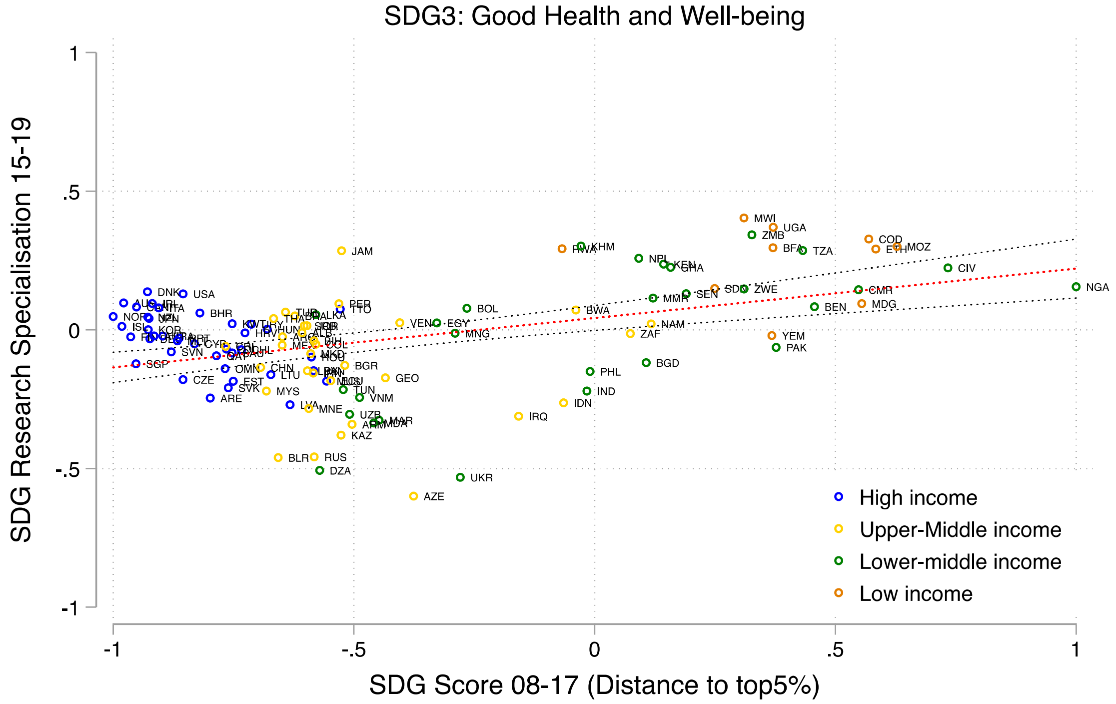
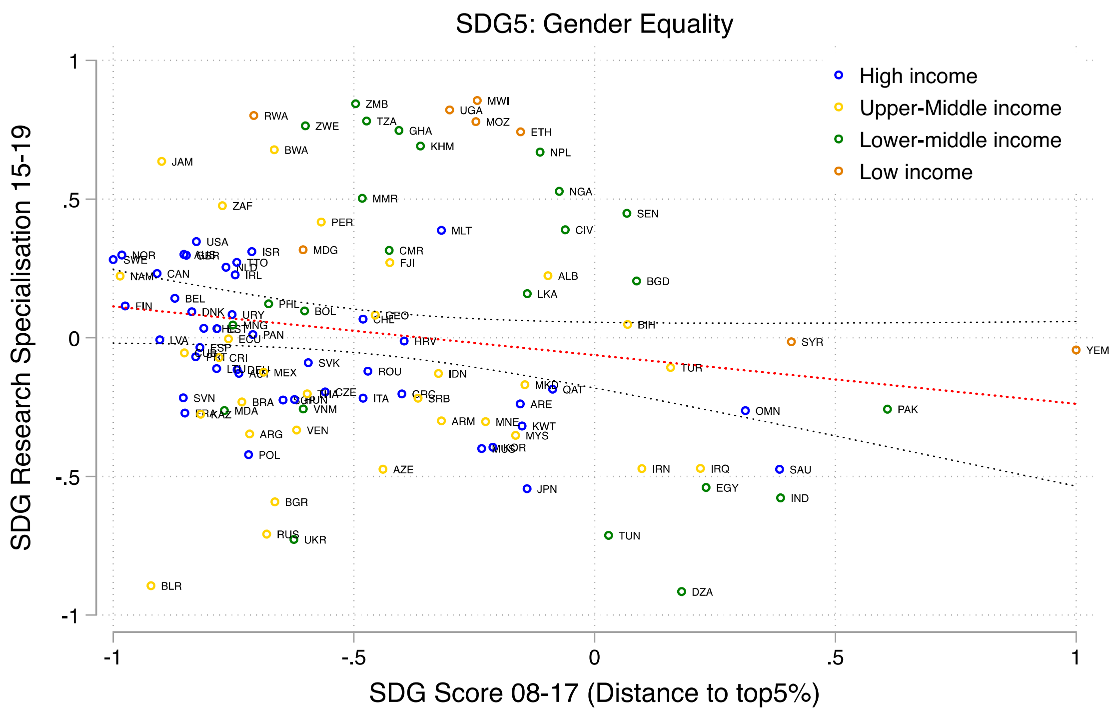
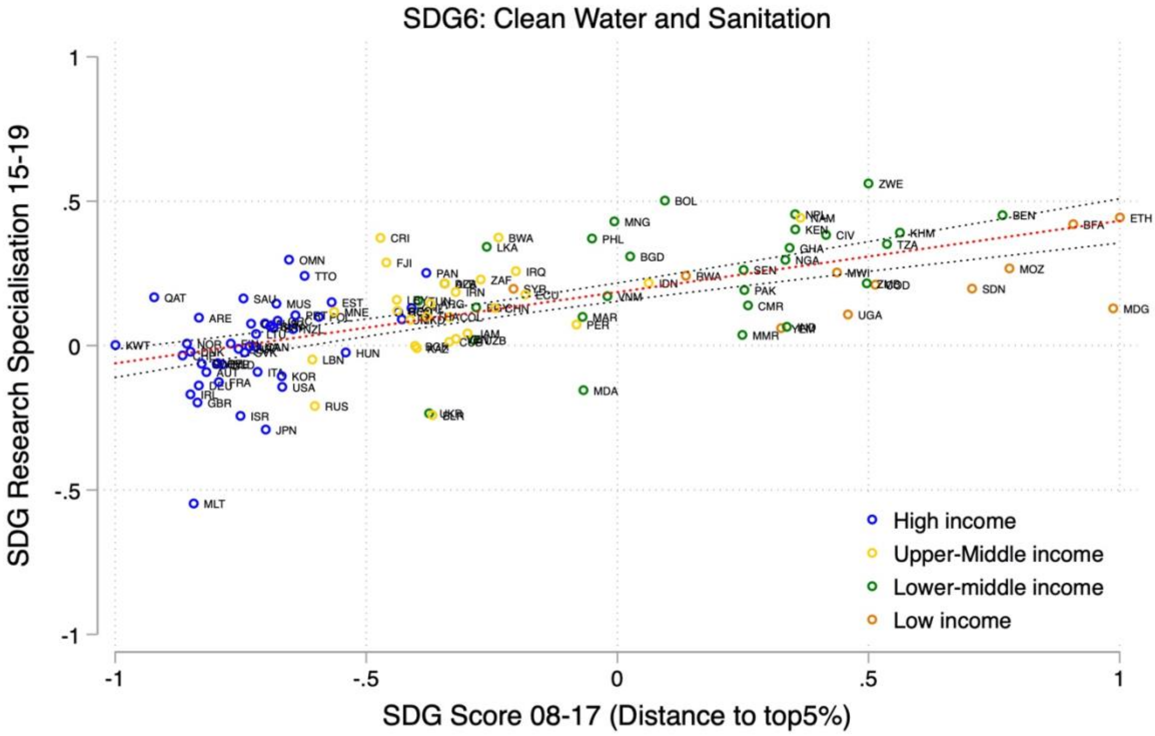


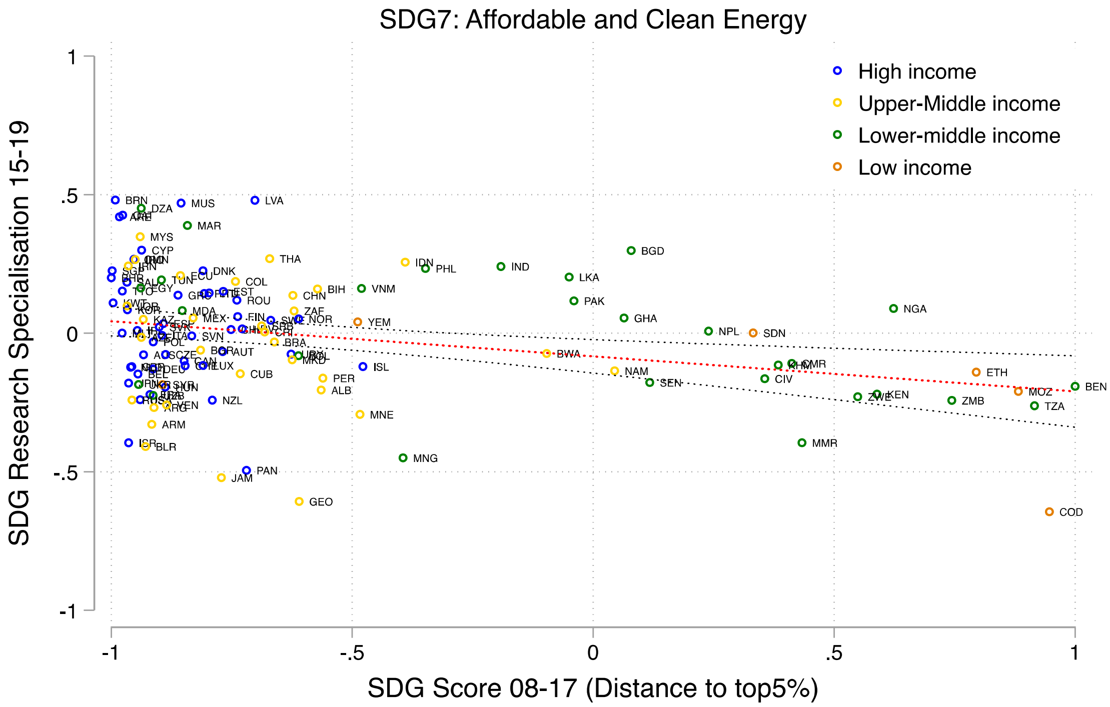
Figure A.4. Scatter plots of relations between SDG challenges (2008-2017) and SDG research priorities (2015-2019) in SDGs 1, 3, 5, 7, 8, 9, 10, 11, 12, 14, 15, 16

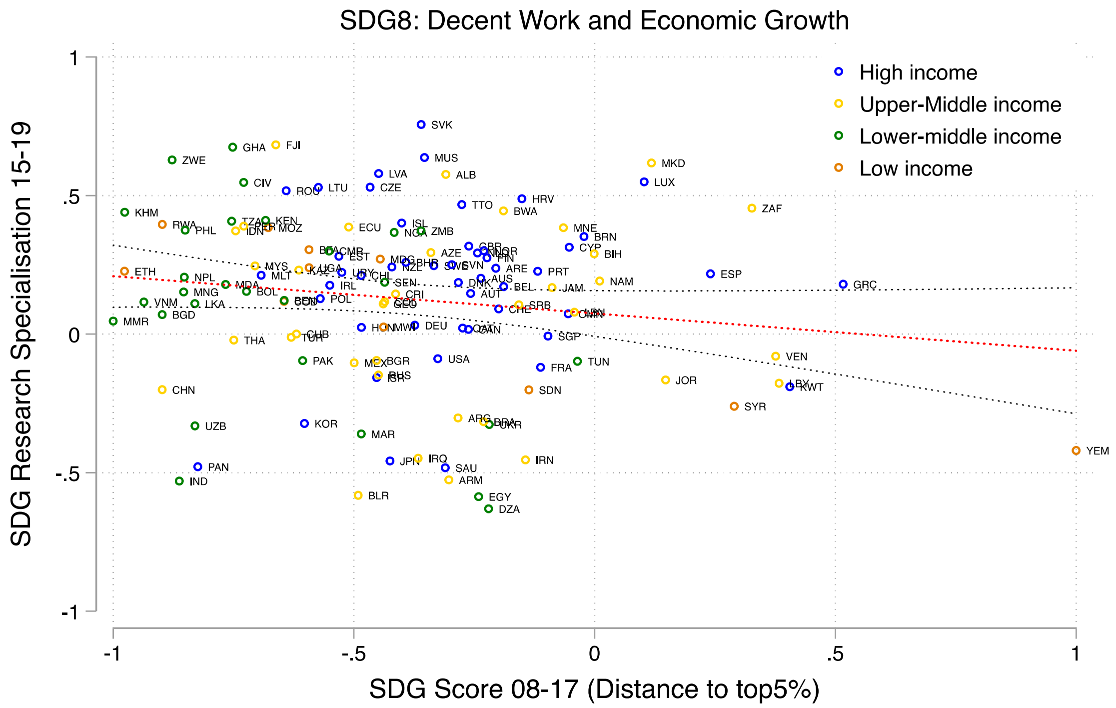


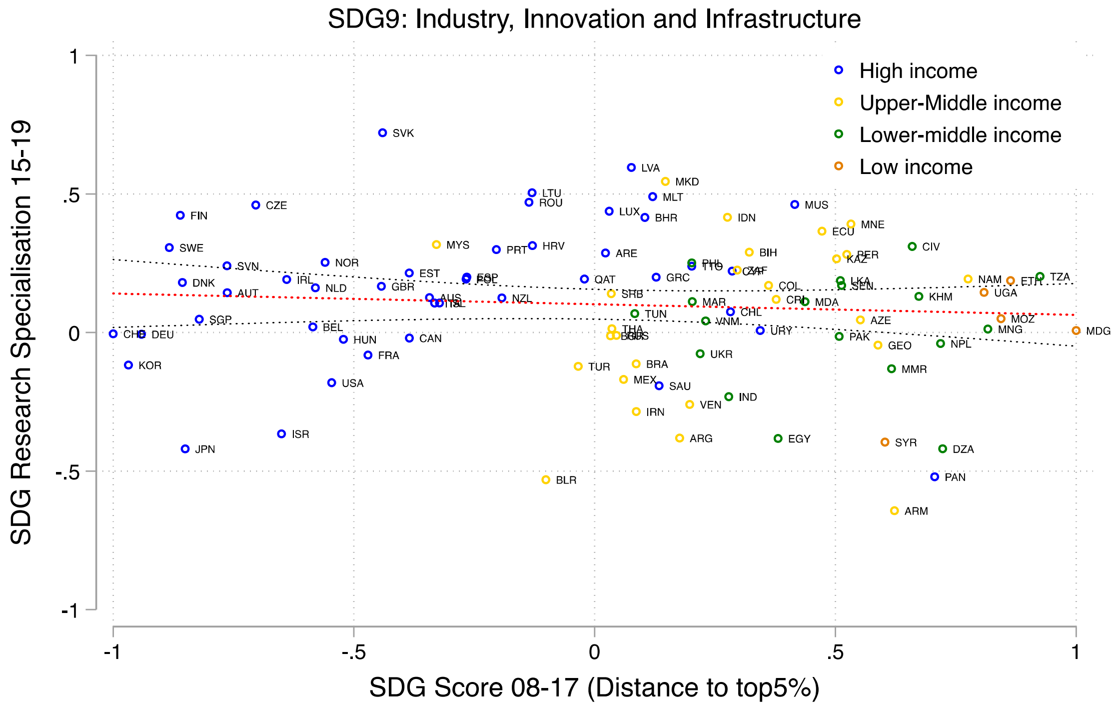

SDG3: Good Health and Well-being
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
High income
Upper-Middle income
Lower-middle income
Low income

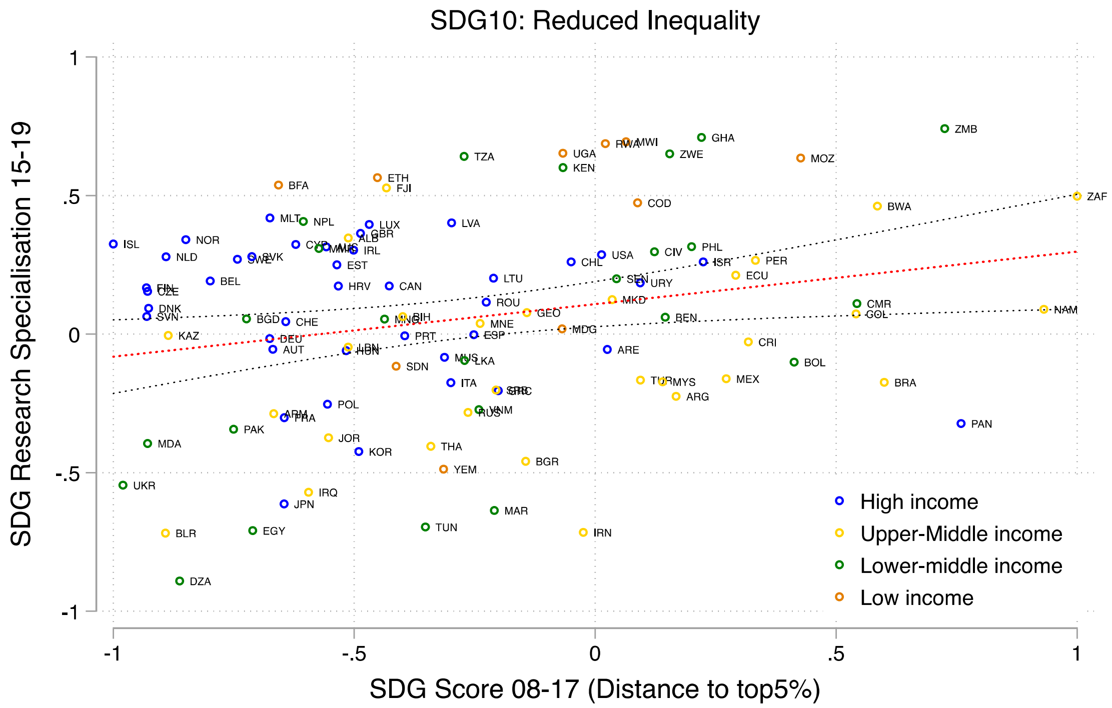

SDG5: Gender Equality
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
High income
Upper-Middle income
Lower-middle income
Low income

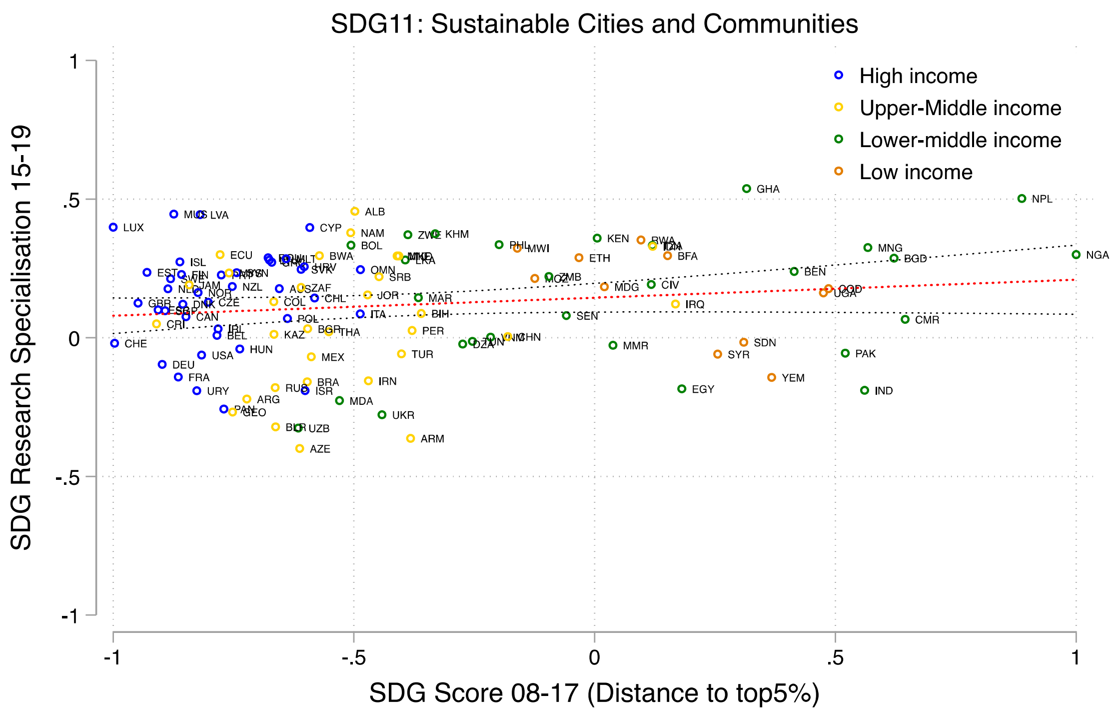

SDG6: Clean Water and Sanitation
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
High income
Upper-Middle income
Lower-middle income
Low income

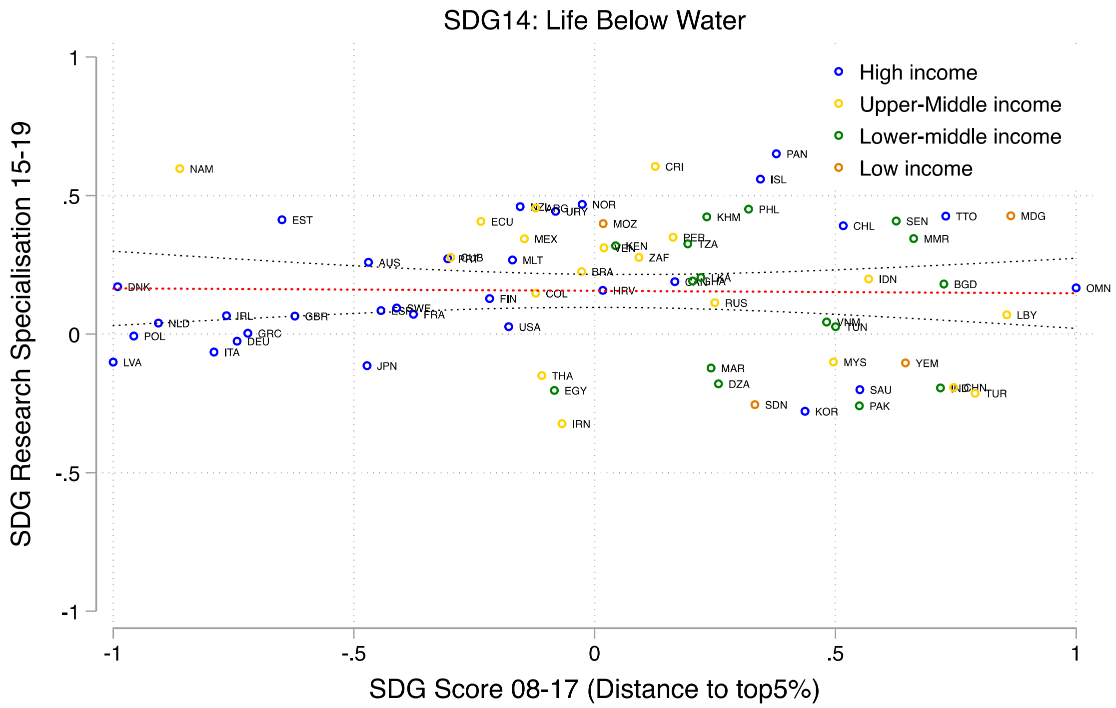

SDG7: Affordable and Clean Energy
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
High income
Upper-Middle income
Lower-middle income
Low income

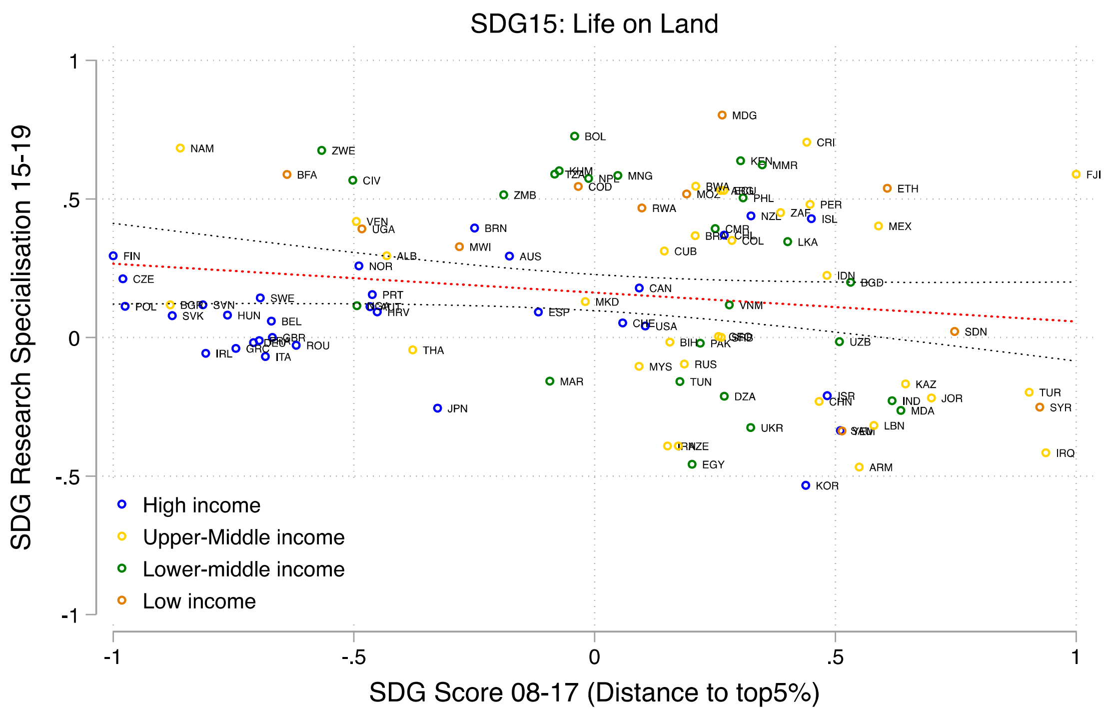

SDG8: Decent Work and Economic Growth
High income
Upper-Middle income
Lower-middle income
Low income
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)

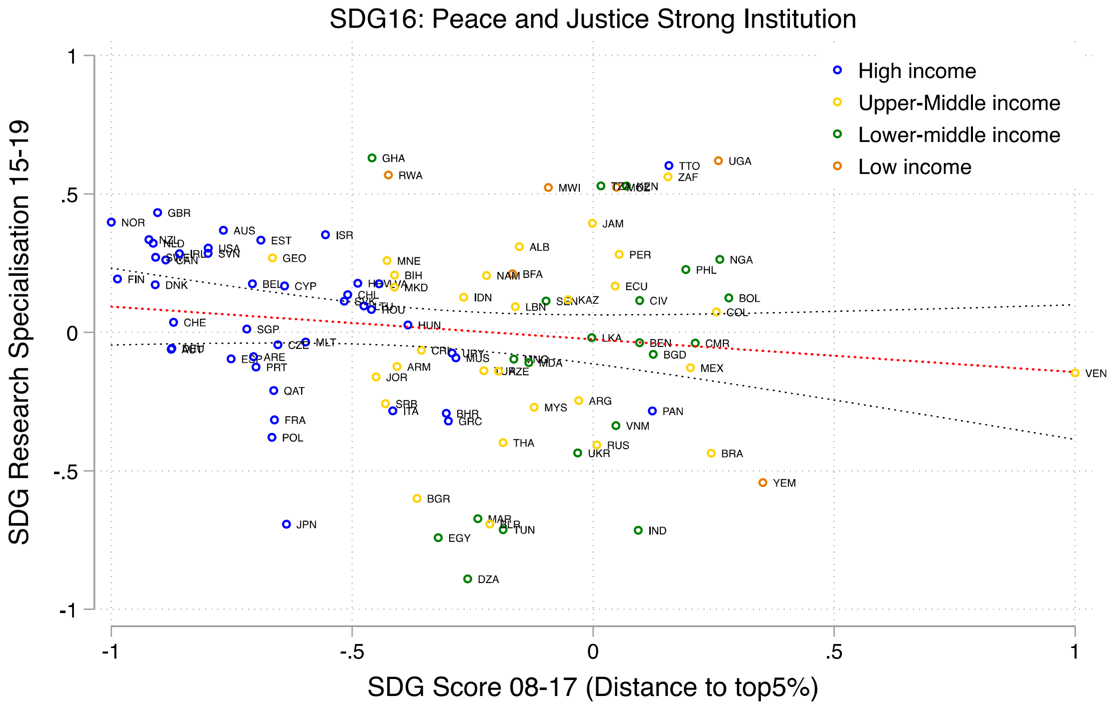

SDG9: Industry, Innovation and Infrastructure
High income
Upper-Middle income
Lower-middle income
Low income
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)


SDG10: Reduced Inequality
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
High income
Upper-Middle income
Lower-middle income
Low income


SDG11: Sustainable Cities and Communities
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
High income
Upper-Middle income
Lower-middle income
Low income


SDG14: Life Below Water
High income
Upper-Middle income
Lower-middle income
Low income
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
-1
-.5
0
.5
1


SDG15: Life on Land
High income
Upper-Middle income
Lower-middle income
Low income
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
1
.5
0
-.5
-1
-1
-.5
0
.5
1


SDG16: Peace and Justice Strong Institution
SDG Research Specialisation 15-19
SDG Score 08-17 (Distance to top5%)
High income
Upper-Middle income
Lower-middle income
Low income
1
.5
0
-.5
-1
-1
-.5
0
.5
1

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